Comparative Study of Different Biogas Recovery Systems by Comparing Greenhouse Gas Emissions

Hunsa Rittipikul[1], Seksan Papong[2,*], Pomthong Malakul[3], and Penjit Srinophakun[4]

***Abstract*—** The effluent from biodiesel production generally contains organic content treated by self-remediation in open lagoon and releasing greenhouse gases (GHG). In order to guarantee environmental-friendly characteristics of palm biodiesel, this study assesses the GHG emissions through palm oil biodiesel production emphasized on difference of biogas recovery systems. The boundary of the study is cradle-to-gate approach including the oil palm plantation, crude palm oil (CPO) production, biodiesel production, and related transport activities. The result shows that, in the best case scenario, 25.28% GHG emission decreases from the worst case scenario baseline. Highlighted on crude palm oil (CPO) production, the biogas recovery system in milling can reduce GHG emissions up to 50.43%. CPO production plays an important role in GHG reduction, therefore, it is suggested that the biogas literally lessen GHG emission and is recommended for improvement of environmental performance.

***Keywords*—**Biodiesel, Biogas recovery, Greenhouse gas, Palm oil mill effluent, Wastewater.

I. Introduction

At the present, worldwide fuel consumption has been increasing resulting from industrialization, population growth, modernization, and also transportation section. The last demands high level of fossil fuel while its renewability is literally low because of long-time anaerobic decomposition. In 2012, proportional of GHG emissions by sector in U.S. was distributed to electricity production, transportation, industry, commercial and residential, and agriculture at 32%, 28%, 20%, 10%, and 10% respectively. As mentioned, one of the carbon sources of transportation GHG emissions is fossil fuels, which include gasoline and diesel over 90% [1]. For this reason, next generation of fuel is invented to substitute fossil fuels usage as renewable fuels.

Biodiesel is one of the fascinating renewable fuels as it has been promoted in many countries [2]. Palm oil is also one of the attractive sources for biodiesel, which has been promoted in Thailand as B3, B5, and B10 biodiesel (3%, 5%, and 10% mixture of biodiesel with diesel) [3]. It is reported that carbon dioxide (CO_2) emission from biodiesel reduced approximately 38% from that of fossil fuel [4]. There are numbers of study that analyze GHG emissions of biodiesel [5]-[7], nevertheless, the studies are different from each other depending on system boundary, data inventory and calculation methods. To reduce consequences of greenhouse gases, it is indispensable to examine all possibilities of the biodiesel production as the environmental-friendly renewable energy. This study aims to assess the GHG emissions of biodiesel production focusing on the reduction capacity of biogas wastewater treatment.

II. Procedure for Paper Submission

A. Goal and scope of study

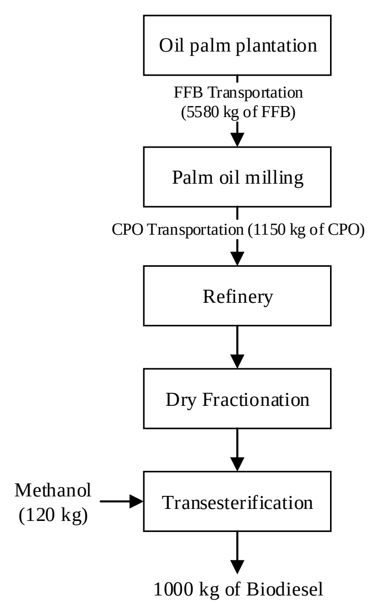

Fig. 1 System boundary of the study

Hunsa Rittipikul[1] is with Interdisciplinary graduate programs in Advanced and Sustainable Environmental Engineering, Thailand Advanced Institute of Science and Technology (TAIST-Tokyo tech), Kasetsart University, Bangkok, 10900, Thailand (e-mail: hunsa.r@ku.th).

Seksan Papong[2,*] is with National Metal and Materials Technology Center, Pathumthani, 12120, Thailand (corresponding author's phone: +662 564 6500 (4774); email: seksanp@mtec.or.th).

Pomthong Malakul[3] is with The Petroleum and Petrochemical College, Chulalongkorn University, Bangkok 10330, Thailand (e-mail: Pomthong.M@chula.ac.th).

Penjit Srinophakun[4] is with Department of Chemical Engineering, Faculty of Engineering, Kasetsart University, Bangkok 10900, Thailand (e-mail: fengpjs@ku.ac.th).

http://dx.doi.org/10.15242/IICBE.C0515046

The goal of this study is to evaluate the GHG emissions of palm oil biodiesel production chain comparing those with and without biogas recovery system. The system boundary is cradle-to-gate approach which consists of oil palm plantation, crude palm oil production, oil refinery, biodiesel production (transesterification), and also transportation at all stages shown in Fig. 1. The functional unit (FU) of this study is 1,000 kg of palm oil biodiesel.

B. Palm oil plantation

Most of oil palm has been grown in Southern part of Thailand especially in Chumphon, Krabi, and Suratthani province. However, it could be founded in Eastern part as well, for example Chonburi and Trat province. The plantation of oil palm can be distinguished into two main stages that are the nursery stage and plantation on the field. During the nursery stage, oil palms are seeded in polyethylene bag until they are approximately 1 year old and prepared for plantation. Oil palm begins to yield after 2.5-3 years. The first batch of harvesting is usually after 5 years. The lifetime of oil palm is over 30 years but, practically, it is cut down about 25 years because of its unreachable height [3]. Nevertheless, in Thailand, oil palm plantations belong to holders who have small size areas for plantation and lack of contemporary management [8]. The data applied at this stage were collected from Thai national database which includes GHG emission from seeding, applied fertilizers, herbicides, harvesting, and energy (biomass, biogas, and electricity from the grid).

C. Crude palm oil production

Fresh fruit branches (FFB) from plantation are transported to crude palm oil mills after harvesting. Palm oil extraction process should be operated immediately; otherwise the quality of palm oil will decrease due to high level of free fatty acid so the mill should not be placed too far from the oil palm plantation. The first step of crude palm oil (CPO) extraction begins with sterilization. FFB are sterilized by steam produced by steam boiler horizontally or vertically depending on technology of mill. In this study, the mill collected data applies horizontal sterilizing process. After the fruits are steamed, they are conveyed to thresher in order to separate the oil palm fruits out of empty fruit branch (EFB). Separated fruits are pressed afterward in pressing process so as to gather palm oil from the fruits. The major product of this stage is CPO that is the input in biodiesel production, co-product is palm kernel. There are wastes generated from the production which are fiber from palm mesocarp, palm oil mill effluent (POME) and EFB. Beneficially, palm kernel can be raw material for palm kernel oil production which is excluded and is allocated the environmental burden in this study. Moreover, palm kernel oil production generates wastes that are palm kernel shell. The palm fiber and palm kernel shell are typically the most common biomass for steam boiler. The production inventory is collected from the mill directly.

D. Biodiesel production

Even if crude palm oil can be promptly used for producing biodiesel, there are an optional processes which is refinery and dry fractionation that can purify and isolate more raw materials to produce biodiesel. Those two processes are included in this study. Triglyceride plays a crucial role in palm oil biodiesel. Refinery gives refined bleached deodorized palm oil (RBDPO) as a product and palm fatty acid distillate (PFAD) as a co-product. Little amount of RBDPO is then delivered to dry fractionation to produce palm stearin and palm olein. The former is one of the raw materials for biodiesel production while the latter is the product for eatable oil production. The remaining RBDPO and palm stearin are conveyed to transesterify with the reaction of alcohol, which is usually methanol, in the present of a catalyst. In this phase, palm oil biodiesel, the so-called methyl ester, is produced. The environmental burden is allocated between biodiesel and glycerol by its energy content. The energy applied in this stage is come from electricity generated by the grid. All production statistics are gathered from the annual production from the biodiesel plant.

E. Transportation

The transportations considered in this study are transportation from field or middlemen to mill and from mill to biodiesel plant. As some sale of FFB operated by middlemen is not always from the farmers to mill directly, distance of the transportation is not the shortest direction. Those transportation data are acquired from the mill and biodiesel plant as well.

F. Greenhouse gas calculation

There are usually six major greenhouse gases which are CO_2, methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), perfluorinated compounds (PFCs), and hydrofluorocarbon (HFC) [9]. In this study, the focused gases are CO_2, CH_4, and N_2O. GHG emission is evaluated according to carbon footprint direction for products and product category rules which are launched by Thailand Greenhouse Gas Management Organization (TGO). The calculation of GHG emission is illustrated in (1) where E stands for total GHG emission in unit of $kgCO_2$ equivalent (kg CO_2eq) per unit, Q stands for the quantity per functional unit of materials applied in production lines and EF stands for emission factor of the materials in unit of kg CO_2eq per quantity [10].

$$E = \sum_i Q_i \times EF_i \tag{1}$$

Equation (2) shows the calculation of allocation. Allocation has an advantage in terms of environmental burden sharing. As biodiesel provides energy for moving cars, the burden was allocated to other co-products by energy content as well. The allocations included in the study were, first, between crude palm oil and palm kernel, and second, between biodiesel and crude glycerol. AF, Q, and E abbreviations stand for allocation factor, quantity of products and energy content of the products [10]. The allocation factors by energy content applied in the study for biodiesel production and CPO production were 94.08% and 75.96% respectively.

$$AF = \frac{Q_i E_i}{Q_i E_i + Q_j E_j} \quad (2)$$

GHG emission during wastewater treatment for open lagoon was considered according to (3) where E and EF stand for emission and emission factor respectively [10]. The biogas unit reduced organic content in wastewater before it flows to open lagoon resulting in low level of chemical oxygen demand (COD). Because electricity generated from biogas was for sale, running the system itself, and applying in palm kernel oil production only, the emission was excluded proportional to the system boundary.

$$E = CODloading \times EF \quad (3)$$

Scenarios of the study are divided into 4 scenarios as follow:

Scenario 1 Wastewater from both CPO and biodiesel productions treated in open pond without CH_4 recovery;

Scenario 2 Wastewater from biodiesel production treated in continuous stirred-tank reactor (CSTR), while that from CPO production treated in open lagoon;

Scenario 3 Wastewater from CPO production treated with CSTR and CH_4 recovery to produce electricity, while wastewater from biodiesel production treated in open lagoon;

Scenario 4 Wastewater from both CPO and biodiesel productions treated by CSTR to produce electricity.

Because the biogas system was not found in actual biodiesel plant, the assumption of biogas recovery at biodiesel plant was minimally set at 50% [11] and authentic biogas recovery at CPO production was acquired from the mill directly. Afterward, GHG emission from milling was calculated in order to identify capacity of GHG reduction by biogas system at the mill.

G. *Emission factors*

Emission factors (EF) are the value that use for converting life cycle inventory into GHG emission [12]. Some of EFs used in the study were obtained from TGO [13], and some are provided by Ecoinvent database. Most of the emissions were calculated according to (1).

TABLE I
EMISSION FACTOR FROM TGO APPLIED FOR THIS STUDY

List	Factor ($kgCO_2$/unit)	Unit
FFB	0.0888	kg
CPO (with biogas)	0.7496	kg
CPO (without biogas)	1.1594	kg
Electricity	0.1693	MJ

III. RESULT AND DISCUSSION

Fig. 2 reveals GHG emission distributed into 5 distributors which are CPO acquisition, chemicals acquisition, wastewater treatment at biodiesel plant, and transportation.

Scenario 1 (S1)

It was the worst case scenario of the study. COD loading was generated 3.65 kg per 1000 kg of biodiesel. Biogas in this scenario was not produced. Total GHG emission was 1785.69 $kgCO_2eq$ per 1000 kg of biodiesel. The first two main distributors were CPO and chemicals acquisition with 1252.59 and 185.54 $kgCO_2eq$ per 1000 kg of biodiesel respectively.

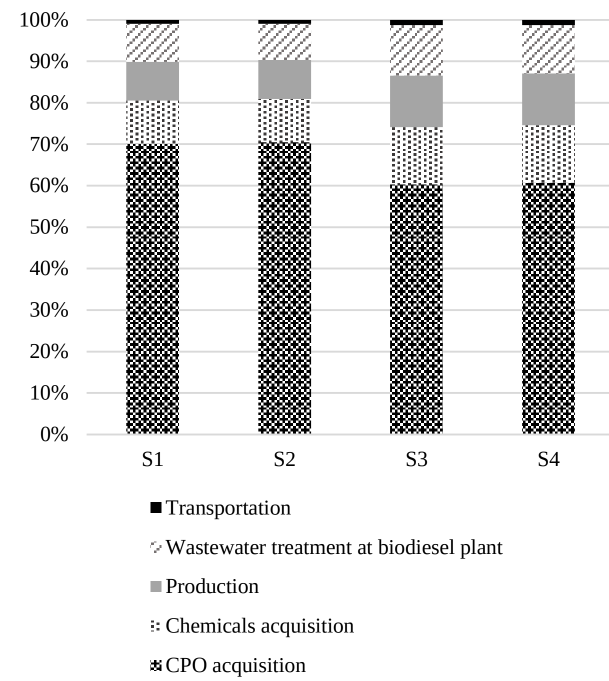

Fig. 2 GHG emissions distribution of biodiesel production.

Scenario 2 (S2)

As the wastewater treatment was set at 50% efficiency, the COD loading per 1000 kg of biodiesel was 1.83 kg per 1000 kg of biodiesel. Entire GHG emission was 1777.10 $kgCO_2eq$ per 1000 kg of biodiesel. In this scenario, CPO production without biogas recovery had the highest emission at 1252.59 $kgCO_2eq$ per kg of biodiesel. Even if at biodiesel plant had biogas recovery that released 155.02 $kgCO_2eq$ per kg of biodiesel, the total emission was still slightly lower than S1. It was indicated that the CPO production should be concerned more in order to reduce the GHG emissions.

Scenario 3 (S3)

COD loading was generated 3.65 kg per 1000 kg of biodiesel since the wastewater has the same condition as S1. Total GHG emission was 1342.89 $kgCO_2eq$ per 1000 kg of biodiesel. There is no different of emission at every stage except emission of wastewater treatment of biodiesel unit. The emission from wastewater treatment was 163.61 $kgCO_2eq$ per 1000 kg of biodiesel.

Scenario 4 (S4)

Because of 50% efficiency of CSTR, COD loading was generated 1.83 kg per 1000 kg of biodiesel. GHG emissions generated from this scenario were 1334.31 kgCO_2eq per 1000 kg of biodiesel. This scenario was considered as the best study. CPO acquisition was the main distributor at 809.80 kgCO_2eq per 1000 kg of biodiesel while production phase distributed 185.54 kgCO_2eq per 1000 kg of biodiesel and wastewater treatment of biodiesel plant emitted 155.02 kgCO_2eq per 1000 kg of biodiesel.

The overall GHG reductions by biogas only at the biodiesel plant itself were about 0.48% (without biogas at mill), and 0.64% (with biogas at mill) which were slightly small. Comparing the S1 to S4, the latter was installed biogas in both productions, the GHG emission reduced by 25.28%.

Fig. 3 compares GHG emissions of this study to those of others, one is the emission from Thailand national database [13] and the other is [3]. The GHG emissions were 1063.40 and 1181.84 kgCO_2eq per 1000 kg of biodiesel, respectively. However, Thailand national database did not clearly distinguish GHG emission of each stage and also was the average value of biodiesel production of the country. Reference [3] calculated the GHG emission of biodiesel production from CPO and indicated that the oil palm plantation and palm oil milling were two major distributors which were 482.24 and 508.64 kgCO_2eq per 1000 kg of biodiesel, respectively. Not only did the system boundary of [3] exclude refinery and dry fractionation and use CPO as a raw material for biodiesel production directly, but also the allocation was executed by economic price. Even though the differences of GHG emissions were depended on the calculation method, allocation, and actual data collection, the GHG emissions of this study had the same tendency as the previous study and national data base for S3 and S4.

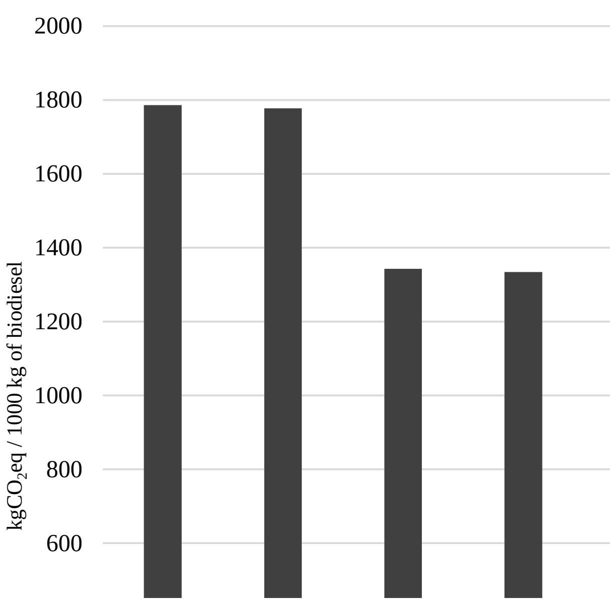

Fig. 3 Total GHG emissions of each scenario compared to others.

Fig. 4 focuses on CPO production with and without biogas system. The GHG emissions of CPO production with and without biogas recovery system were 585.54, and 1181.12 kgCO_2eq per 1000 kg of CPO, respectively (50.43% reduction). The FFB acquisition was the main distributor in CPO production with biogas recovery (431.43 kgCO_2eq per 1000 kg of CPO) while, without biogas unit, wastewater treatment was the highest emission (690.08 kgCO_2eq per 1000 kg of CPO). The largest contributor came from nitrogen fertilizer application releasing N_2O [14]. Biogas recovery plays and crucial roles in GHG emission as well. Wastewater from CPO production had a high value of COD loading. In this case, without biogas recovery, COD loading was 181.70 kg per 1000 kg of CPO. The efficiency of CSTR was found at 86.31% with 24.88 kg COD loading per 1000 kg of CPO to the open lagoon.

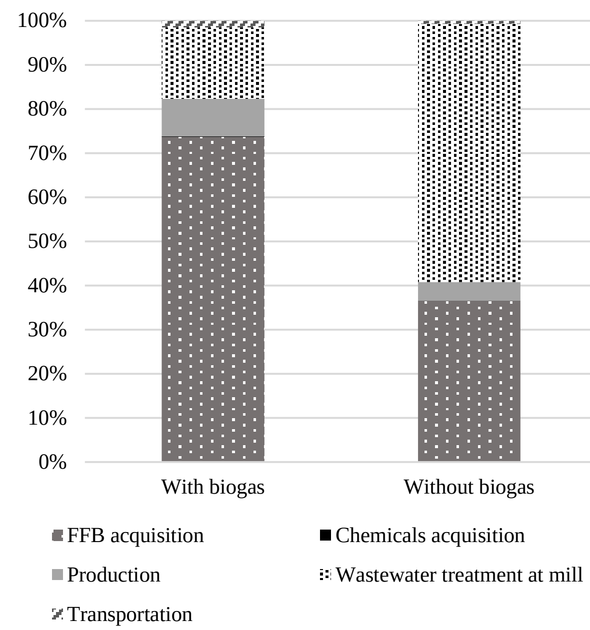

Fig. 4 GHG emissions distribution of CPO production.

IV. Conclusion

The present study shows that the GHG emissions of palm biodiesel production have the highest at CPO production stage. Wastewater management using biogas recovery system during biodiesel plant insignificantly reduces the GHG emissions. The GHG reductions of the worst case and the best case was 25.28%, hence the key to be more environmental-friendly is CPO production process. Biogas recovery from wastewater treatment system in palm oil milling can crucially reduce the emission due to low organic content for anaerobic digestion at open lagoon. GHG emissions of CPO production with and without biogas were 50.43%. It should be noted that fertilizer application and plantation management are also the important activities because excess nitrogen and carbon content can be converted into nitrous oxide and carbon dioxide which affect the GHG emissions of all over production chain. Organic composting is recommended to shrink the environmental burden from this phase and leads to low GHG emission.

V. Acknowledgement

This research is advocated by the Agricultural Research Development Agency (Public Organization) and the National Metal and Materials Technology Center under National Science and Technology Development Agency, Ministry of Science and Technology. The authors would like to express gratitude all data providers for this study and also Asst. Prof. Egashira Ryuichi (Tokyo Institute of Technology) for advice and giving a direction.

References

[1] US Environmental Protection Agency, Sources of Greenhouse Gas Emissions, http://www.epa.gov/climatechange/ghgemissions/ sources.html#ref3, 2014.

[2] G. Sorda, M. Banse, and C. Kemfert, "An overview of biofuel policies across the world," Energy Policy, vol. 38, no. 11, pp. 6977-6988, 11// 2010.

[3] T. Silalertruksa and S. H. Gheewala, "Environmental sustainability assessment of palm biodiesel production in Thailand," Energy, vol. 43, no. 1, pp. 306-314, 2012. http://dx.doi.org/10.1016/j.energy.2012.04.025

[4] K. F. Yee, et al., "Life cycle assessment of palm biodiesel: Revealing facts and benefits for sustainability," Applied Energy, vol. 86, no. pp. S189-S196, 2009.

[5] G. Pehnelt and C. Vietze, "Recalculating GHG emissions saving of palm oil biodiesel," Environ Dev Sustain, vol. 15, no. 2, pp. 429-479, 2013/04/01 2013.

[6] S. Yacob, et al., "Baseline study of methane emission from anaerobic ponds of palm oil mill effluent treatment," Science of The Total Environment, vol. 366, no. 1, pp. 187-196, 7/31/ 2006.

[7] J. Germer and J. Sauerborn, "Estimation of the impact of oil palm plantation establishment on greenhouse gas balance," Environ Dev Sustain, vol. 10, no. 6, pp. 697-716, 2008/12/01 2008.

[8] S. Papong, et al., "Life cycle energy efficiency and potentials of biodiesel production from palm oil in Thailand," Energy Policy, vol. 38, no. 1, pp. 226-233, 2010. http://dx.doi.org/10.1016/j.enpol.2009.09.009

[9] United Nations Framework Convention on Climate Change (IPCC), Kyoto Protocol, 2014.

[10] Intergovernmental Panel on Climate Change (IPCC), 2006 IPCC Guidelines for National Greenhouse Gas Inventories, http://www.ipccnggip.iges.or.jp/public/2006gl/pdf/2006gls_all_in.zip, 2014.

[11] C. Da Costa Gomez, "1 - Biogas as an energy option: an overview," in The Biogas Handbook, A.W.M. Baxter, Ed. Cambridge: Woodhead Publishing, 2013, pp. 1-16.

[12] R. Kaewmai, A. H-Kittikun, and C. Musikavong, "Greenhouse gas emissions of palm oil mills in Thailand," International Journal of Greenhouse Gas Control, vol. 11, no. pp. 141-151, 2012.

[13] Thailand Greenhouse Gas Management Organization (TGO), Emission Factor for Carbon Footprint of Product, http://thaicarbonlabel.tgo.or.th /download/Emission_Factor_CFP.pdf, 2014.

[14] T. O. Rodrigues, et al., "GHG balance of crude palm oil for biodiesel production in the northern region of Brazil," Renewable Energy, vol. 62, no. pp. 516-521, 2014.