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Environmental Evaluation of Biodiesel Production from Palm Oil in a Life Cycle Perspective

S. Pleanjai, S. H. Gheewala*, and S. Garivait

The Joint Graduate School of Energy and Environment,
King Mongkut's University of Technology Thonburi, Bangkok, Thailand
*Corresponding Author: shabbir_g@jgsee.kmutt.ac.th

Abstract: Biodiesel is one of the most promising alternative fuels for transportation in Thailand. It is a very good candidate for substituting petroleum-diesel in engines because of its similar properties. Obtained from transesterification of fatty materials, biodiesel can be produced from various vegetable and/or animal oils. Regarding raw material supply and production cost, palm oil is found to be a wonderful suitable raw material for biodiesel production in Thailand. In this study, an environmental evaluation of biodiesel production from palm oil has been developed in a life cycle perspective in order to assess the environmental implications of the proposed substitution. To this end, the study is divided into 3 stages: oil palm plantation, palm oil production and transesterification into biodiesel. For each stage, the materials and energy flows are presented and discussed. The emissions to air, water and soil compartments are inventoried. The emissions such as wastewater discharge, solid waste load, volatile organic compounds and other major air pollutants are discussed in terms of their potential environmental impacts.

Keywords: biodiesel, life cycle perspective, oil palm plantation, palm oil production, transesterification.

1. INTRODUCTION

The highly increasing trend of oil price especially in this year (2004) has had a great impact on both the agricultural and industrial sectors because of the higher cost of production. The tremendous loss of foreign exchange through the import of petroleum products has caused the Thai government and private sector to consider new sources of energy to substitute for the expensive petroleum products. Using biodiesel is an alternative to diesel fuel, which will improve the environment, reduce foreign imports and increase the use of renewable fuels. It can be produced from various vegetable and/or animal oils with methanol or ethanol, yielding methyl or ethyl ester – or biodiesel – with glycerol as the by-product.

The production of biodiesel entails emissions to the environment such as fertilizers and herbicides during plantation and emissions from fuel use during oil extraction, transportation, etc. Hence, the environmental implications of biodiesel production need to be addressed. Life cycle assessment (LCA) is one method for such an evaluation. LCA studies the environmental aspects and potential impacts throughout a product's life from raw material extraction through production, to use and disposal (i.e. from cradle to grave) [1].

An LCA is a methodological framework for estimating assessing the environmental impacts attributable to the life cycle a product, such as climate change, stratospheric ozone depletion, photochemical ozone (smog) creation, eutrophication, acidification, toxicological stress on human health and ecosystems, the depletion of resources, water use and others. The emissions and consumption of resources, as well as other environmental exchanges at every relevant stage (phase) in a product's life cycle are compiled. After the compilation and preliminary analysis of all environmental exchanges (emissions, resource, consumptions, etc.), called the life cycle inventory (LCI), it is often necessary to calculate, as well as to interpret, indicators of the potential impacts associated with such exchanges with the natural environment [2]. LCA study of biodiesel production from palm oil has not been worked out in Thailand, although its production process from oil palm has been studied [3-10].

This study aims to compile an inventory of relevant inputs and outputs of biodiesel production from palm oil; evaluate their associated potential environmental implications and serving as the database for the life cycle impact assessment.

2. METHODOLOGY

The methodology developed in this study is based on the LCA. Goal and scope definition: the goal of this study is to evaluate the environmental performance of biodiesel production from palm oil based on a life cycle perspective. Impact assessment of the emissions is not included in this study.

Biodiesel production needs palm oil, which comes from fresh fruit bunches from oil palm plantation. It is produced from palm oil by transesterification.

The life cycle of biodiesel production is divided into 3 stages: oil palm plantation, palm oil production and transesterification into biodiesel. Relevant data for resource consumption and emissions to air, water and soil must be collected for all the stages. The life cycle diagram of biodiesel production is shown in Fig. 1.

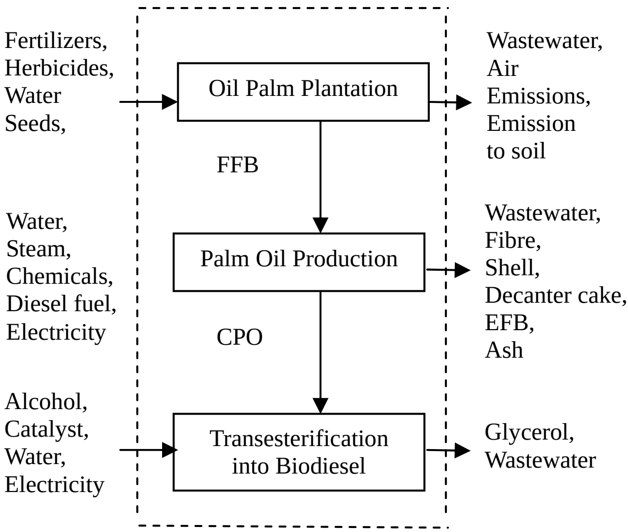

Figure 1. Life cycle diagram of biodiesel production.

The data were collected by direct measurements, plant reports and literature review. The data analysis includes materials and energy inputs and outputs of each stage. The materials and energy are normalized to a ton of product.

Environmental evaluation: after compiling the data and analysis of all emissions, resource consumptions, etc., the potential environmental impacts thereof are discussed.

The sites for the data in this study are as follows:

- The oil palm plantation is located in the Krabi province, in the southern part of Thailand. Materials and energy: Input data are fertilizers, herbicides, water, and seeds. Output data are emissions to air, soil, and wastewater, and fresh fruit bunches (FFB).
- The palm oil production facility is also located in the Krabi province. Materials and energy: Input data are FFB, water, steam, diesel and electricity. Output data are fibre, shell, decanter cake, empty fruit bunches (EFB), ash, wastewater, air emissions, crude palm oil (CPO) and kernel.
- The biodiesel production (transesterification) facility is located in the South of Thailand. Materials and energy: Input data are palm oil, water, electricity, methanol and sodium hydroxide. Output data are methyl ester (biodiesel), glycerol and wastewater.

3. RESULTS AND DISCUSSION

3.1 Oil Palm Plantation

The results of this stage are presented in Fig. 2. Water requirement for the oil palm plantation is mostly from the rain water in the 25 years' lifetime of the plant [11]. The plantation has 21-22 trees/rai (1 rai = 1600 m^2). The fertilizers used are N from ammonium sulphate (21-0-0), P from ground rock phosphate (0-3-0), K from potassium chloride (0-0-60) and Mg from kieserite (26% MgO). They are used every year, but the rates of application are different depending on the age of the plants. Paraquat and glyphosate are used as herbicides between 1-3 times per year at 0.1-0.2 kg/rai/time and 0.3-0.5 kg/rai/time respectively. Furadan is used as an insecticide in the nursery only in case the seedlings are attacked by insects. However, insects are not a problem after the seedings mature and are planted in the field.

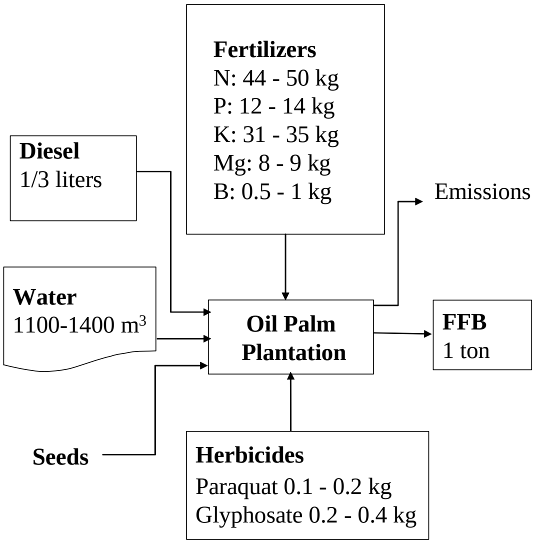

Figure 2. Unit process of oil palm plantation.

Oil palms start bearing bunches 2½- 3 years after field planting. The usual frequency of a harvesting round is 10-15 days or 2-3 times a month. Young palms are harvested with a chisel whereas old and tall palms are harvested with a long-handled sickle. As they are harvested only by manual labor, there is no fossil energy input to harvesting. The fruit bunches are generally transported to palm oil mill on the day of harvesting. The nursery & loading ramp are 1.5 km away from the oil palm fields. A 3-ton truck is used for FFB collection. Emissions to air from diesel combustion have not been included in the study. The FFB as resources are sent to the palm oil mill for extraction of the palm oil.

The FFB yield is 2.7-2.8 tons/rai/year that is nearly similar to the yield from Malaysia (2.5-3.8 tons/rai/year) because the seeds come from Malaysia and are thus the same type. If there is some excess of nutrients applied for oil palm tree, they may remain in the soil or be lost through erosion or leaching, diluted in runoff water or dispersed in other ways. Erosion is a serious kind of soil degradation, since it is irreversible. For example, in Malaysia there is about 0.1 kg of erosion per square meter per year [12]. An excess of nitrogen can lead to nitrate leakage. Nitrate leakage and phosphorus losses during the cultivation period contribute to nutrient enrichment. However, phosphorus and potassium are important for the long-term fertility of the soil. Nitrogen fertilizer to soils may be lost shortly by volatilization after incorporation as NH_3 and NO_x and then transformed to N_2O (nitrous oxide). The default values for NH_3 and NO_x volatilization from nitrogen fertilizer is 0.1 kg N per kg fertilizer [13]. Paraquat (gramoxone) is sprayed on oil palm tree as an herbicide. One hour after spraying the paraquat, about 11 mg per kg body weight may be retained on the laborer’s skin. This may be discharged 14 days later at 10.21 mg per liter in the person’s urine [14]. Paraquat is nonpersistent and is decomposed in the soil in a few weeks because of the activity of soil micro-organisms and photodecomposition. Glyphosate is contact pesticide or nonsystemic which can used for controlling weed also. Carbofuran (furadan) is a systemic pesticide. The toxicity of furadan is relatively lower than organic phosphate in mammals. It does not accumulate much in soil and is decomposed by photodecomposition during period 2 weeks to 1 year.

3.2 Palm Oil Production

The palm oil mill production capacity is around 45 tons of FFB per hour or around 1000 tons of FFB per day. The mill operates for approximately 16-24 hours per day. Palm oil tree and fresh fruit bunch are shown in Fig. 3.

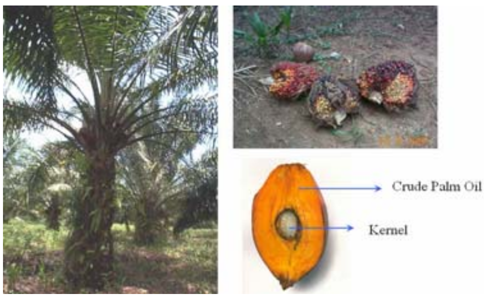

Figure 3. Palm oil tree and fresh fruit bunch in Krabi province.

Unit operations involving in palm oil mill process consist of

- **Loading ramp**: after passing over the weighbridge, the fruit has to be held for a time until it can enter the first stage of processing. For loading, the ramp is the place where the FFB are transported and unloaded in the mill.

- **Sterilization** of the FFB is done batchwise in an autoclave for 1 hour 40 minutes for the FFB to be completely cooked. The temperature inside is about 120-130°C. The steam condensate is the wastewater generated at this step.
- **Stripping (threshing)**: to separate the sterilized fruits from bunch stalks. This processing step generates the empty fruit bunches (EFB).
- **Digestion**: the separated fruit fruits are put into the digester where they are mashed under steam-heated conditions. No residue occurs in this step.
- **Crude palm oil extraction**: the homogenous oil mash from the digester is pushed through a screw press, and later passes through a vibrating screen, a hydrocyclone and decanters to remove fine solids and water. Decanter wastewater and decanter cake are the major wastes at this step. Centrifugal and vacuum driers are used to further purify the oil before sending it to a storage tank. The temperature of oil (60°C) in the storage is maintained with steam coil heating before the CPO is sold.
- **Nut/ Fibre Separation**: the fibre and nuts from the screw press are separated in a cyclone. The fibre that passes out of the bottom of the cyclone is used as boiler fuel from which ash is produced after combustion.
- **Nut Cracking**: the nuts are cracked in a centrifugal cracker. After the cracking process, the kernels and shells are separated by clay suspension (Kaolin). The separated shells from the kernels are sold to other mills as fuel. The kernels are sent to the kernel drying process in a silo dryer to sell (for extraction) to other mills.

The characterization of wastewater from the palm oil mill is shown in Table 1 and the materials and energy flow for palm oil production are shown in Fig. 4.

Table 1. Characterization of wastewater from palm oil milling process.

Parameter	Unit	POME[1]	Standard[2]
pH		7.45-9.24	5.0-9.0
BOD_5	mg/l	195	<100
COD	mg/l	1200	<1000
Suspended Solids	mg/l	890	<150
Oil & Grease	mg/l	90	<25
Temperature	°C	36-40	<40

[1]Palm oil mill effluent (POME) [15]
[2]Effluent wastewater standards for Thai palm oil mill industry (Department of Industrial Works, 1997)

From Table 1, it can be seen that the effluent wastewater from the palm oil mill is not within the standard of industrial palm oil mill in Thailand. However, this wastewater is not directly discharged into any water body, but is treated by pond or through land application.

From Fig. 4 it can be seen that on the average one ton of crude palm oil (CPO) is produced from 5.8 ton of FFB. Fibre, shell, decanter cake and EFB are 30, 6, 3, 28.5% of the FFB respectively. EFB is a bulk solid residue and its use as a fuel for boiler is constrained by its high moisture content and low heating value (<10 MJ/kg dry EFB). Utilization of the EFB as substrate for mushroom cultivation and for the production of particle board is preferable. EFB could also be used as organic fertilizer and mulching material. Palm fibres are used mainly as fuel for boilers (heating value of <5 MJ/kg dry fibres). Although palm shell can be used as boiler fuel with a heating value of 17 MJ/kg, it causes black smoke [16]. Palm shell would be better used for activated carbon rather than fuel due to those undesirable emissions. Decanter cake can be used as a fertilizer. Flue boiler emissions should be measured because high particulate concentrations indicate improper combustion of fibre. Palm oil mill effluent (POME) is the mixture of polluted effluent, which should be treated before release. At the palm oil mill selected for this study, POME is digested anaerobically to yield biogas which is used in modified diesel engine with a 90 kW induction motor. This contributes to effluent treatment as well as helps to reduce amount of electricity needed from off-site production. This electricity is used at the office, labor house and anaerobic digester plant in the palm oil mill.

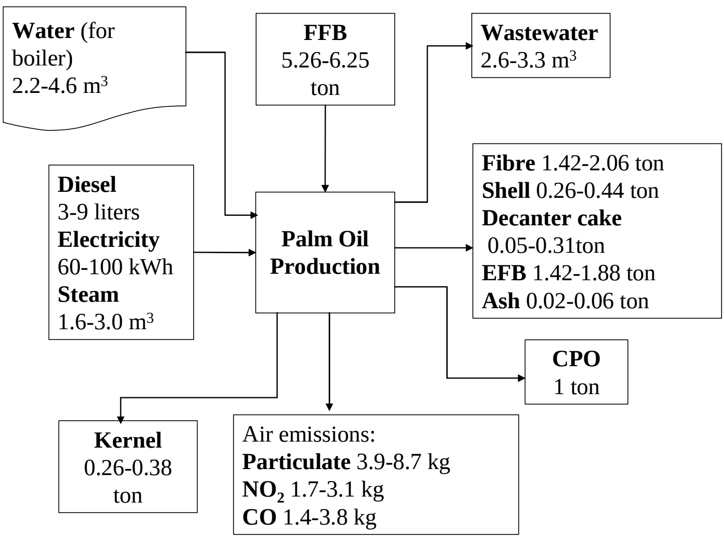

Figure 4. Unit process of palm oil production.

3.3 Transesterification into Biodiesel

The reactor for producing biodiesel from palm oil is a 20,000-L batch type reactor operating at a maximum of 3 batches/day with a reactor time of 8 hr/batch. The temperature is 50-60^{o}C. Productivity of biodiesel is around 16 tons/batch. Palm oil is preheated at 55^{o}C. Alternatively, used cooking oil (which mainly used palm oil) is preheated at 100^{o}C to remove the moisture. Transesterification of the oil produces methyl esters (biodiesel) and glycerol. The methyl ester layer is a light yellow liquid that is on top of the glycerol layer, which is dark brown in color. The mixtures may be kept overnight and allowed to separate by gravity. Otherwise, the methyl ester is separated from the glycerol and washed with water and acetic acid until the washing water is neutral. The methyl ester is then dried by heating. Materials and energy flows for the transesterification of palm oil into biodiesel are shown in Fig. 5.

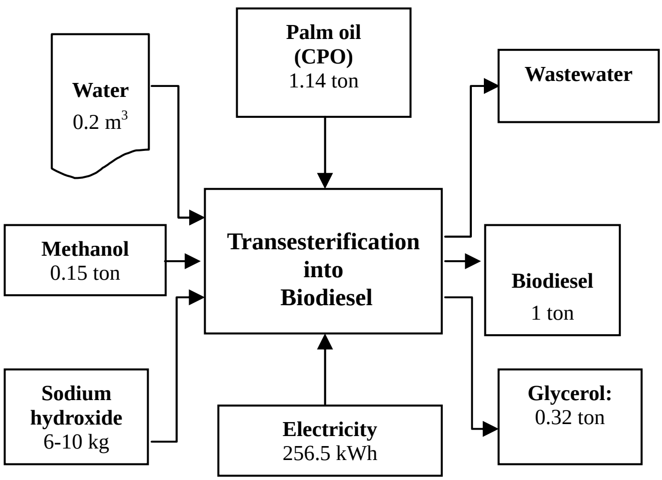

Figure 5. Unit operation for transesterification into biodiesel from palm oil.

Fig. 5 shows that the yield of biodiesel is around 87%. The percentage of yield for biodiesel production can be calculated based on a stoichiometric material balance as per the following simplified equation:

$$\underset{\text{1 mole}}{\text{palm oil}} + \underset{\text{3 moles}}{\text{methanol}} \longrightarrow \underset{\text{3 moles}}{\text{palm oil-methylester}} + \underset{\text{1 mole}}{\text{glycerol}}$$

Corresponding masses (calculation based on C-18 chain of palm oil):

$$884\ \text{g} + 96\ \text{g} \longrightarrow 888\ \text{g} + 92\ \text{g}$$

Glycerol is the by-product that may be used to produce soap or other materials. Wastewater from the process should be treated before disposal or release into the environment. The wastewater generated is about 0.2 m^3, estimated from the water input.

Further study will address the emissions from using biodiesel in diesel engines for transportation. Currently the National Biodiesel Board and the US Environmental Protection Agency (USEPA) reported their analytical and experimental work on various biodiesel blends on diesel engines that the B100 and B20 formulas significantly cut combustion exhausts. The Department of Naval Dockyards, Royal Thai Navy, reported a 60% cut in black smoke through using biodiesel on a 145 horsepower diesel engine [17].

4. CONCLUSION

The total flux of materials, energy, and emissions from the life cycle of biodiesel production from palm oil are summarized in Table 2.

1 ton of biodiesel is produced from about 1.14 tons of crude palm oil (CPO) or about 6-7 tons of fresh fruit bunches (FFB).

The major water requirement for the production of biodiesel comes from oil palm agriculture. Nitrogen is the largest input from fertilizer although potassium and phosphorus are also significant contributors. Diesel requirements come primarily from agriculture and palm oil production. The transesterification process has the largest demand for electricity (kWh). Other material and energy inputs are shown in Table 2. One should keep in mind that additional inputs to each step will produce more waste.

Table 2. The inventory list of 1 ton biodiesel production.

Parameter	Quantity	Parameter	Quantity
Raw Mat.		**Energy**	
Fertilizer (kg)		Steam (m^3)	1.8-3.5
N	265-340	Electricity (kWh)	360-380
P	74-95	**Air Emissions**	
K	190-240	Particulate (kg)	4.2-9.4
Mg	48-61	NO_2 (kg)	1.8-3.3
B	4-5	CO (kg)	1.5-4.1
Paraquat (kg)	0.5-0.9	**Wastewater (m^3)**	3-4
Glyphos. (kg)	1.4-2.2	**Solid waste**	
FFB (ton)	6-7	Fibre (t)	1.6-2.4
NaOH (kg)	6-10	Shell (t)	0.3-0.5
Methanol (t)	0.15	Decanter cake (t)	0.06-0.14
Diesel (L)	5-13	EFB (t)	1.6-2.1
Water (m^3)	6,500-10,000	Ash (t)	0.02-0.07
		Output	
		Biodiesel (t)	1.0
		Glycerol (t)	0.32

For emissions to air, soil and wastewater:

- Emissions associated with the plantation include N-fertilizer, which is applied to oil palm plants in the nursery and field. This emits N_2O to the air which contributes to global warming. This fertilizer may also contribute to nitrate and phosphate leakage to the groundwater, however the excess is not known. The herbicides paraquat and glyphosate are also spread on the soil in the plantation, and the insecticide furadan is applied to the nursery, but these chemicals are less toxic because of photo- and bio-degradability.
- In the steam generation step of palm oil production emissions are composed of particulate matter, NO_2, and CO (in flue gas), all of which contribute to photochemical ozone formation. In addition wastewater from the palm oil mill process is sent to the Thai industrial palm oil mill and produces biogas which is used for electricity production. Solid wastes such as fibre, shell, decanter cake, empty fruit bunches and ash are used in agriculture and industry.
- In palm oil transesterification into biodiesel wastewater is produced from washing of methyl esters. Although the water is low in pollution, contaminants may include sodium hydroxide catalyst, methanol, glycerol, palm oil, etc. In addition there are emissions to the air when biodiesel is combusted in diesel engines for transportation which will be considered later.

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