PALM OIL BIODIESEL: CHALLENGES, RISKS AND OPPORTUNITIES FOR REDUCING AND REPLACING THE NON-RENEWABLE FOSSIL FUEL DEPENDANCY - A REVIEW

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ABSTRAK

Biodiesel merupakan sumber energi terbarukan yang diharapkan memegang peranan penting dalam mengurangi dan menggantikan bahan bakar fosil yang tidak dapat diperbarui. Minyak kelapa sawit merupakan salah satu bahan baku yang telah digunakan bertahun-tahun dan memiliki banyak kelebihan diantaranya tingginya perolehan kembali minyak, murah dalam memproduksi dan menyulingnya, mempunyai karakteristik yang mirip dengan bahan bakar Diesel, dan memiliki emisi yang rendah. Namun, beberapa permasalahan timbul seperti ketahanan pangan, peralihan lahan, dan punahnya keanekaragaman hayati, sehingga perlu disikapi dan diatasi secara bijak. Studi *life cycle assessment* (LCA) menunjukkan total energi positif dan total penyerapan gas rumah kaca yang juga positif (sampai dengan level konversi tertentu dari minyak kelapa sawit ke biodiesel) yang berarti biodiesel dari minyak kelapa sawit memiliki potensi tinggi untuk menggantikan bahan bakar fosil dan juga sekaligus sebagai bahan bakar ramah lingkungan.

Kata kunci: Biodiesel, minyak kelapa sawit, *life cycle assessment*

ABSTRACT

Biodiesel is a renewable source of energy which is expected to play a significant role for reducing and replacing the existing non-renewable fossil fuels. Palm oil is one source of biodiesel feed stock which has been used for many years and gave so many advantages such as high oil yield, cheap to produce and to refine, has similar characteristics with petroleum-derived diesel, and has lower emission. However, some issues, such as food stock security, land use changes, and biodiversity extinction, have arisen which need to be considered and solved wisely. Life cycle assessment (LCA) study shows a positive net energy and a net positive sequestration on GHG emission (up to some level of conversion from palm oil to biodiesel) which means biodiesel from palm oil has a high potential to replace fossil fuel and also an environmental friendly fuel.

Keywords: *Biodiesel, palm oil, life cycle assessment*

I. INTRODUCTION

The increasing fossil fuel demands (due to population growth, consumerisms, etc.) escalating prices of petroleum in the world market, diminishing supply of fossil fuels, and increasing greenhouse gas emission (GHG) which is suspected to be responsible for global climate change. All of these factors have raised concerns for a need of renewable energy sources such as palm oil biodiesel (POB).

Controversies which challenge the sustainability of palm oil as an environment-friendly source of energy such as:

- GHG emission. According to IPCC, deforestation, mainly in tropical areas, accounts for up to one-third of total anthropogenic CO_2 emission.
- Land use changes from food-crops-land, peatland and forests to oil palm plantations including habitat destruction leading to demise of critically

endangered species and reduction of biodiversity (UNEP, 2007). Furthermore, around 90% of area's flora and fauna are lost when the land is converted into monoculture plantations when the plants are grown in the straight lines (Datamonitor, 2010).

- Food stock security and stability. The American Oil Chemist Society (AOCS) reported that the usage of palm oil as an industrial biodiesel feedstock rose from 15% (2000/01) to 23% (2009/10). This fact and the supply-demand contraction are responsible for the fluctuation of palm oil price in the market.

There is a substantial increasing figure of oil palm plantation area and crude palm oil production as a source of POB, especially in The South East Asia, Central and West Africa and Central America. According to 'The Economist' (2010), oil palm produced 38% of vegetable oil output on 4% of the world's vegetable-oil farmland with total production of 46.9 million tons in 2010. It produces up to 10 times more oil per unit area as soybeans, rapeseed or sunflowers.

Oil palm tree has a relatively high oil productivity compare to the other biodiesel feed stock (Table 1). Although it has the second highest productivity after microalgae, the total production capacity (oil productivity combined with palm oil production) is the largest amongst all feedstocks.

The conversion technologies from palm oil to POB are already available and proven. Furthermore, the biodiesel product has similar characteristics with diesel fuel, hence the POB could be used directly as a mixed with diesel fuel without engine/equipment modifications.

The aim of this study is to gain a clear understanding about POB as a promising source of renewable energy in the present year and in the future. This study also reviewed the potential usage of POB as a sustainable source of energy by reviewing all relevant literatures and experimental data including the Life cycle analysis (LCA) to evaluate net energy and CO_2 emission assessment, POB characteristic compare to diesel fuel, recent research and development (R&D) programs for improving palm oil production and POB usage. A study case of POB usage on commercial industrial steam boiler at PT. Petrokimia Gresik, Indonesia is also discussed in this review.

II. PALM OIL BIODIESEL FEEDSTOCK

In general, biodiesel feedstock can be categorized into three groups: vegetable oil (edible or non-edible

Table 1
Oil productivity of different crops
(Lin *et al*, 2011)

Oil Crops	Productivity (gallons per acre per year)
Microalgae	5,000 – 15,000
Oil Palm	635
Rapeseed	127
Sunflower	102
Soybeans	48
Corn	18

Table 2
Percentage of fatty acid from palm oil and other vegetable oil (Balat and Balat, 2010)

Oil	Palmitic (C16:0)	Palmiloteic (C16:1)	Stearic (C18:1)	Oleic (C18:1)	Linoleic (C18:1)	Linolenic (C18:3)	Other Acid
Palm	**42.6**	**0.3**	**4.4**	**40.5**	**10.1**	**0.2**	**1.1**
Rapeseed	3.5	0.1	0.9	54.1	22.3	-	0.2
Sunflower	6.4	0.1	2.9	17.7	72.9	-	-
Soybean	11.9	0.3	4.1	23.2	54.2	6.3	-
Corn	6.0	-	2.0	44	48	-	-

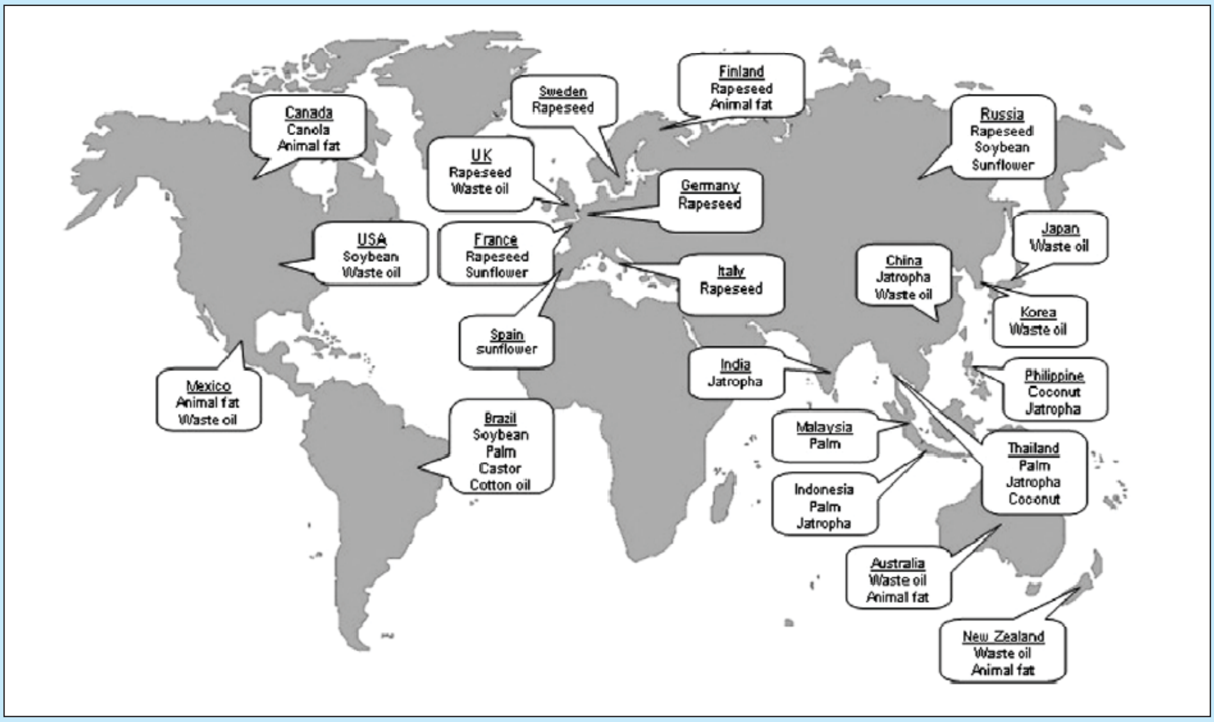

Figure 1
Palm oil and other vegetable oils distribution (Lin *et al*., 2011)

oils), animal fats, and used cooking oil including triglycerides. Palm oil for POB feedstock is categorized as edible vegetable oil produced from oil palm, *Elaeis sp*. The oil is extracted from the palm fruit which has high content of fatty acid. The composition of palm oil is shown in Table 2 in comparison with composition from other vegetable oil.

Oil palm plantations are distributed mostly in wet tropical region, but it is a hardy crop and has performed very well in areas with a marked dry season and on a very wide variety of soils (Figure 1). Total plantation area is increasing from year to year where Malaysia and Indonesia contribute to more than 80% area. The palm oil production in both countries is also increasing as shown in Figure 2 whereas comparison between Palm oil and other vegetable oils in terms of oil production and planted area are shown in Figure 3.

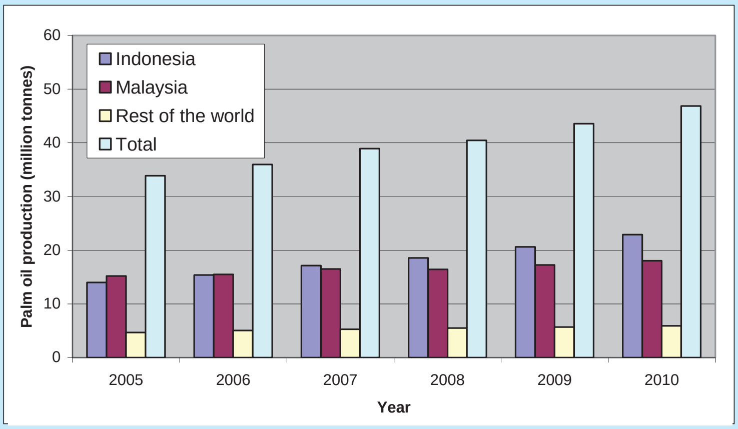

Figure 2
Palm oil productions and its estimation at 2010 (Claire *et al.*, 2007)

According to AOCS, palm oil is the largest, the cheapest commodity vegetable oil and also the cheapest oil to produce and to refine. This potential mainly comes from a higher palm oil yield and also the availability of relatively cheaper labors compared to others vegetable oil plantations. As shown in Figure 3, oil palm supplied 32% of vegetable oil output on 4% of the world's vegetable oil farmland.

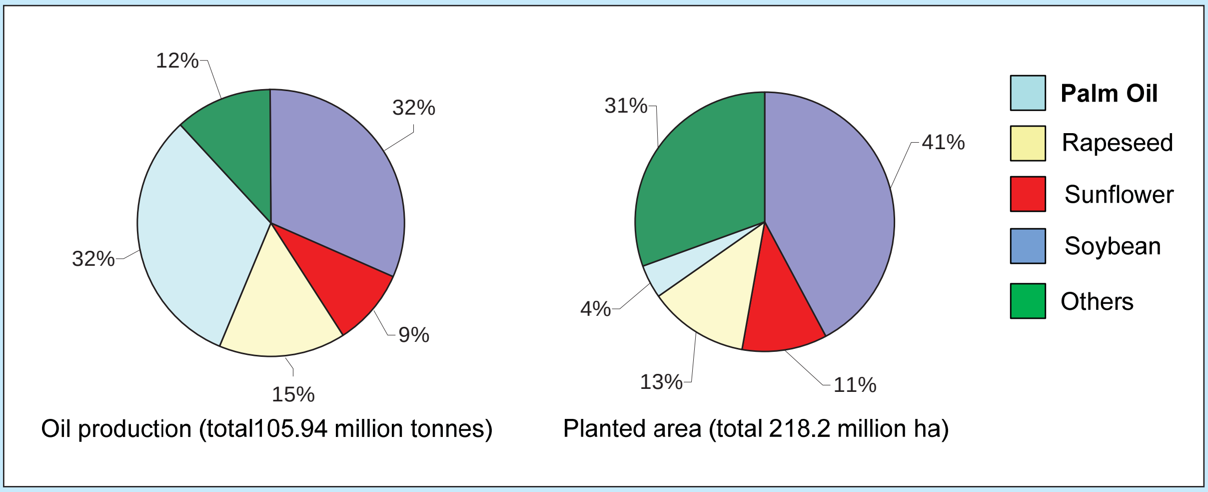

Figure 3
Oil production and planted area of palm oil compare to other vegetable oils in 2005 (Yee *et al.*, 2009)

Table 3
Comparison of main biodiesel conversion techniques (Lin *et al.*, 2011)

Techniques	Advantage	Disadvantage
Dilution or microemulsion	Simple process	1. High viscosity 2. low volatility 3. Low stability
Pyrolysis	1. Simple process 2. No-polluting	1. High temperature is required 2. Equipments are expensive 3. Low purity
Transesterification	1. Fuel properties is closer to diesel 2. High conversion efficiency 3. Low cost 4. Suitable for industrial application	1. Low free fatty acid and water content are required (for base catalyst) 2. Pollutant will be produced because the product must be neutralized and washed 3. Accompanied by side reaction 4. Difficult reactions product separation
Supercritical methanol	1. No catalyst is required 2. Short reaction time 3. High conversion 4. Good adaptability	1. High temperature and pressure are required 2. Equipment cost is high 3. High energy consumption

The uses of palm oil are varied and they include the food industry (cooking oil, margarine, cocoa butter equivalent/CBE, etc), cosmetics (soaps), raw materials for chemical compounds (detergent, tire, etc), biofuel and biodiesel feedstock. Palm oils could be used directly as biofuel for heavy machineries or vehicles. However, they have some disadvantages due to their viscosity and volatility which are not compatible with common engines. In addition, polyunsaturated hydrocarbons containing in the oil are unstable components for this process (Balat and Balat, 2010). This disadvantage could be reduced by blending with diesel fuel to some blending ratio, or by converting it to Fatty Acid Methyl Ester (FAME) which is commonly known as biodiesel.

III. PALM OIL BIODIESEL CONVERSION AND UTILISATION

There are some processes available for converting palm oil to biodiesel. Conventional physical process such as mixing and formation of micro-emulsion might be used easily to improve these poor characteristics. However, some encountered problems such as formation of carbon deposits, fuel dilution and high temperature pyrolyis cracking is difficult to be controlled. Therefore, some techniques involving chemical reactions, such as pyrolysis, transesterification and supercritical methanol, have been applied to solve these problems. The advantage and disadvantage of these techniques is summarized in Table 3.

Among these techniques, catalytic transesterification is the most widely used for industrial biodiesel production. This technique can reduce the high viscosity of the oil and increases cetane number. In addition this technique is low cost and high efficient process.

Transesterification is a reversible chemical reaction between triglycerides and short-chain alcohol in the presence of catalyst (such as lipase catalyst, acid catalyst or alkali catalyst) as shown in Figure 4. The alcohol and catalyst commonly used in the process are methanol and NaOH respectively. Methanol is used commercially because of its low price whilst sodium hydroxide (alkali catalyst) is used because of its faster reaction, lower temperature and cheaper compared with other catalysts.

A comparison betwen POB characteristic with diesel and biodiesel derived from various vegetable oils is shown in Table 4. Table 4 exhibits that FAME extracted from palm oil has viscosity of approximately 4.7 mm^2/s which is close to diesel fuel viscosity. In addition, the cetane number of Palm Oil

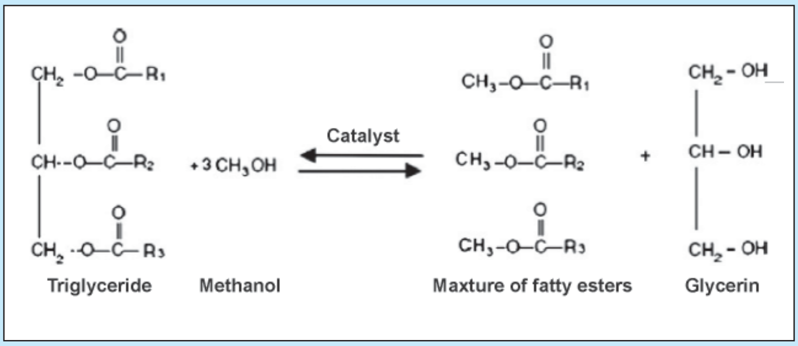

Figure 4
Transesterification reaction of triglycerides to FAME

Table 4
Some important characteristics of POB compared to Diesel and biodiesel derived from various vegetable oils (Lin *et al*., 2011 and Balat, 2010)

Fuel	Kin.viscosity (mm^2/s, 40°C)	Density (g/cm^3, 21 °C)	Cetane Number	Flash point (°C)	Cloud Point (°C)	Pour point (°C)
Diesel	2.0 – 4.5	0.820 -0.860	51.0	55	-18	-25
Palm Oil (100 %)	**42.66**	**0.85**	**42**	**304**	**-**	**-**
Palm Oil (FAME)	**4.71**	**0.864**	**57.3**	**135**	**16**	**12**
Soybean ME	4.08	0.884	50.9	131	-0.5	-4
Rapeseed ME	4.83	0.882	52.9	155	-4	-10.8
Sunflower ME	4.60	0.880	49.0	183	1	-7

FAME is higher than cetane number belongs to both palm oil and diesel oil. Viscosity is the most important property of biodiesel since it affects the operation of the fuel injection equipment. High viscosity leads to poor atomization of the fuel spray and less accurate operation of the fuel injectors (Balat, 2010). The cetane number indicates the ignition quality and measures the readiness of the fuel to auto-ignite when injected into the engine. The higher the cetane number, the better the quality of the fuel. The flash, cloud and pour point of FAME are higher than diesel fuel, but these characteristics do not affect fuel injection and combustion processes significantly. In fact, higher flash point offers safety benefits because it is much less combustible (Balat, 2010).

Table 5
Advantages and disadvantages of POB as diesel fuel (Balat, 2010)

Advantages	Disadvantages
High portability	Higher viscosity
Ready availability	Lower energy content
Higher combustion efficiency	Higher cloud and pour point
Lower sulfur and aromatic content	Higher nitrogen oxide emission
Higher cetane number	Lower engine speed
Higher biodegradability	Injector coking
	Relatively higher price
	Higher engine wear

The advantages and disadvantages of POB as diesel fuel are shown in Table 5. Generally, POB has heating value of approximately 37,333 kJ/kg which 12% less than heating value of diesel fuel, 42,700 kJ/kg. The lower value is caused due to the presence of electronegative element oxygen (Balat, 2010). Some techniques for determinations of biodiesel to ensure its quality are already available as standard method such as European Standard EN 14214 and American Society for Testing Materials ASTM D6751.

Biodiesel can be used as pure fuel (B100) or blended with diesel with certain blending ratio. The most common biodiesel blends are: B2 (2% biodiesel), B5 (5% biodiesel) and B20 (20% biodiesel). According to Balat (2010), biodiesel blends up to B20 can be used in nearly all diesel equipment without engine modification. In addition, they are compatible with most storage and distribution equipment. The European car industries are clearly focusing on B5 or B10 where B100 will not be introduced on a large scale for passenger cars, since the development of engines and pollution control systems for the limited amount of B100 available cannot be economically justified (Rupillius and Ahmad 2007). However, for commercial industrial scale, especially for steam boiler and furnace, modification is not required even for B100. The application results for B100 carried out by PT Petrokimia Gresik are summarized in Table 6.

Table 6 indicates that low gross calorific value (GCV) of B100 (87.2% of diesel's GCV) resulted in higher B100 consumption rate (119.6% of diesel) and lower fuel to steam efficiency (98.8% of diesel). Furthermore, biodiesel utilization in diesel engine combustion substantially reduces emission of hydrocarbons (HCs), carbon monoxide (CO), particulate matters (PM), sulfates, polycyclic aromatics HCs and nitrated polycyclic aromatics HCs. However, these levels of reduction to be smaller as the amount of biodiesel blended into diesel fuel decreases, whereas the nitrogen oxide (NOx) increases with increasing of biodiesel amount in the blended fuel. The higher NOx in emission gas of biodiesel combustion is caused by higher nitrogen content in biodiesel rather than in diesel fuel. Since the combustion temperature in the engine is the same, the production of NOx is not only from *Thermal-NO* and *Prompt-NO* but also from *Fuel-NO* mechanism (Mullinger, 2008).

IV. LIFE CYCLE ASSESSMENT

A. Life cycle assessment methodology

The life cycle assessment (LCA) study of POB was performed in order to investigate and validate whether the POB is a sustainable, green and environmental friendly fuel. Based on this study, the net energy balance and green house gas (GHG)

Table 6
Application results of B100 as biofuel for commercial industrial boiler and furnace at PT Petrokimia Gresik, Indonesia (2008)

ITEM	UNIT	Diesel	B100	(B100/Diesel)*100%
Gross calorific value (GCV)	kJ/kg	45,615.19	39,758.77	87.2
Fuel consumption rate	L/hour	587.29	644.12	119.6
Fuel to steam efficiency	**%**	**81.3**	**80.3**	**98.8**
Furnace chamber temperature	°C	933	933	100
Stack temperature	°C	226	234	103.5
Steam pressure	kg/cm^2	6.99	6.96	99.6
Fuel per /ton steam	L/ton	86.60	88.53	102.2
CO	ppm	4	4	100
CO_2	%	12.4	9.9	79.8
O_2	%	6.7	3.9	58.2
NOx	**mg/Nm^3**	**144.5**	**189**	**130.8**
SOx	mg/Nm^3	32	14	43.75

emission will be assessed through the entire cycle of POB. The LCA study presented in this project was taken from one case study in Malaysia in 2009 (Yee, *et al.*, 2009).

The LCA study was divided into three main stages: agricultural activities, oil milling and transesterification process (Figure 5).

Assumptions used in this LCA study are:

1. Fresh fruit bunch (FFB) harvested from the oil palm plantation will be processed immediately to prevent a rapid rise in free fatty acid (FFA).
2. Palm oil mills are located near the plantations.
3. Based on 2007 data, 0.81% CPO produced was used for biodiesel production.
4. The agricultural stage produces 19 tons of FFB per each hectare of plantation land.
5. For each ton of FFB processed, 0.2 tons of CPO is produced.
6. The conversion of CPO to biodiesel is at 99% efficiency.
7. All fossil fuel used in oil palm plantation is regarded as petroleum-based diesel.
8. Transferring FFB from plantation to the mill and empty fruit bunches (EFB) from the mills to oil palm plantation are carried out by traction with energy consumption 644.24 MJ/ton CPO.
9. Average usage of fertilizers are 76 kg N/ha; 86 kg P_2O_5/ha; 119 kg K_2O/ha.
10. Electricity usage in administration, research laboratory and nursery buildings related to oil palm cultivation and the electricity in overhead agricultural stage is assumed to be 1 MJ/ton of FFB harvested.
11. 80% of fibers and shells are fed into boilers producing 15.6 GJ/ton CPO per year and 20% of them are sold as fuel with total energy content of 3.9 GJ/ton CPO annually.
12. In order to process 1 ton of FFB, 0.73 ton of steam is required.
13. About 1.6% of steam energy is assumed to be lost to the atmosphere.
14. The required electricity for mill processing is 52.2 MJ/ton FFB
15. Around 0.371 of diesel fuel is used for boilers (including the start up).
16. The electricity needed for 1 ton of POB is about 31.9 kWh.

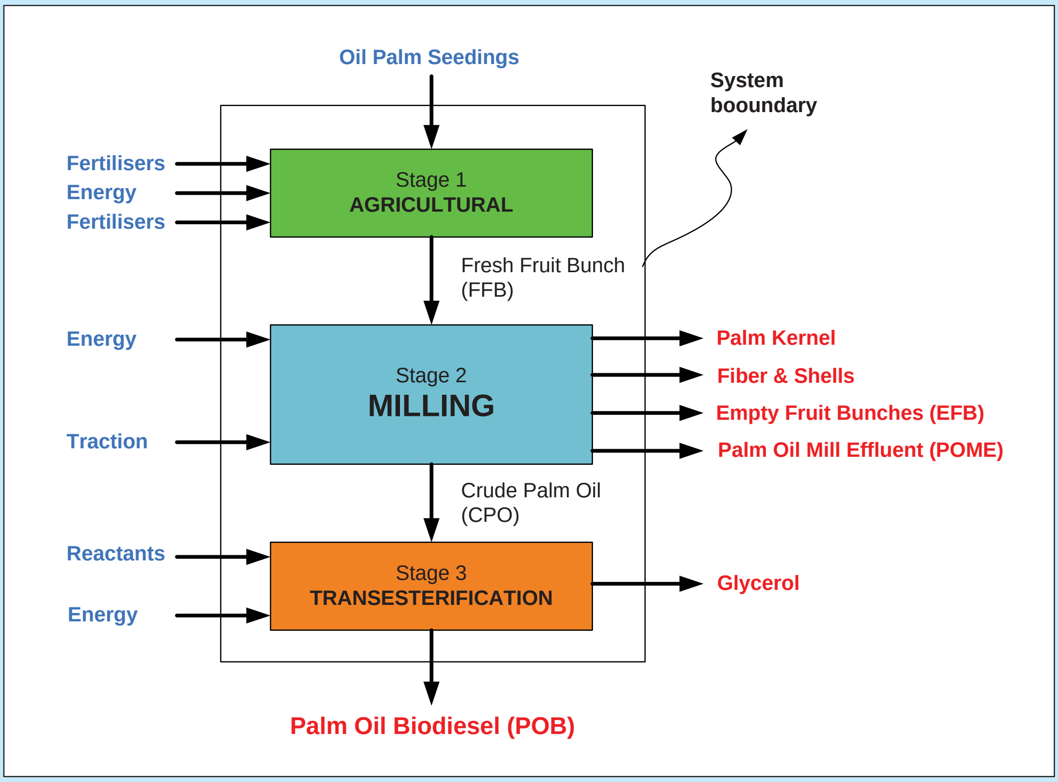

Figure 5
System boundary and stages in LCA POB study

17. The catalyst used in transesterification process is not recovered and used.

The agricultural stage consists of:

- Planning (feasibility study and Environment Impact Assessment processes).
- Nursery establishment (seeding, cultivating and transferring to field which took 12-13 months)
- Site preparation (land survey, clearing of existing vegetation, establishment of road and field drainage systems and also soil conservation)
- Field establishment (lining, holing and planting of poly bag seeding at a density of 136-148 bags per hectare)
- Field maintenance (maintenance processes throughout maturing period such as Integrated Pest Management)
- Harvesting and collection of fresh fruit bunches (undertaken up until 24-30 years after field planting)

Table 7
FFB, CPO and CPO feedstock for biodiesel production and plantation area in Malaysia in 2007 as LCA calculation basis (Yee *et al.*, 2009)

Parameter	2007 data
Fresh fruit bunches (FFB)	81,793,366 tons
Crude palm oil (CPO)	15,823,368 tons
CPO for biofuel production	128,193 tons
Biodiesel (0.99% efficiency of CPO)	126,911 tons
Plantation area	4,305,720 ha

- Replanting (oil palm trunks are shredded and placed back in the field)

The palm oil processing involves four major unit operations:

- *Sterilization* (using live steam with pressure 26.4-31.6 t/m^2 for 50-75 min to deactivate the enzyme).

- *Threshing and stripping of fruits* (to strip and separate the fruits from the bunch in rotary drums)
- *Digestion* (converts the fruits into a homogenous oil mash suitable for pressing in digesters)
- *Oil extraction* (the digested mashes are pressed under pressure, hydraulically or mechanically, to extract the crude palm oil/CPO)

The transesterification stage consists of:

- *Transesterification reaction* (palm oil reacted with methanol in the presence of alkaline sodium hydroxide which acts as the homogenous catalyst)
- *Separation process* (the mixture kept overnight and allowed to separate by gravity where FAME at the top layer separated from glycerol at the bottom)
- Products storage (FAME pumped to storage tanks whilst glycerol pumped to gycerol tanks and can be used to produce soap or other materials).

The data used for LCA study are adopted from Malaysian oil palm plantation in 2007 (Table 7).

B. Net energy assessment

Mass and energy balance for system boundary (as shown in Figure 5) by using all data and assumptions were performed to calculate the net energy balance for the production of 1 ton of POB. The net energy balance calculation for energy input and output is summarized in Table 8 and 9 respectively.

Based on the calculation results (Table 10 and 11), the ratio of output to input energy for the production of 1 ton of POB is:

Table 8
Summary of annual energy utilization in the POB production (Yee *et al.*, 2009)

Stage	Energy	Quantity (MJ/ton CPO/year)
Agricultural	Diesel fuel (traction)	644.24
	Fuel for fertilisers	1,755.06
	Overhead Electricity	5.17
	Total	**2,404.47 MJ**
Palm oil mill	Steam for Process	9,826
	Electricity Process	269.83
	Overhead electricity	0.39
	Diesel for vehicles	39.29
	Diesel for boiler start-up	77.08
	Total	**10,212.59 MJ**
Transesterification	Electricity	113.69
	Steam	1,346.4
	CPO	319.62
	Methanol	18.58
	Sodium hydroxide	1.5
	Total	**1,799.79 MJ**
Primary energy to produce	*Fertilizers*	
	Nitrogen	1,437.64
	Phosphorus	180.16
	Potassium	207.2
	Petroleum diesel	913.25
	Methanol	36.19
	Sodium hydroxide	1.89
	Total	**2,776.34 MJ**
Grand Total Input Energy		**17.19 GJ**

Table 9
Summary of energy content in POB glycerol and biomass (Yee *et al.*, 2009)

Product	Quantity (MJ/ton CPO per year)
Biodiesel	39,204.00
Glycerol	1,981.38
Fibers and shells (heat generated)	19,534.74
Total Output Energy	**60.72 GJ**

$$Ratio\ of\ energy\ output - input = \frac{60.72\ GJ}{17.19\ GJ} = 3.53$$

This result represents a positive net energy for the production of palm oil biodiesel.

1. Greenhouse gas (GHG) assessment

GHG assessment is carried out to determine the effect of POB utilization on GHG emission. In this assessment, all data and assumptions from LCA and net energy assessment were used whilst additional assumptions are listed below:

- Producing 1 ton of CPO on peat land generates 15–70 tons of CO_2 over 25 years as a result from forest conversion, peat decomposition and emission from fires associated with land clearance. The average value 42.5 tons of CO_2 emission is used in this study (Yee *et al,* 2009), hence 1.7 tons of CO_2 per ton CPO per year is released.
- Electricity generation for all equipments including transesterification and building is come from natural gas with CO_2 emission 0.53 kg CO_2 per kWh.
- Boiler's fuel to steam efficiency using light oil is 50%.

Emission of CO_2 per unit item used in POB production and data on gross assimilation for oil palm plantation can be found in Table 10, whereas summary of the CO_2 emission per ton of POB produced is shown in Table 11.

Table 11 shows that to produce 1 ton biodiesel, around 1,796,968.33 kg of CO_2 is sequestrated (positive CO_2 sequestration). This result reflects the CO_2 released to produce and combust 1 ton of biodiesel from only 0.81% of the total CPO produced (128,193 ton out of 15,823,368 tonnes). The

Table 10
Emission of CO_2 per unit item (Yee *et al.*, 2009)

Item	CO_2 emission
Peat land	1.7 tons CO_2/ton CPO produced
Light oil for industrial boiler	2.83 tons CO_2/m^3 light oil
Diesel	73.10 kg CO_2/GJ
Biodiesel combustion in vehicles	1.641 tons CO_2/ton biodiesel
Fertilizers	1.22 kg CO_2/kg fertilizer
Methanol	1.33 kg CO_2/l methanol
Sodium hydroxide	0.79 kg CO_2/kg NaOH
CPO in transesterification	1.161 tons CO_2/ha/year
Biomass	1.19 kg CO_2/kg biomass

Table 11
Summary of the CO_2 assessment for POB (Yee *et al*., 2009)

Parameter	CO_2 (kg CO_2/ton biodiesel)	
	From atmosphere	To atmosphere
Plantation		
Gross assimilation	5,462,257.45	
Total respiration		3,273,961.76
Peatland		211,996.97
N-P-K fertilizers		11,630.88
Traction (diesel)		5,872.81
Palm oil mill		
Biomass incineration		117,234.33
Diesel for boiler start up		702.65
Diesel for vehicles		358.16
Transesterification		
CPO		39,392.72
Methanol		232.95
Sodium hydroxide		5.63
Electricity		2,087.26
Boiler		199.01
Diesel engine vehicles		
Biodiesel combustion (kg CO_2 per ton biodiesel combusted)		1,641.00
Total	**5,462,257.45**	**3,665,289.12**
Net CO_2 emission	3,665,289.12 - 5,462,257.45 = **- 1,796,968.33**	

CPO, which is not converted to biodiesel and not combusted as biodiesel, stored CO_2 in form of carbon compound or fatty acid. This is the reason why the calculation in Table 11 shows a high amount of sequestrate CO_2. However, if all CPO output is converted into biodiesel, then the results are different. Further calculation (Table 12) shows that to produce 1 ton of biodiesel, around 28,620.76 kg of CO_2 is released to the atmosphere (negative CO_2 sequestration).

Table 12
Calculation of GHG Emission if 100% CPO output is converted into biodiesel (calculated using the data from Yee *et al*., 2009)

Parameter	**CO_2 (kg CO_2/ton biodiesel)**	
	From atmosphere	**To atmosphere**
Plantation		
Gross assimilation	44,252.47	
Total respiration		26,524
Peatland		1,717.49
N-P-K fertilizers		94.23
Traction (diesel)		47.58
Palm oil mill		
Biomass incineration		949.77
Diesel for boiler start up		5.69
Diesel for vehicles		2.9
Transesterification		
CPO		39,392.72
Methanol		232.95
Sodium hydroxide		5.63
Electricity		2,087.26
Boiler		199.01
Diesel engine vehicles		
Biodiesel combustion (kg CO_2 per ton biodiesel combusted)		1,641.00
Total	**44,252.47**	**72,873.24**
Net CO_2 emission	72,873.24 - 44,252.47 = **+ 28,620.76**	

V. FOOD STOCK SECURITIES, LAND USE AND BIODIVERSITY CHANGES

A. Food Stock Securities

As the world population grows (estimated up to 1.1% growth rate per year by US Census Bureau), the demand for food will continue to rise even at a higher rate. Furthermore, the need for energy, including the energy from fossil fuel, will also increase. The depletion of fossil fuel resources will increase the demand for alternative energy, such as biodiesel, to balance the total fuel requirement. In the case of POB, palm oil as the feedstock is categorized as edible oil for food industries. Therefore, the rise of fuel demand will, directly or indirectly, conflict with the food demand. According to AOCS, within 10 years (year 2000 to 2010), palm oil used for food industries decreased from 85% to 77% and it is predicted to fall down in the future.

The fluctuation of crude oil price in the market contributes to the palm oil price fluctuation, consequently the food price will be affected. As shown in Figure 6, the higher price of crude oil, the higher the price of palm oil. This phenomenon can be described as follows, when the oil price increases, the demand for POB for blending with petrol will increase significantly. According to supply-demand law, higher demand will trigger higher price. In this case, the price of food will also increase due to low supply of palm oil for food industries.

As described previously, palm oil is the cheapest commodity in comparison with other vegetable oil. In addition, processing cost for refining and producing POB is extremely cheap. The comparison between palm oil price and the other vegetable oils is presented in Figure 7. Therefore, palm oil has emerged as one of the most potential feedstock for biodiesel. On the other hand, it will threaten the feedstock of food. As an example, as reported by GAPKI (Indonesian Palm Oil Association) in February 2011, the shortage in palm oil stock triggered food inflation in India, Thailand, Egypt and Argentine where this oil is used

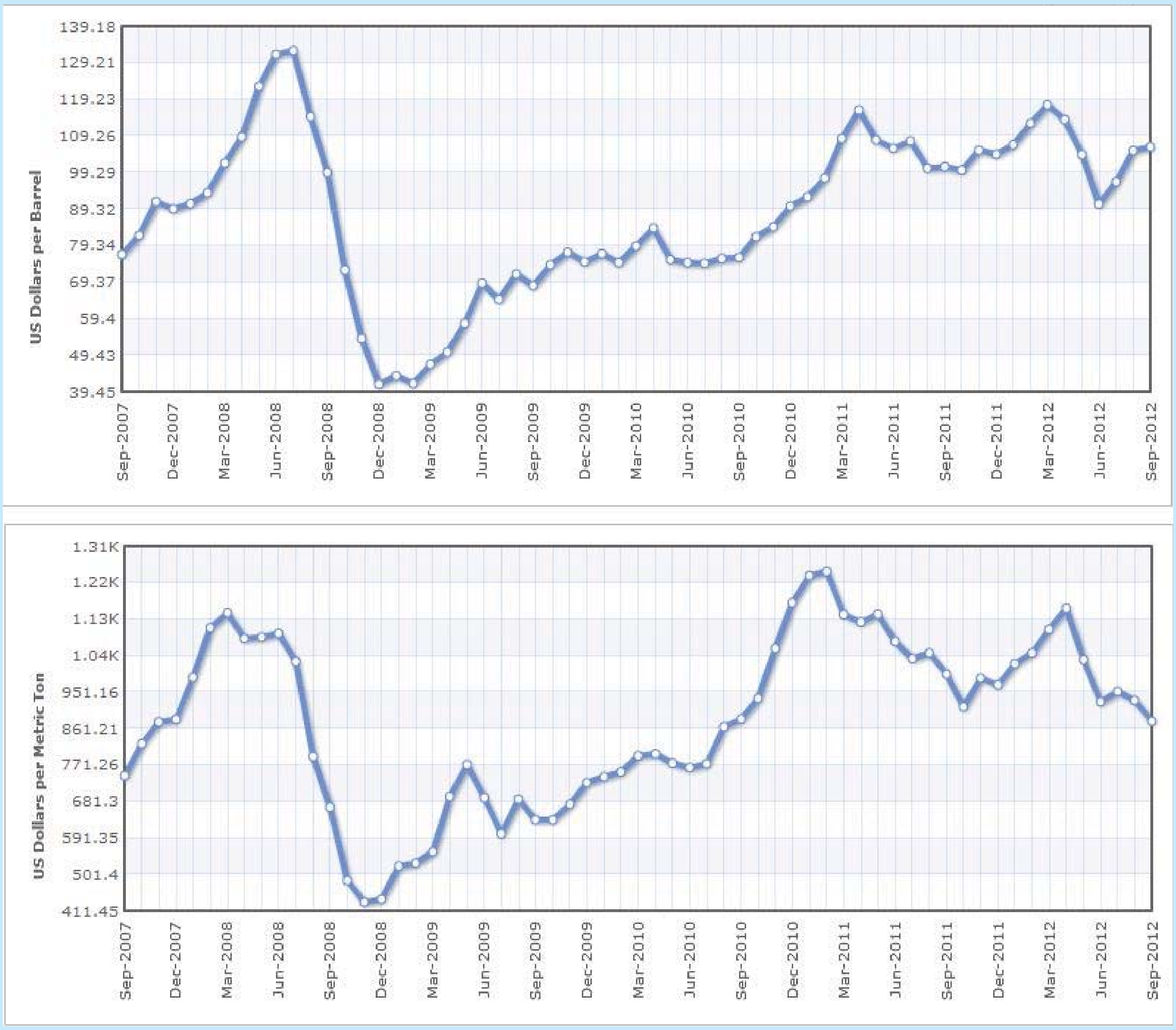

Figure 6
Palm oil price affected by crude oil price in the market (www.indexmundi.com/commodities)

as cooking oil. Substituting the oil by other vegetable oil, such as soy oil or rapeseed oil, will increase the cost since the price is more expensive than palm oil. Although, the palm oil shortage is caused by rain, the same effect could be happened if palm oil absorption for biodiesel is too high and uncontrolled.

B. Land Use and Biodiversity Changes

POB is widely known as an environmental-friendly biodiesel and green alternative for fossil fuels. Some issues regarding oil palm plantation triggered controversies especially from environmental organizations such as Greenpeace, WWF (World Wildlife Fund) and Rainforest Action Network. These issues mainly focused on land use changes due to deforestation and biodiversity extinction have been debated in international scale between oil palm producers and environmental organization. Some of the issues and facts published in international journals, include '*slash and burn*' technique applied by the oil palm farmers to the rainforest to create more farmland is destroying rainforest across Malaysia and Indonesia. United Nation Environment Programme (UNEP, 2007) predicted that most of the country's forest will be destroyed by 2022. There is also biodiversity issue which is around 90% of an area's flora and fauna (especially orangutan) are lost when the land is converted into monoculture plantations where the plants are grown in straight lines. It is believed that orangutan could be extinct within 12 years if the current momentum of rainforest destruction to make way for oil palm plantations is maintained. In term of CO_2 emissions, an estimated two billion tons of carbon dioxide are released each year from the drainage and burning of peat land forests. Indonesia reportedly ranks as the world's third-largest producer of carbon, behind the US and China, because of farmers' practices of burning down rainforest for oil plant plantation contributes to 4% of global annual emissions (Datamonitor, 2010).

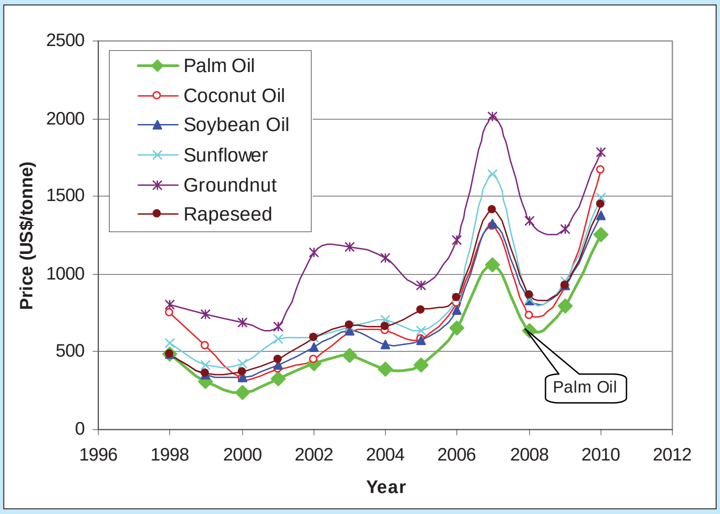

Figure 7
Price of main oil crops (Lin *et al.*, 2011)

Opposing to these facts, some researchers, oil palm plantation companies and countries which rely on palm oil production show different data. In 2009, only 10% of peat land was used for oil palm plantation as shown in Table 13 (Yee *et al.*, 2009). In addition, most of the oil palm plantation is established by converting degraded land and secondary forest. The main cause for deforestation is from illegal logging which is not related to oil palm plantation (www.reuters.com). Moreover, oil palm plantations generate a net sequestration of CO_2 as opposed to forest which only generates a dynamic CO_2 equilibrium (Yee et al., 2009). Therefore changing the forest, especially secondary forest, to palm oil plantation could give advantages since the carbon will be stored in palm oil as fatty acids.

Table 13
Percentage of oil palm plantation in soil land and peat land (Yee *et al.*, 2009)

Oil palm land	Plantation area (ha)	Share (%)
Soil land	3,884,914	90.24
Peat land	420,000	9.76
Total	4,304,914	100

All the issues described above create controversies which are debated by international organizations world wide. However, actions and plans have already been taken to reduce the controversies and to make the POB more sustainable.

VII. REDUCING CONTROVERSIES AND MAKING POB MORE SUSTAINABLE

Some actions which may reduce the opposite attraction between food and palm oil as biodiesel feedstock have been planned as follows.

1. Creating market differentiation between palm oil for food and chemical raw material (including for biodiesel). This mean the target quantity and quality of palm oil for food must be regulated. Each country could have different regulation depend on the social and economic condition. For example, in Indonesia, cooking oil has been stated as one of the nine basic needs (together with rice, sugar, petrol, etc). Therefore, the production, quality and distribution are controlled by Indonesian government.
2. Creating Roundtable for Sustainable Palm Oil (RSPO)

   RSPO is an organization established in 2004 consisting of 40% of palm oil traders. The goals of this organization are:
   - To develop an objective, transparent, measurable standards for responsible palm oil production.
   - To certify that the palm oil producer produced their oil in a sustainable way. This includes restrictions on plantation infringement into virgin forest.

3. More selective on choosing land for oil palm plantation by using degraded land instead of primary forest or peatland. For example, Malaysia's palm planters expanding their plantations to African region where more degraded land can be utilized. Furthermore, on 20 May 2011, Indonesia as the biggest palm oil producer, has signed a 2 years moratorium on clearing primary forest and peatland.
4. Applying zero-burning policy for opening new plantations. Malaysia has been applying the policy since 1989 whilst in Indonesia the policy is legalized in 1984 and renewed in 1997. However, implementation of this policy needs a better and tighter control.
5. Increasing palm oil yield. The best oil yield is achieved by Malaysia's plantation with yield 4.2 tons CPO/ha/year, whilst the average yield across the world is 3.4 tons CPO/ha/year (Figure 8). By increasing the yield from 3.4 to 4.2 tons CPO/ha/year, palm oil production could be also increased up to 8 million tons/year without opening a new farmland. Furthermore, according to AOCS, the best oil palm plantation has yield 7-8 tons CPO/ ha/year.

- Research and development to find oil palm strains with superior characteristics. Some techniques which are being developed include (Murphy, 2007):
    - *DNA marker-assisted selection*. The advent of marker-assisted selection allows breeders to analyze the characters of the plant by selecting a few plants that are likely to express the required characters from amongst tens of thousands of progeny before the plants have developed to maturity. This technique could save time to find and breed plants with superior characteristics.
    - *Mass propagation*. This technique can be used to multiply genetic stock based on traits such as yield, quality and disease resistance, in a faster and cheaper way.
    - *Genomics*. Study of the DNA and protein sequences in an organism and the specification of when and where such sequences are expressed. This study provides genetic maps that can be used for DNA marker-assisted selection and opens the possibility on creating a new strain of crop with superior characteristics.

VI. CONCLUSIONS

1. Due to its high yield, palm oil is the largest, the cheapest commodity of vegetable oil and also the cheapest oil to produce and to refine.
2. The technology for palm oil conversion to biodiesel has already been developed

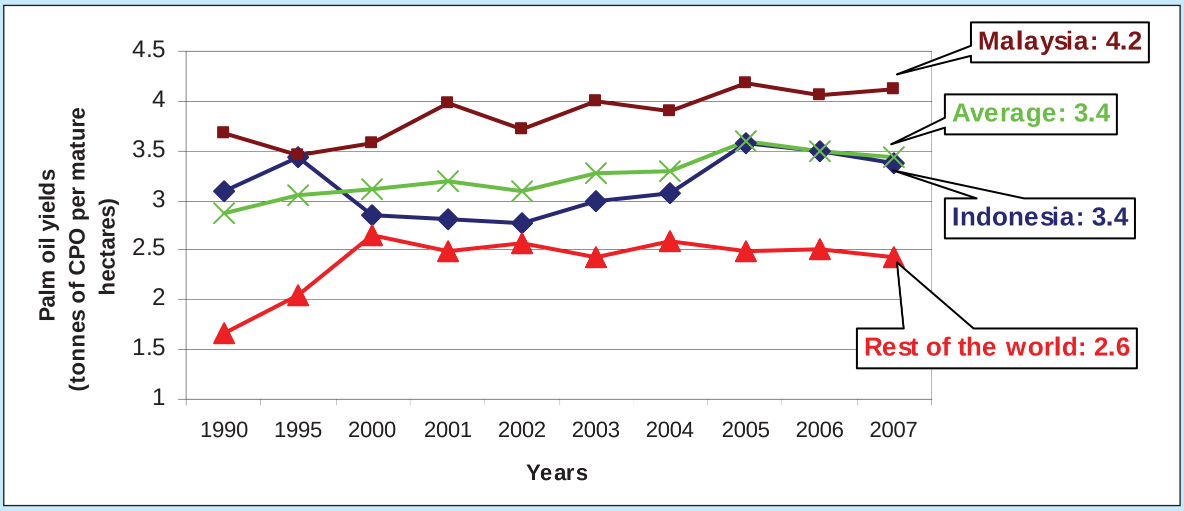

Figure 8
Palm oil yield (Carter *et al.*, 2007)

and proven where a biodiesel of similar characteristic with petroleum-based diesel could be produced.

3. By using palm oil biodiesel, the emission from diesel engine are better compare to petroleum-based diesel except for NOx emission which is higher due to higher nitrogen content in biodiesel (Fuel-NO mechanism).
4. Life cycle assessment (LCA) study shows a positive net energy and positive GHG emission (up to some level of palm oil utilization to biodiesel), which mean biodiesel is a potential fuel for replacing fossil fuel and also an environmental friendly fuel.
5. Some controversies regarding oil palm plantation such as food stock securities, deforestation, land use changes and biodiversity extinction still need to be resolved by taking some actions like establishing RSPO (Roundtable for Sustainable Palm Oil), zero-burning policy, selective land-choosing for oil palm plantation, increasing yield and also through continual research and development programs.

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