Life cycle cost and sensitivity analysis of palm biodiesel production

H.C. Ong a,e, T.M.I. Mahlia a,b, H.H. Masjuki a, Damon Honnery c

a Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
b Department of Mechanical Engineering, Syiah Kuala University, Banda Aceh 23111, Indonesia
c Department of Mechanical and Aerospace Engineering, Monash University-Clayton Campus, P.O. Box 31, Victoria 3800, Australia

A R T I C L E   I N F O

Article history:
Received 2 July 2011
Received in revised form 13 March 2012
Accepted 15 March 2012
Available online 30 March 2012

Keywords:
Life cycle cost
Techno-economic analysis
Biodiesel
Palm oil
Sensitivity analysis

A B S T R A C T

Increased biodiesel production is being proposed as one solution to the need to ease the impact of increased demand for crude oil and to reduce emissions of greenhouse gases. Despite this, biodiesel has yet to reach its full commercial potential, especially in the developing countries. Besides technical barriers, there are several nontechnical limiting factors which impede the development of biodiesel such as feedstock price, production cost, fossil fuel price and taxation policy. This study assesses these by undertaking a techno-economic and sensitivity analysis of biodiesel production in Malaysia, the second largest producer of crude palm oil feedstock. It was found that the life cycle cost for a 50 tonne palm biodiesel production plant with an operating period of 20 years is $665 million, yielding a payback period of 3.52 years. The largest share is the feedstock cost which accounts for 79% of total production cost. Sensitivity analysis results indicate that the variation in feedstock price will significantly affect the life cycle cost for biodiesel production. One of the most important findings of this study is that biodiesel price is compatible with diesel fuel when a fiscal incentive and subsidy policy are implemented. For instance, biodiesel price with subsidies of $0.10/l and $0.18/l is compatible and lower than fossil diesel price at crude palm oil price of $1.05/kg or below. As a conclusion, further research on technical as well as nontechnical limitations for biodiesel production is needed before biodiesel can be fully utilized.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

Our over dependence on fossil fuels has caused various negative impacts on global climate by emissions of greenhouse gases (GHGs), and local air quality by emissions of hydrocarbons, NOx and particulate matter. There is therefore an urgent need to find alternative energy sources which are clean, reliable and yet economically feasible. The possibility of future oil scarcity places the additional requirement for the alternative to be renewable. Currently, renewable energy contributes only 13.3% of the total global energy use [1]; much less for transport fuels.

Being biomass based, biodiesel is a renewable fuel and, because of its ease of use in existing engines, is considered to be an ideal substitute for fossil fuel derived diesel fuel. Its use brings additional benefits through its lower environmental impact, especially in respect of air quality [2–6]. It is for these reasons that there have been many studies examining the development of biodiesel as an alternative transport fuel [7–10].

The biodiesel industry is still in its infancy but is growing rapidly. The world total biodiesel production in 2007 was 8.4 million tons and it increased to 20 million tons in 2010; it is expected to reach 150 million tons by 2020 [11]. However, variability in feedstock and fossil fuel price, as well as the production capacity of biodiesel, have given rise to instability within the industry [12]. These factors have affected the economical viability of biodiesel at a global scale. Many countries have introduced legislation setting mandatory biofuel targets to assist the development of this important fuel [13,14].

Biodiesel is produced by the transesterification of a biomass derived oil or fat. Palm oil is one of the highest oil bearing crops producing on average 4–5 tons of oil/ha annually. This yield is about 10 times and 6 times the yield of soybean and rapeseed oil respectively [15]. Palm oil is rich of phytonutrients such as tocopherol, tocotrienol, carotenoid, sitosterol and sterol. Malaysia is the world’s second largest producer and exporter of palm oil after Indonesia. In 2010, it produced 17 million tons of palm oil compared to 23 million tons in Indonesia [16]. Fig. 1 shows the top 10 palm oil producing countries around the world [17]. Malaysia has approximately 362 palm oil mills, processing 71.3 million tons of fresh fruit bunch per year, which produces an estimated 19 million tons of crop residue annually in the form of empty fruit bunch, fibre and shell [18,19].

In Malaysia, the current installed biodiesel production capacity is about 10.2 million tons for palm oil based biodiesel [20]. A life cycle assessment study conducted by Yee et al. [21] showed that palm biodiesel has a positive energy yield ratio of 3.53 (output energy/input energy) which is large compared to 1.44 for rapeseed oil. Palm oil is therefore one of the most efficient oil bearing crops in terms of land utilization, efficiency and productivity.
Although Malaysia is one of the biggest producers of biodiesel fuel, the commercialization of biodiesel is yet to be undertaken at a large scale. Besides the technical factors, there are several non-technical limiting factors slowing the development of biodiesel such as feedstock price, biodiesel production cost, crude oil price and taxation [22]. Among these factors, no matter how much biodiesel production processes are improved, the cost of feedstock remains the major component in production costs.

The examination by life cycle analysis is vital to the evaluation of the energy needs, material inputs and environmental releases of a manufacturing process. Life cycle analysis has enabled manufacturers to quantify how much energy and raw materials are consumed, as well as how much solid, liquid and gaseous waste are generated at each stage of the production's stage. Life cycle cost can be defined as an economic model for pricing equipment and processes over the life span of a production plant. For biodiesel production, it includes feedstock price, installation cost, operating costs, maintenance costs and salvage value at the end of project lifetime. This study makes use of this approach to examine the life cycle costs and payback period for biodiesel production in Malaysia. The paper begins by presenting a review of previous work in this area. This is followed by the development of the life cycle cost model and a discussion of the results which includes a sensitivity analysis of important inputs. In particular, the taxation and subsidy scenarios for the current palm biodiesel production costs will be analyzed and presented.

### 2. Summary of previous techno-economic studies of biodiesel production

There have been a number of techno-economic assessments of biodiesel production which have included among other variables various feedstocks and production methods. A summary of these studies is given in Table 1.

Marchetti et al. [23] and Marchetti and Errazu [24] reported biodiesel production costs of $0.51/l and $0.98/l via homogeneous and supercritical processes respectively for a 36 ktons biodiesel plant based on waste cooking oil. Supercritical production processes tend to have lower economic viability due to the higher capital costs associated with their greater process energy inputs.

A study of biodiesel production from soybean oil was carried out by Haas et al. [25] and You et al. [26] using an alkali catalyst. Their results revealed a biodiesel production cost of $0.53/l and $0.78/l for production capacities of 36 ktons and 8 ktons respectively. Another study conducted using rapeseed gave a price of $1.15/l without taking into account glycerol by-product credit [27]. Moreover, Sotoff et al. [12] reported a production cost of $2.04/l for biodiesel produced from rapeseed oil using an enzyme catalyst. Another study, requiring a $12 million initial investment for its 36 ktons palm oil plant, yielded a price of $0.37/l based on a raw material cost of $358/ton of biodiesel [28]. Alternatively, a study of a 1 kton palm oil batch production process via a biological catalyst resulted in a production cost of $2.30/l [29]. In general, it can be observed that biodiesel production using enzymes and biological catalysts are more costly and slower than alkali and acid catalysts. The higher production costs are due to the higher cost of the enzyme catalysts.

### 3. Conceptual design and data collection

#### 3.1. Conceptual design

The life cycle analysis for biodiesel production starts from the feedstock seed acquisition and ends with biodiesel consumption. This includes studying the extraction of raw materials, energy consumption, emission and costing analysis during the life cycle process. This cycle can be divided into three specific phases, which are grouped around agricultural, production and consumption processes, Fig. 2. This study focuses on the costs associated with the biodiesel production phase with a typical production scheme shown in Fig. 3.

Generally, biodiesel is produced by a transesterification process. This process is regarded as the best method to convert vegetable oil or animal fat into a fatty acid methyl ester (FAME). In this process, a short chain alcohol such as methanol or ethanol is used to transesterify triglycerides with or without the presence of a catalyst to produce FAME with glycerol as a by-product. There are many examples in the literature which present technical aspects of the transesterification process [34–36]. The technology used in this study is a continuous transesterification process making use of sodium hydroxide (NaOH) as the alkaline catalyst. Although palm oil can be used directly in engines, it is generally solid at room temperature and highly viscous at typical engine operating conditions. The reaction process significantly reduces the viscosity of the feedstock while maintaining a high rate of feedstock conversion. Relative to the biological catalyst and supercritical processes, alkaline catalyst transesterification represents a low cost, high conversion yield production technique.

In this study, it is assumed that approximately 100 tons of crude palm oil will react with 10.7 tons of methanol to produce 98 tons of biodiesel and 9.85 tons of glycerol, an important by-product generated during this reaction. However, the extraction of phytonutrients from palm oil, an important additional co-product, is not included in this study. In a 2008 study, the retail price of biodiesel...
Table 1

<table>
<thead>
<tr>
<th>Plant capacity tons/year</th>
<th>Feedstock</th>
<th>Feedstock cost $/ton biodiesel</th>
<th>Glycerol credit $/ton biodiesel</th>
<th>Biodiesel cost$/l</th>
<th>Location</th>
<th>Remark</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>36,036</td>
<td>Waste cooking oil</td>
<td>445</td>
<td>73.8</td>
<td>0.51</td>
<td>Argentina</td>
<td>Homogeneous alkaline catalyst with acid preesterification</td>
<td>[23]</td>
</tr>
<tr>
<td>36,036</td>
<td>Waste cooking oil</td>
<td>905</td>
<td>67.5</td>
<td>0.98</td>
<td>Argentina</td>
<td>Supercritical process</td>
<td>[24]</td>
</tr>
<tr>
<td>8000</td>
<td>Waste cooking oil</td>
<td>525</td>
<td>91.3</td>
<td>0.95</td>
<td>Canada</td>
<td>Alkali catalyst</td>
<td>[30]</td>
</tr>
<tr>
<td>7260</td>
<td>Waste cooking oil</td>
<td>248</td>
<td>0</td>
<td>0.58</td>
<td>Japan</td>
<td>Batch, KOH catalyst</td>
<td>[31]</td>
</tr>
<tr>
<td>36,000</td>
<td>Soybean oil</td>
<td>486</td>
<td>35.8</td>
<td>0.53</td>
<td>USA</td>
<td>Sodium methoxide catalyst</td>
<td>[25]</td>
</tr>
<tr>
<td>8000</td>
<td>Soybean oil</td>
<td>779</td>
<td>380</td>
<td>0.78</td>
<td>USA</td>
<td>Alkali catalyst</td>
<td>[26]</td>
</tr>
<tr>
<td>50,000</td>
<td>Rapeseed oil</td>
<td>1158</td>
<td>–</td>
<td>1.15</td>
<td>Greece</td>
<td>–</td>
<td>[27]</td>
</tr>
<tr>
<td>8000</td>
<td>Rapeseed oil</td>
<td>3042</td>
<td>2215</td>
<td>2.04</td>
<td>Denmark</td>
<td>Enzyme catalyst</td>
<td>[12]</td>
</tr>
<tr>
<td>8050</td>
<td>Castor oil</td>
<td>1156</td>
<td>44.1</td>
<td>1.56</td>
<td>Brazil</td>
<td>Alkali catalyst</td>
<td>[32]</td>
</tr>
<tr>
<td>36,000</td>
<td>Palm oil</td>
<td>358</td>
<td>33.5</td>
<td>0.37</td>
<td>Mexico</td>
<td>Alkali catalyst</td>
<td>[28]</td>
</tr>
<tr>
<td>1000</td>
<td>Palm oil</td>
<td>588</td>
<td>200</td>
<td>2.30</td>
<td>India</td>
<td>Batch, biological catalyst</td>
<td>[29]</td>
</tr>
</tbody>
</table>

**Fig. 1.** World top 10 palm oil producing countries [17].

**Fig. 2.** Life cycle analysis diagram for biodiesel production.
in the USA was around $0.79/l compared to around $1.06/l in European countries [24]. According to the current market price, the price of biodiesel in Malaysia is estimated to be $0.82/l.

3.2. Data collection

Data collection is an essential part of this study. The input data were collected from various technical sources such as biodiesel production experts, researchers, practitioners experienced in this field, technical notes and research papers as well as following the latest market prices.

The initial installation cost or capital cost of biodiesel production plant is usually based on the production capacity. The capital costs take into account the required land area, building construction, equipment and instrumentation required for the plant. Fig. 4 shows the highest, average and lowest initial capital costs of biodiesel plant based on plant capacity [37].

In this study, crude palm oil was used as a feedstock for biodiesel production. 51 ktons of crude palm oil are required to produce 50 ktons of biodiesel with the overall conversion of 98%. Recently, crude palm oil price has increased rapidly. For instance, in 2006 the average price of crude oil price was around $400/ton but increased significantly to a peak of $1248/ton in February 2011. However, the price of crude palm oil fell to $1020/ton in January 2012. Fig. 5 shows the historical price of crude palm oil in Malaysia between 1986 and 2012 [38].

3.3. Economic indicator

The lifetime of the project has been set to be 20 years which includes one year for construction and start-up of the plant. The plant was assumed to operate at 100% capacity during the entire project lifetime. The initial capital cost is considered to be paid from private investment and no loans have been taken into account. It is assumed that the selling price of the produced biodiesel does not vary over time. Table 2 shows the summary of economic data and indicators.

4. Methodology

4.1. Life cycle cost

The economic benefit of the plant is evaluated by life cycle cost analysis. In this section, the life cycle cost model for biodiesel production from palm oil is developed and grouped into six categories as follows:

$$LCC = CC + \sum_{i=1}^{n} OC_i + MC_i + FC_i \left(\frac{1}{1 + r}\right)^i - SV \left(\frac{1}{1 + r}\right)^n + \sum_{i=1}^{n} BP_i \left(\frac{1}{1 + r}\right)^i.$$

4.4.1. Present worth factor

Present worth factor (PWF) is the value by which the future cash flows are gathered in order to obtain the current present value of the project. The present worth factor is used to determine the feasibility of biodiesel production plant investment for a given rate of interest. The present worth factor in year i is defined as,
PWF = \frac{1}{(1 + r)^t}. \quad (2)

Summing this over a project life of \( n \) years yields the compound present worth factor,

\[ \text{CPW} = \sum_{i=1}^{n} \frac{1}{(1 + r)^i} = \frac{(1 + r)^n - 1}{r(1 + r)^n}. \quad (3) \]

### 4.1.2. Capital cost

Capital costs take into account the required land area, building construction, equipment and instrumentation required for the plant. Capital cost of the initial installation depends mainly on the biodiesel plant capacity [37]. Based on this figure, for an annual biodiesel production capacity of \( PC = 50 \) ktons, the estimated project capital cost is \( CC = $12 \) million.

### 4.1.3. Operating cost

Operating cost includes the cost of labour, utilities, laboratory services, factory expenses, supervision, administration, transportation cost, all other material and energy flows except those of the CPO feedstock. Operating costs also include costs associated with waste water treatment and sludge waste processing to remove residual acids and any other contaminant (e.g., methanol and NaOH). Given their dependence on production capacity, operating costs are calculated by setting a fixed cost per ton of biodiesel produced. Over the life of the plant, total operating costs are,

\[ \text{OC} + \sum_{i=1}^{n} \frac{\text{OR} \times \text{PC}}{(1 + r)^i}. \quad (4) \]

#### 4.1.4. Maintenance cost

The annual periodical maintenance and service cost is assumed to be \( \text{MR} = 2\% \) of the initial capital cost. This value is considered to be constant over the entire project lifetime. Maintenance costs are calculated over the life time of the plant as,

\[ \text{MC} = \sum_{i=1}^{n} \frac{\text{MR} \times \text{CC}}{(1 + r)^i}. \quad (5) \]

#### 4.1.5. Feedstock cost

Annual feedstock consumption is determined by adjusting the plant capacity by the feedstock to biodiesel conversion efficiency, \( \text{FU} = \frac{\text{PC}}{\text{CE}} \).

Based on the historical price of crude palm, Fig. 5, crude palm oil price is estimated to be \( \text{FP} = $1050/\text{ton} \) by taking the average price for the past 1 year. This is assumed constant over the life of the plant. The sensitivity to this assumption is discussed in a following section. Based on this price, total cost of the feedstock over the life of the plant is given by,

\[ \text{FC} = \sum_{i=1}^{n} \frac{\text{FP} \times \text{FU}}{(1 + r)^i}. \quad (7) \]

#### 4.1.6. Salvage value

The salvage value is the remaining value of the components and assets of the plant at the end of the project lifetime. In this study, it has been assumed that a depreciation rate of \( d = 10\% \) occurs annually. The salvage value model is based on the replacement cost rather than the initial capital cost and is expressed by,

\[ \text{SV} = \text{RC}(1 - d)^{n-1}. \quad (8) \]

Thus, the present value of salvage cost can be calculated as,

\[ \text{SV}_{pv} = \frac{\text{RC} \times (1 - d)^{n-1}}{(1 + r)^n}. \quad (9) \]
4.1.7. By product credit

Glycerol is generated during the biodiesel production process. It can be sold as a useful by-product. Calculation is based on setting a fixed price for glycerol with production determined by a plant capacity to glycerol conversion factor. Value of the credit over the life of the plant is given by,

\[ \text{BP} = \sum_{i=1}^{n} \frac{\text{GP} \times \text{GCF} \times \text{PC} \times 1000}{(1 + r)^i} \]  

(10)

4.2. Payback period

Payback period is defined as the time taken to gain a financial return equal to the original investment cost. The payback period is a simple method of evaluating the viability and feasibility of the investment. The payback method uses the ratio of capital cost over annual earning as an approach to monitor the project. Taxes are included as a percentage of total biodiesel sales. The payback period is calculated by the following model,

\[ \text{PP} = \frac{\text{CC}}{\text{TBS} - \text{TPC} - \text{TAX}} \]  

(11)

4.3. Sensitivity analysis

Sensitivity analysis is an investigation into how projected performance varies with change in key assumptions on which the projections are based. It also enables examination of how uncertainty, for example in international prices, can alter project outcomes. Important variables are crude palm oil price, interest rate, initial capital cost, oil conversion yield and capital cost. Crude palm oil price is perhaps the most important. It will follow the market value and can be expected to be sensitive to global biodiesel production if growth in this sector is expected to occur. This could lead to two differing outcomes. If palm oil producers expand production ahead of growth in biodiesel capacity, CPO will likely fall, if biodiesel production capacity outstrips crude palm oil production, CPO price will likely increase. Crude oil supply and demand side factors can also feed into biodiesel production cost through changes in production quality and yield if changes in crude quality occur.

5. Results and discussion

5.1. Life cycle cost analysis and payback period

Life cycle cost is calculated for a typical 50 ktons biodiesel plant located in Malaysia using the data of Table 2. Results are presented in Table 3 and Fig. 6.

The life cycle cost of palm biodiesel production is $665 million, which yields a palm biodiesel unit cost of $0.632/l. This price is lower than the $2.30/l obtained by Jegannathan et al. [29] which made use of a batch process via a biological catalyst. However, this cost is higher than the $0.37/l of Lozada et al. [28] which used a similar production process to that used here, although from a smaller 36 ktons plant. It is also higher than the fossil diesel retail price in Malaysia which is currently $0.58/l.

It can be seen that feedstock (CPO) cost represents the largest share in the final biodiesel production cost; feedstock cost accounts 79% of total production cost which is around $0.5/l followed by operating cost at $0.13/l. The sale of glycerol by-products contributes $12.33 million over the life of the project.

The payback period for the 50 ktons palm biodiesel production plant was found to be 3.52 years. Being less than one third of the 20 year project life, this result indicates that the project is economically feasible.

5.2. Sensitivity analysis

Fig. 7 presents the results of the sensitivity analysis for five input variables. The legend on the left of the figure gives the variation in the sensitivity variable from favourable, to planned, to unfavourable. As expected, variation in the price of CPO represents the dominant impact on the life cycle cost; second to this is the present value interest rate. The CPO price range examined covers a variation typical of the crude oil price for the last 2 years, Fig. 5. Variation in oil conversion yield and operating costs have the lowest impact of the on-going costs, but together can offset significant variation in CPO price. Continual improvement in the biodiesel conversion processes and greater operating efficiency can therefore lead to a significant reduction in overall biodiesel production costs.

Because of its importance in determining the cost per litre of biodiesel produced, the effect of change in crude palm oil price was further analyzed, Fig. 8. From this it can be seen that crude palm oil price has a linear correlation with biodiesel production cost; an increase of crude palm oil price by $0.1/kg will cause a $0.05/l rise in biodiesel production cost.

5.3. Biodiesel taxation and subsidy scenarios

In this section, taxation and subsidy scenarios are presented for the final biodiesel cost. Table 4 shows a comparison of final biodiesel price with fossil diesel at different taxation and subsidy scenarios. The scenarios considered are total tax exemption, 15% taxation, a subsidy of $0.10/l and $0.18/l for biodiesel in comparison with fossil diesel price. The $0.10/l and $0.18/l of subsidy cost were chosen based on the current subsidy cost for diesel and petrol respectively in Malaysia. The fossil diesel price is based on $0.581/l retail price of diesel in Malaysia. There is a difference in energy content between fossil diesel and palm biodiesel which are 35.1 MJ/l and 32.2 MJ/l respectively [39]. Therefore, a fuel consumption substitution ratio of palm biodiesel to fossil diesel of 1.09 has been taken into account for calculation. The results indicate that the final cost of biodiesel with subsidies of $0.10/l and $0.18/l are compatible and lower than fossil diesel if the CPO price is $1.05/kg or below.

Fig. 9 shows the taxation and subsidy scenarios of palm oil based biodiesel production cost as a function of the CPO price. As shown in the figure, biodiesel is competitive with fossil diesel when the CPO price is below $0.85/kg with tax exemption. For a biodiesel subsidy of $0.10 and $0.18/l, the CPO price could reach $1.04 and $1.2/l respectively in order to preserve the competitiveness of biodiesel with fossil diesel. However, when the price of CPO surges up to $1.2/kg, the biodiesel production price is higher than fossil diesel although $0.18/l of subsidy is provided.

| Summary of total production cost and payback period of palm biodiesel production plant. |
|---------------------------------|------------------|
| **Life cycle cost ($)** | **Unit cost ($/l of biodiesel)** |
| Total capital investment | 12,000,000 | 0.0114 |
| Crude palm oil cost | 525,972.183 | 0.0499 |
| Operating cost | 117,454.064 | 0.1306 |
| Maintenance cost | 235,635.5 | 0.0022 |
| Salvage value | 289,323 | 0.0003 |
| By product credit | 12,315.300 | 0.0117 |
| Total biodiesel cost | 665,404.185 | 0.6322 |
| Payback period (year) | 3.52 |
**Fig. 6.** Distribution of palm biodiesel production cost.

**Fig. 7.** Sensitivity analysis of life cycle cost for palm biodiesel production.

**Fig. 8.** The impact of crude palm oil price on the biodiesel production cost.
### Table 4

Biodiesel taxation and subsidy level scenarios at current production cost.

<table>
<thead>
<tr>
<th>$/l</th>
<th>Biodiesel total tax exemption</th>
<th>Biodiesel 15% of taxation</th>
<th>Biodiesel with subsidy $0.10/l</th>
<th>Biodiesel with subsidy $0.18/l</th>
<th>Fossil diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production cost ($/l)</td>
<td>0.632</td>
<td>0.632</td>
<td>0.632</td>
<td>0.632</td>
<td>–</td>
</tr>
<tr>
<td>Taxes/subsidy ($/l)</td>
<td>0</td>
<td>0.095</td>
<td>0.100</td>
<td>0.180</td>
<td>–</td>
</tr>
<tr>
<td>Total ($/l)</td>
<td>0.632</td>
<td>0.727</td>
<td>0.532</td>
<td>0.452</td>
<td>0.581</td>
</tr>
<tr>
<td>Total cost including fuel substitution ratio</td>
<td>0.688</td>
<td>0.792</td>
<td>0.580</td>
<td>0.492</td>
<td>0.581</td>
</tr>
</tbody>
</table>

#### 6. Conclusion

This paper has presented a techno-economic and sensitivity analysis of biodiesel production from palm oil in Malaysia. The life cycle cost model and sensitivity analysis for a 50 ktons biodiesel plant were developed and evaluated over a 20 year plant life. The model developed in this study is flexible as it can be modified to calculate different plant capacity, capital cost, change in feedstock and production cost, as well as other specific variables. It was found that the life cycle cost of the biodiesel production plant is $665 million over the project lifetime and the payback period is 3.52 years. Moreover, this study reveals that an increase of crude palm oil by $0.10/kg will cause a $0.05/l rise in biodiesel production cost. As a conclusion, biodiesel price is only compatible with palm oil by $0.10/kg will cause a $0.05/l rise in biodiesel production.

#### Acknowledgements

The authors would like to express his acknowledgement to University of Malaya, Kuala Lumpur, Malaysia for the financial support under HIR Grant (D000006-16001). Besides, grateful thanks for proofreading go to Abdelaziz Emadeldin Atabani and Yeap Soo Inn, University of Malaya.

#### References


[37] Howell S. Time to take the biodiesel plunge? Sierra: Render Magazine; 2005.
