Reduction in ecological cost through biofuel production from cooking oils: an ecological solution for the city of Campinas, Brazil

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Abstract

The aim of the present study was to produce biodiesel from mixtures of cooking oil and provide a possible environmental solution for the region of Campinas (state of São Paulo, Brazil) based on the theory of environmental cost accounting (ECA). Cooking oil collected from homes in Campinas was mixed with ethanol at a ratio of 7:1 and transesterified at 60 °C for one hour for the obtainment of biodiesel using NaOH as a catalyst. The results of the physicochemical analyses demonstrated that the biodiesel possessed characteristics close to those required by Brazilian standards. A recent survey carried out in the city of Campinas revealed that residents are not concerned with the increased environmental impact and ecological costs in the region caused by the disposal of used cooking oil, which is discarded in sewers and soil. Urgent action is recommended, beginning with raising awareness among the population and the implementation of a policy to determine the storage, periodic collection and use of cooking oil for the production of biodiesel. This fuel could be used for buses, trucks and machines or sold to fuel distributors, offering a savings of US$ 0.8 to 4.5 millions. Campinas could then gain environmental credits and become a sustainable city. Moreover, used cooking oil constitutes low-cost biodiesel with no consumption of raw materials and will reduce worldwide criticism directed at Brazil regarding the use of oleaginous plants for biodiesel production.

1. Introduction

The concept of innovation has been used in a wide range of contexts and theoretical development has proven extremely valuable, providing important insights into intra-market competition, strategies and regulatory policies. The automotive industry offers a fertile field for progress in the theory-building process regarding innovation, especially with the introduction of alternative fuels and powertrain technologies (Zapata and Nieuwenhuis, 2010). Alcohol and biodiesel are considered important energy options as replacements for fossil fuels and constitute an endless renewable resource, as they are produced from biomass — generally an agricultural crop. The current belief is that replacing fossil fuels with biodiesel could reduce greenhouse gas emissions (Ometto and Roma, 2010; Pereira and Ortega, 2010).

The aim of the present study was to produce biodiesel from mixtures of cooking oil and provide a possible environmental solution based on the theory of environmental cost accounting for the city of Campinas, Brazil.

1.1. Environmental cost accounting (ECA)

According to Romanini (2007), the effect of global warming is one of the factors that have reignited discussions on sustainability by alerting society of the need for companies to adopt proper attitudes toward the environment. In order to express the concept of sustainability, a company must display environmental integrity, social equality and economic success (Bansal, 2005). Becoming a sustainable enterprise means reducing a company’s impact in an economically feasible manner by using preventive approaches together with the principles of continuous improvement (Labodová, 2004). Rubenstein (1994) states that a sustainable company should work in accordance with six guidelines:
- Qualitative growth, respecting human rights and the environment;
- Conservation and use of the environment and natural resources for the benefit of present and future generations;
- Maintenance of ecosystems and essential biospheric processes, preservation of biodiversity and fulfilment of the principle of optimised sustainable productivity;
- Establishment of environmental protection standards and supervision of all changes, publishing relevant data on the environment and the use of resources;
- Implementation of all changes in accordance with the environmental developments that arise;
- Periodic communication to everyone who may be significantly affected by forecast changes in business activities.

According to Romanini (2007), the discussion regarding sustainable companies does not only relate to large companies, which are pressured by their shareholders to demonstrate that their businesses are not running the risk of being devalued due to improper social and environmental attitudes. Small businesses are also now seen by society as offering possible risks to the environment in which they operate.

However, it is difficult to measure and integrate the internal and external costs in such a way as to demonstrate the contribution made by these companies toward sustainability. The literature lists environmental cost accounting (ECA) as a way to calculate this contribution. As an example, Jiménez (2006) successfully applied ECA to a Spanish transportation company based on the concepts of data reduction, data disclosure and verification.

Such initiatives have proven to offer adequate quality and efficiency and help maintain a company’s good image in the eyes of society. Upon achieving self-sufficiency, such companies are rewarded for their practices with ISO 9001 and ISO 14001 certificates.

1.2. Biodiesel and its advantages

Biodiesel is a biodegradable fuel derived from renewable sources and obtainable through different processes, such as cracking, esterification or transesterification. It can be produced from animal fat or vegetable oils. It can either entirely or partially substitute the diesel oil used in automotive engines in trucks, tractors and cars as well as stationary machines, such as power and heat generators (Benjumea et al., 2008; Lin and Lin, 2007; Ranganathan et al., 2008). Biodiesel can be used either pure or blended with diesel at different proportions. Such a blend containing 2% biodiesel is called B2 and so on until reaching pure biodiesel, which is called B100. According to Brazilian Law 11.097 from January 13, 2005, biodiesel is a “biofuel derived from renewable biomass for use in internal combustion engines with compression ignition or, in accordance with regulations, for the generation of other kind of energy, which may partially or wholly substitute fossil fuels.” This law also establishes a required blend of 2% biodiesel (B2) beginning in January 2005 and 5% (B5) beginning in January 2013 throughout Brazil. It establishes the authority of the Brazilian Petroleum Regulatory Authority to regulate and enforce the production and commercialisation of biofuel (ANP, 2007). After 2008, the B2 blend was required for mineral diesel and B3 the current blend in Brazil (CATI, 2008; PNPB, 2008).

The environmental benefits resulting from the emissions inherent to the use of biodiesel in engines, as opposed to those from petroleum diesel, are evident. Biodiesel is sulphur free, non-toxic and biodegradable. It reduces the emission of gas pollutants, reduces global warming, is economically competitive and may be produced by small companies. Production may be regionalised and economically favourable to small communities. Moreover, its by-product (glycerol) has a number of industrial applications (Benjumea et al., 2008; Faccio, 2004; Lin and Lin, 2007; Ranganathan et al., 2008; Serrão and Ocâcia, 2007).

1.3. Increased glycerol market

Glycerol has many applications in the pharmaceutical, food, arms and chemical industries. The demand is growing mostly in the fields of personal care, oral hygiene and the food industry, in which the product is of greater purity and value, corresponding to 64% of the market. In the food industry alone, the demand for glycerol and its by-products is growing by 4% a year (Knothe et al., 2006).

As a by-product of biodiesel production, the market price of glycerol could undergo a major reduction, eliminating part of its production from other sources, which currently stands at 0.8 to 1.0 thousand tons/year. From 1995 to 2003, prices fluctuated between US$ 1.32/kg and US$ 3.97/kg, with a trend in recent years towards US$ 2.20/kg. As each ton of biodiesel produces over 104.4 kg of glycerol, this by-product alone adds US$ 230 of value to each ton of biodiesel produced.

Glycerol can be used as a humectant and to preserve beverages and food stuffs, such as soft drinks, sweets, cakes, cheese and meat pastes and dry animal feed. Such purposes are currently served by sorbitol, which is lower in price. If there were a major increase in the supply of glycerol at lower prices as a result of biodiesel production, with a large part of the sorbitol market being taken over by glycerol, there would be a new demand estimated at 300,000 tons/year (BIO DIESELBR, 2009).

1.4. Carbon credits and biodiesel

The carbon credit market emerged in December 1997 with the signing of the Kyoto Protocol, which prioritises a 5.2% reduction in greenhouse gas emissions (relative to the year 1990) between 2008 and 2012. However, in order to avoid compromising the economies of the participating countries, the protocol enabled the purchase of these credits from other nations through “clean development mechanism” (CDM) projects (BIO DIESEL BR, 2009; Giraçol et al., 2009a and 2009b).

Therefore, the carbon credit trade emerged based on carbon sequestration or mitigation projects. This negotiation of future carbon credit contracts is already practiced at the Chicago stock exchange and in countries such as Canada, the Czech Republic, Denmark, France, Germany, Japan, the Netherlands, Norway and Sweden (BIO DIESELBR, 2009; Giraçol et al., 2009a and 2009b).

In 2005, the European Union created the European regional market, denominated the “European Union Emission Trading Scheme”. In the same year, the Brazilian Market for Emission Reduction was created through a joint action between the Brazilian Mercantile and Futures Exchange and the Ministry of Development, Industry and Trade. In practice, this is another titles market that will be operated by the stock exchange and securities may be negotiated by any investor who already buys similar kinds of assets on the derivatives market (BIO DIESELBR, 2009; Giraçol et al., 2009a and 2009b).

Therefore, the benefits generated by biodiesel production in Brazil may be converted into economic advantages through the agreement established in the Kyoto Protocol and the CDM directives. The gain in carbon credits resulting from reduced CO₂ emissions by burning cleaner fuels is estimated at roughly 2.5 tons of CO₂ per ton of biodiesel. In the European market, carbon credits are sold at around US$ 9.25/ton (BIO DIESELBR, 2009; Giraçol et al., 2009a and 2009b).
1.5. Problems caused by the reutilisation of cooking oils

The quality of the oils and fats used for frying in restaurants and bars has been the subject of recent studies. At frying temperature, the oil interacts with the air, water and particles of the food being fried, generating compounds that produce unpleasant odours and degradation of the oil used for long periods. In a study carried out in the region of Sào José do Rio Preto in the state of São Paulo (Brazil), 30% of samples had polar compound values above the established limit for the disposal of frying oils and fats. Moreover, 18.3% and 8.3% of the samples respectively had free fatty acid and peroxide values above the established disposal limits. The high amounts of total polar compounds (57.4%) found in a significant number of samples reveals the need for improvement in the quality of frying oils and fats in this food service industry (Ans et al., 2007).

This demonstrates the potential that these oils and fried foods have with regard to causing health problems for consumers and polluting the environment when discarded in bodies of water. Moreover, this pollution can contaminate the entire food chain that depends on these aquatic resources (Candeias et al., 2006; Giraçol et al., 2009a and 2009b).

1.6. Soybean oil biodiesel

The majority of biodiesel production in Brazil is derived from soybean oil, yielding around 98.1% and 96% when produced with methanol and ethanol, respectively. Methyl biodiesel can be produced faster than ethyl biodiesel. However, in terms of economics, toxicity and degree of non-saturation, ethyl biodiesel is the more favourable option (Candeias et al., 2006; Cavalet and Ortega, 2010).

A study involving an integrated environmental assessment of biodiesel production from soybean oil in Brazil found that 8.8 kg of topsoil are lost through erosion for every litre of biodiesel produced, along with the cost of 0.2 kg of fertilizers, about 5.2 m² of crop area, 7.33 kg of abiotic materials, 9.0 tons of water, 0.66 kg of air and about 0.86 kg of CO₂ (Cavalet and Ortega, 2010). Moreover, the soybean production model adopted in Brazil is generally based on monoculture farming practices and the extensive use of herbicides/pesticides and burning, with consequent water, air and soil degradation (Ometto and Roma, 2010).

There is considerable criticism worldwide regarding the use of oleaginous plants for biodiesel production due to the tendency toward driving up the prices of food products derived from these plants, such as cooking oils, textured vegetable protein and soy milk. Furthermore, this process will require an expansion of the farming industry, which may cause further devastation to remaining forest fragments (Giraçol et al., 2009a and 2009b; Santana et al., 2008).

In Brazil and Asia, soybean and palm plantations, the oils of which are potentially substantial sources of biodiesel, are invading tropical rainforests, which are important pockets of biodiversity. Although these crops are not currently cultivated in Brazil with the aim of being used for biodiesel, this concern should be considered (BIODIESEL, 2009).

2. Material and methods

2.1. Biodiesel production

The frying oil used in the present study was collected from homes in the region of Campinas (state of São Paulo, Brazil). Ethanol and sodium hydroxide were supplied by VETEC (Rio de Janeiro, Brazil). A 1:7 volumetric ratio of cooking oil to ethyl alcohol was used for transesterification. Solid sodium hydroxide was used as a catalyst to minimise the presence of water after the reaction. A jacketed reaction chamber was used to heat a total volume of 100 mL. The volume of reagents in the reaction chamber was 80 mL and the reaction occurred at 60 °C (±2 °C) with constant agitation for one hour (Faccio, 2004; Serrão and Ocácia, 2007).

The esterified material was centrifuged to separate the glycerol. The blend was then transferred to a decanting funnel to separate the phases. After some time, three distinct phases were observed: a thin, clear phase; a second phase of medium density and little turbidity; and a third denser, darker phase. After resting for 24 h, the fractions of biodiesel were separated (Barakos et al., 2008; Benjumea et al., 2008; Faccio, 2004; Knothe et al., 2006; Lin and Lin, 2007; Serrão and Ocácia, 2007).

2.2. Physicochemical analyses

The following properties were determined: specific mass at 20 °C using the ASTM-D4052 method; flash point using ASTM-D93 method; acid value using Ca 5-40 method; saponification value using the Cd 3-25 method; moisture content using the Af 2-54; and boiling point using the calorimetric method. These methods are found in AOCS (1985), Ascar (1985), Benjumea et al. (2008), Candeias et al. (2006), Faccio (2004) and Lin and Lin (2007).

Yield calculations were based on Table 1, which displays the percentage of fatty acids in soybean oil, and the results obtained for residual acids and saponification value. Based on this composition, mean molecular weight was 835 g mol⁻¹ for soybean oil and 881 g mol⁻¹ for the blends of ethyl esters (Barakos et al., 2008; Benjumea et al., 2008; Faccio, 2004).

2.3. Environmental cost accounting strategies

1) The steps suggested for an eco-friendly solution for discarding frying oils are presented below. These steps are commonly illustrated in a table and represent the following stages (Burritt and Saka, 2004; Chulián, 2006; Fresner and Engelhardt, 2004; Jimenéz, 2006):

   Stage 1 — the current stage of a company in an unsustainable position. At this stage, many of the environmental impacts result from process feedstock and waste production, not including the costs of this production.

   Stage 2 — a more sustainable position in which a company is taking steps to reduce its impact on the environment.

   Stage 3 — a position in which operations should have no impact on the environment.

   Stage 4 — a position in which a company is self-sustainable, whereby the environmental accounting balance of its operations results in credits for the company. Once reaching this stage, a company is qualified to receive quality certificates, such as the ISO 9001 and ISO 14001.

   The externality mentioned in the ECA model put forth by Chulián (2006) is understood as the social and environmental impact caused by the activities of a company that is not recognised in the economic information system. Thus, there is externality under two conditions: the activity of a given agent causes a gain or loss in the wellbeing of another and this gain or loss is not compensated.

Table 1

<table>
<thead>
<tr>
<th>Fatty acids</th>
<th>Composition (%)</th>
</tr>
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<tbody>
<tr>
<td>Palmitic acid (C16:0)</td>
<td>11.3 ± 0.01</td>
</tr>
<tr>
<td>Stearic acid (C18:0)</td>
<td>3.48 ± 0.03</td>
</tr>
<tr>
<td>Oleic acid (C18:1)</td>
<td>23.63 ± 0.11</td>
</tr>
<tr>
<td>Linoleic acid (C18:2)</td>
<td>54.71 ± 0.07</td>
</tr>
<tr>
<td>Linolenic acid (C18:3)</td>
<td>6.88 ± 0.01</td>
</tr>
</tbody>
</table>
The first stage consists of a qualitative summary of the social and environmental programmes and attitudes to be implemented through the Campinas sustainability policy. The second stage consists of presenting the external costs that city hall will incur (externality). Positive externality costs constitute spending on social and environmental programmes and negative externality costs constitute spending resulting from pollution by city vehicles and cooking oil disposal based on governmental studies (Jiménez, 2006).

Finally, a procedure for reducing environmental impact and costs based on ECA will be presented, namely, the collection of used cooking oils from homes by the Campinas Environmental department. The complete environmental solution will take the form of the production of biodiesel and glycerol as well as the acquisition of carbon credits.

3. Results and discussion

3.1. Characteristics of the biodiesel obtained

The biodiesel fuels obtained from the reaction achieved conversion yields of over 95%. These yields were similar to those reported by Ranganathan et al. (2008) and more than those reported by Barakos et al. (2008) and Benjumea et al. (2008), who describe yields of approximately 80%. The biodiesel (B100) produced from samples collected from different homes exhibited distinct physical characteristics. The three most representative of these sample biodiesel were selected, two of which took the form of a liquid and the other took the form of a gel at laboratory room temperature (25 °C). Lin and Lin (2007) report the same behaviour (B100) in a study in which the authors associated the transesterification of animal fat oils (high molecular-weight acids) extracted during frying processes. In other words, oil used excessively in different frying processes yields a biodiesel of poorer quality. This solidifying characteristic is not ideal, as it tends to clog up the pump filters at petrol stations (Ferreira et al., 2005).

Table 2 displays the results of the analyses conducted on the biodiesel samples in comparison to the maximal values recommended by the Brazilian Petroleum Regulatory Agency (ANP, 2007). Many of the parameters analysed fall within the regulatory standards for biodiesel in Brazil, with the exception of the flash point.

The samples were categorised based on density: light biodiesel \( \left( d = 745 \text{ kg m}^{-3} \right) \), medium biodiesel \( \left( d = 825 \text{ kg m}^{-3} \right) \) and heavy biodiesel \( \left( d = 836.7 \text{ kg m}^{-3} \right) \). Biodiesel is thought to be composed of smaller acid esters obtained from the fragmentation of larger fatty acid molecules during frying and mixed with the ethanol, which was found in excess, resulting in a density below that recommended by the Brazilian Petroleum Regulatory Agency (ANP, 2007). The melting point demonstrates that it may be a eutectic composition. The flash point of both biodiesels was above the recommendation of the Brazilian Petroleum Regulatory Agency (ANP, 2007), indicating that more energy is needed to initiate the combustion of the vapours.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Biodiesel Sample</th>
<th>ANP Values (^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light</td>
<td>Medium</td>
</tr>
<tr>
<td>Soaping Value (mgKOH/g)</td>
<td>122.2</td>
<td>138.1</td>
</tr>
<tr>
<td>Acid value, (% m/m)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Moisture, (% m/m)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Density (kg/m(^3))</td>
<td>745</td>
<td>825</td>
</tr>
<tr>
<td>Flash Point (°C)</td>
<td>45</td>
<td>54</td>
</tr>
<tr>
<td>Boiling Point (°C)</td>
<td>16–20</td>
<td>23–25</td>
</tr>
</tbody>
</table>

\(^a\) Brazilian Petroleum Regulatory Agency (2007).

The values obtained for acidity, moisture and flash point in the present study were better than those reported by Candeias et al. (2006) for methyl and ethyl esters. The yield rate was similar to that achieved by Candeias et al. (2006) and Lin and Lin (2007). Benjumea et al. (2008) obtained a biodiesel from palm oil with density ranging from 888 to 899 kg m\(^{-3}\). Ferreira et al. (2005) achieved a biodiesel from soybean oil with some parameters not in accordance with Brazilian law, but nevertheless found that the biodiesel functioned perfectly in a mixture of up to 10% with diesel oil in electricity generators.

3.2. Economic assessment of biodiesel production

B3 diesel (3% biodiesel) is currently commercialised, which has led to a small increase in price. The estimated biodiesel price is US$ 1.833/L, with B3 increasing the diesel price by US$ 0.057 (Craide, 2009; FECOMBUSTÍVEL, 2009; Pontual, 2009). Table 3 displays the price composition for diesel currently sold in the state of São Paulo. The values were converted to US dollars based on the current exchange rate (Folha de São Paulo, 2010).

Based on the price commercialised at refineries and using the biodiesel cost of US$ 1.833 (which includes transportation costs), the cost of biodiesel obtained by the public authorities would be composed as follows:

- Assuming that the monthly B3 diesel consumption by the bus fleet is 2.84 million litres (EMDEC, 2009) and using the distributor’s sales price (US$ 1.122/L), the monthly cost of B3 diesel is calculated as B3 Purchase Price = 2.84 million \( \times \) US$ 1.122 = US$ 2.653 million

- When producing B3, the city would only spend on the purchase of pure diesel from the refinery (transportation cost included), as all the other charges and prices are part of the minimal price composition that the distributor can commercialise. Therefore, B3 production cost = monthly volume of oil (fraction of pure diesel oil)\( ^* \)price of oil at refinery + fraction of B100\( ^* \)price of B100.

B3 cost \( = \) 2.84 million litres\( ^* \)(0.97\( ^* \)R$0.6226 + 0.03\( ^* \)R$1.833)

B3 cost \( = \) US$ 1.871 million

Therefore, the monthly savings with B3 production \( = \) (2.653–1.871)\( \times \)10\(^6\) = US$ 0.782 million.

This value can be discounted from the price composition of the local bus fare. According to the 2006 balance sheet issued by the Campinas transport administration company (EMDEC, 2009), spending on fuel corresponds to roughly 21.16% of the price of the local bus fare. Therefore, with the production of biodiesel, the current bus fare (US$ 1.29) could be reduced by as much as 6.25% (US$ 0.08).

Around 85,200 L of pure biodiesel are used to obtain 2.84 million litres of B3 diesel, which is the equivalent of 68.2 tons of biodiesel (Faccio, 2004). As the production of B100 generates...
approximately 7.1 tons of glycerol, the potential profit is close to US $15,620 from commercialising this by-product at its estimated average price of US $2.20/kg. Moreover, each ton of B100 accumulates 2.5 tons of carbon credit, which can be negotiated at around US $9.25/ton on the European market (BIO DIESEL, 2009), meaning another US $1970 in profit from the 85.2 tons of B100, in other words, 213 tons of carbon credits. Adding this to the glycerol, the profit is US $19,058.

According to Giraçol et al. (2009b), the monthly amount of cooking oil used to supply the biodiesel demand for the Campinas bus fleet would be easily attained, as it has been shown that there is a monthly consumption of around 1 L of oil in homes in the state of São Paulo and the population surveyed has agreed that such a collection should be made every two weeks.

This amount of used cooking oil could generate roughly 250,000 L of oil if the collection was made at all the homes in the city of Campinas. It has also been demonstrated that this biodiesel can be used for buses, trucks and other engines pertaining to city hall or sold to a fuel distribution companies. Through the transesterification reaction, glycerol is produced as a by-product, which can be sold to the arms, chemical, cleaning product and pharmaceutical industries.

This would lead to an excess of 164,800 L of B100 (250,000 − 85,200 = 164,800 L), which could be sold to other companies, generating an additional profit of US $302,212 or US $3.66 million after selling the 5493 million litres of B3 as well as an additional US $30.195 with glycerol and US $3048 with carbon credits (Table 4).

Therefore, it is possible to save US $0.815 to 4.437 million with the production of B100, B3 and biodiesel derivates using biodiesel made from used cooking oil, which reinforces the feasibility of the ECA proposal for the city of Campinas. Thus, the introduction of biodiesel in the fuel oil composition will enable good economic and environmental returns. Moreover, biodiesel is an important option for meeting energy needs; it is renewable and its use could reduce greenhouse gas emissions (Ometto and Roma, 2010; Pereira and Ortega, 2010; Zapata and Nieuwenhuis, 2010).

### 3.3. ECA for Campinas

2) A previous analysis of the city of Campinas city with regard to the environmental management of cooking oil waste revealed that the residents and owners of bars and restaurants are not concerned with used cooking oil, which is basically discarded in sewers and soil. This has significant environmental, social and economic impacts and increases the ecological costs of the city (Bansal, 2005; Burritt and Saka, 2004; Chulián, 2006; Labodová, 2004).

The current situation is considered critical. The city is increasing its ecological cost with each passing day, as the disposal of this waste in sinks, streams and — to a lesser extent — soil pollutes the environment, especially with the heightened chemical oxygen demand of bodies of water (Giraçol et al., 2009a and 2009b; Jimenéz, 2006; Rubenstein, 1994; Santana et al., 2008).

Moreover, this polluted water requires of a considerable amount of processing stages, thereby increasing treatment costs. There is also the risk of the proliferation of illnesses the neighbouring communities and the ugly appearance and bad odour of the water has a negative impact on the society of Campinas (Giraçol et al., 2009a and 2009b; Jimenéz, 2006; Rubenstein, 1994; Santana et al., 2008).

As a first step for the application of ECA, the local authorities will be shown that it is possible to use these waste products. The intention is to pull the authorities from this current state of inertia and alert them to the effects that the disposal of this waste causes to the environment, society and the health of the city of Campinas, leading them to create an ECA policy for such waste (Giraçol et al., 2009a and 2009b; Jimenéz, 2006; Rubenstein, 1994; Santana et al., 2008).

The authorities should then raise the awareness of the population as well as bar and restaurant owners through community centres and the media to alert the public to the effects of oil disposal and the need to store this oil for subsequent collection by a public service. At this stage, the ECA policy would be underway and the environmental costs would be coming down (Bansal, 2005; Burritt and Saka, 2004; Chulián, 2006; Labodová, 2004).

The third stage would entail the local authorities responsible for environmental matters and waste collection scheduling the collection of these cooking oils from homes, bars and restaurants on an established timetable. In this stage, the environmental cost of cooking oil disposal would be zero and the city would no longer be polluting by means of this waste product (Bansal, 2005; Burritt and Saka, 2004; Chulián, 2006; Labodová, 2004).

Furthermore, the production of the biodiesel will produce carbon credits (2.5 credits = 1 ton of biodiesel), which will both improve the city’s image and also provide financial returns (BIO DIESEL, 2009). Table 5 displays a simplified demonstration of the strategy to be adopted for the city of Campinas to attain ecological sustainability in relation to the reutilisation of cooking oils from homes, bars and restaurants.

The following are the advantages of biodiesel production from cooking oil over soybean oil (Cavalett and Ortega, 2010; Giraçol et al., 2009a and 2009b; Ometto and Roma, 2010; Santana et al., 2008):

- The biodiesel obtained is of low cost;
- The environmental impact of discarding used cooking oil into bodies of water will be eliminated;
- There is no topsoil erosion;
- There is no cost with fertilizers, herbicides or pesticides;
- There is no consumption of air, CO₂ or abiotic materials;
- There is negligible water consumption;
- This is no use of agricultural area, thereby preventing the expansion of farm areas

(in Brazil, reducing this expansion prevents the devastation of forest reserves, such as the Amazon forest);

- Soybean oil can be used for food products alone, thereby avoiding an increase in the price of this oil due to its use as a biofuel;
- There will be a reduction in criticism regarding the use of oleaginous plants for the production of biofuels.

<table>
<thead>
<tr>
<th>Type</th>
<th>Quantity</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excess B100 (litre)</td>
<td>164,800</td>
<td>302,212</td>
</tr>
<tr>
<td>Glycerol from excess B100 (litre)</td>
<td>13,725</td>
<td>30,195</td>
</tr>
<tr>
<td>Carbon Credit from excess B100 (ton)</td>
<td>330</td>
<td>3048</td>
</tr>
<tr>
<td>B3 from excess B100 (litre)</td>
<td>5,493,333</td>
<td>3621,781</td>
</tr>
<tr>
<td>Solving for the excess B3 - derivates</td>
<td>33,244</td>
<td></td>
</tr>
<tr>
<td>Solving for B100 from the excess B3 - derivates</td>
<td>3,655,026</td>
<td></td>
</tr>
<tr>
<td>Solving for use of B3 in Bus from ECA</td>
<td>782,000</td>
<td></td>
</tr>
<tr>
<td>Total for B100+ Bus</td>
<td>815,244.4</td>
<td></td>
</tr>
<tr>
<td>Total for excess B3 - Bus</td>
<td>4,437,026</td>
<td></td>
</tr>
</tbody>
</table>
4. Conclusions

The biodiesels obtained exhibited distinct physical attributes. The one in gel form likely had a high composition of animals fats extracted during the cooking process. The physicochemical properties of these biodiesels approached those recommended by Brazilian law. Thus, the present study demonstrates that it is possible to produce biodiesel from a blend of cooking oils and generate both a greener fuel and glycerol as a by-product, for which there is a high demand in different industries. This study also demonstrates that the environmental impact stemming from the disposal of waste oil in bodies of water can be reduced. Moreover, the biodiesel manufactured from used cooking oils collected from the homes of Campinas came close to the standards set by Brazilian law.

Thus, by interacting with local authorities, it is possible to reuse cooking oil and reduce the environmental costs caused by its disposal. The process would begin with the storage and collection of used oil and its subsequent use to produce biodiesel and glycerol. Campinas city hall could therefore reduce its impact and ecological costs through the use of biodiesel in its fleets of vehicles. Moreover, this biodiesel could be sold to a fuel distribution company and the glycerol could be sold to different industries, thereby leading to a savings of US$ 0.8 to 4.5 millions and environmental gains in the form of carbon credits.

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Cavalett, O., Ortega, E., 2010. Integrated environmental assessment of biodiesel production from soybean in Brazil. Journal of Cleaner Production 18, 53–70.


