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Life Cycle Assessment of Third Generation Biofuels Production.

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This paper provides an environmental assessment using LCA methodology for the production of biodiesel from microalgae. The life cycle stages evaluated were: production of biodiesel and distribution and use. The biodiesel plant was simulated on Aspen Plus® 2006.5 using as raw materials Chorella vulgaris microalgae oil and methanol. The Impact Assessment was made using SIMAPRO 7.1 software and ECOINVENT database, the impact categories evaluated were: climatic change (CCI), acidification (AI), eutrophication (EI), photochemical smog formation (POI), respiratory effects (REI) and non-renewable energy (NRE). The LCA methodology was applied following the procedures established by the ISO 14040 and 14044 (2006). According to the environmental profiles obtained, the stage of distribution and use of the B10 blend (10% biodiesel) has the greatest influence in the impact categories studied. This work was supported by the Ibero-American Program on Science and Technology for Development (CYTED) project 306RTO279 “New technologies for biofuels production” UNESCO codes 330303, 332205, 530603, 330999 and the Colombian Department of Science, Technology and Innovation COLCIENCIAS, projects CT 475-2007 and CT 272-2008.)

1. Introduction

Biodiesel is a transportation fuel that has grown immensely in popularity over the past decade. With the dwindling reserves of fossil fuels, it is now more important than ever to search for transportation fuels that can serve as alternatives to crude oil-based fuels such as gasoline and diesel fuel. Common sources for biodiesel feedstock include soy, sunflower, safflower, canola, and palm. Lately there has been growing controversy about the use of potential food sources for the production of fuel. In attempt to address these concerns, researchers have turned their focus from the popular feedstock and are currently investigating the use of alternative, non-food related feedstock such as oil from microalgae (Pokoo Aikins et al., 2009). High production yields of microalgae have called forth interest of economic and scientific actors but it is still unclear whether the production of biodiesel is environmentally interesting and which transformation steps need further adjustment and optimization.

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Biodiesel is a generic term that refers to fatty acid esters obtained by transesterification of oils with an alcohol (usually methanol). Biodiesel is renewable and therefore is presented as a substitute for fossil fuel gained advantages from the environmental viewpoint. Transesterification can be catalyzed by acid and basic homogeneous catalysts (Gerpen, 2005), heterogeneous catalysts, enzyme catalysts (Ranganathan et al., 2008), in supercritical conditions (Vasudevan and Briggs, 2008). On the other hand there are several possibilities for oil: used cooking oil, microalgae or vegetable oil (Vasudevan and Briggs, 2008). For biodiesel refining stage are different alternatives depending on the feedstock and the type of catalyst used (Jordan and Gutsche, 2001; Karaosmanoglu et al., 1996). Production has been analyzed from the economic point of view (Zhang et al., 2003b, Haas et al., 2006).
The LCA is a standardized method which allows the integral record, quantification and evaluation of the environmental damages connected with a product, a procedure, or a service in the context of a given question. The structure of such an LCA is described in the DIN/ISO 14040 (and following) standard series. At first, it is necessary to define the objective and frame of the survey. Secondly, the inventory analysis has to be drawn up. Here, the streams of material and energy of the respective process steps are recorded in relation to a quantity concerning the benefit (benefit unit) under consideration of certain rules. In a third step, the impact assessment can be started after the completion of the factual balance. This impact assessment serves the identification, summation and quantification of the potential environmental effects of the examined systems and provides essential information for the subsequent interpretation that follows in a fourth step. Here, the results of the mass and energy balance and impact assessment are summarized, discussed and evaluated.

2. Methodology

Life Cycle Assessment has been chosen as the methodology to evaluate the environmental loads of studied biofuel. This methodology is described below:

2.1. Goal and Scope Definition

The purpose of this study was to evaluate the environmental sustainability of the biodiesel production from microalgae oil, applying the LCA methodology. The function of the product was to serve as fuel for a vehicle that works with blends of diesel and biodiesel. Functional unit was established in 100.000 ton biodiesel /year. On the other hand, the temporal horizon was quantified annually, and the scenario for the analysis was the Andina region (Colombia). Besides, neither the construction nor the maintenance of the plant was taken into consideration. Likewise, economic and social factors were not included. Also, a cradle and a grave were established for the raw materials involved in the process, studies are still being made. Regarding the assignation rules for the transesterification stage, the hierarchy proposed by the ISO 14040 standard was followed.

1.2 Life Cycle Inventory

Environmental and energy flows for the different raw materials and the process involved in the biodiesel production from microalgae oil were calculated using mass and energy balances data from the Ecoinvent software database.

2.2.1 Oilgae Transesterification.

In this study, biodiesel production is based on the transesterification reaction of microalgae oil with methanol in the presence of homogeneous basic type catalyst process shown in Figure 1. Besides, the mass and energy balances of each one of these subdivisions were simulated in ASPEN PLUS® 2006.5. In order to simplify the calculations, the pressure drop in the different equipments was neglected within this study.

To perform the simulations the first step was to define the components of the mixture and the thermodynamic model used. Taking into account the presence of polar compounds in the process (methanol, glycerol) was chosen as model package thermodynamic properties NRTL and RK-Soave (Pokoo Aikins et al. 2009) for process simulation.

Based on the data reported by Petkov and García (2007), microalgae *Chlorella sp*. marine specie composition was selected and normalized to include those four fatty acids with the highest compositions. In this way, fatty acid composition used was 34% of 16:0, 13% of 16:2, 27% of 18:2, and 26% of 18:3. Miao and Wu (2006) have reported that microalgal oil was not suitable for the basic transesterification probably because of its high acid value. To the best of authors knowledge, since no exact information have been published regarding to *Chlorella sp*. marine specie oil free fatty acid (FFA) content, in this work it will be assumed that its FFA content is negligible. Thus, a basic catalyst transesterification is selected because it perfoms faster and has less corrosion issues that the acid catalyzed alternative. NaOH have been selected as the basic catalyst. A small amount, i.e. 1% catalyst/oil mass ratio was used. Short chain alcohols have been studied for the transesterification reaction. Despite of its safety issues, methanol is preferred on industrial scale because of its high reactivity and its low cost. According to the stoichometry, a mole of triglyceride (MAO) reacts with 3 mole of alcohol (methanol) to produce 3 moles of fatty acid methyl esters (BD) and a mole of glycerol. To favor the reaction towards the formation of products, a excess methanol was used (6:1 methano/oil mol ratio).

First, the methanol and the NaOH were mixed inside a tank to dissolve the catalyst. Then, the mixture was pre-heated until 60 °C in order to avoid formation of methanol vapours. In order to obtain biodiesel from microalgae oil a transesterification reaction was performed in a continuous stirred tank reactor. In this reactor, 97.7 % of the triglycerides which enters were transformed into BD and glycerol. A small amount of unreacted oil, catalyst, and alcohol was present in the BD and glycerol products. In order to remove the glycerol rich phase a decanter was used. Both BD rich phase and glycerol rich phase contains basic catalyst that must be neutralized with an strong acid to avoid the formation of soaps and emulstion (Zhang et al., 2003b). Therefore, H_2SO_4 was used in stoichometric proportions to do it so. Glycerol rich phase then was sent to a flash separator were most of the methanol was removed and a 77.5 % (mass basis) stream of glycerol was obtained. The BD obtained after neutralization was sent to a distillation tower in order to remove methanol. A 10 ideal stage with total condenser, kettle reboiler, and a 2.5 reflux ratio were used to remove approximately 90% of the methanol in the BD stream. After glycerol and methanol removal the BD stream was sent to washing stage in order to remove impurities. A decanter was then used to separate water from BD.

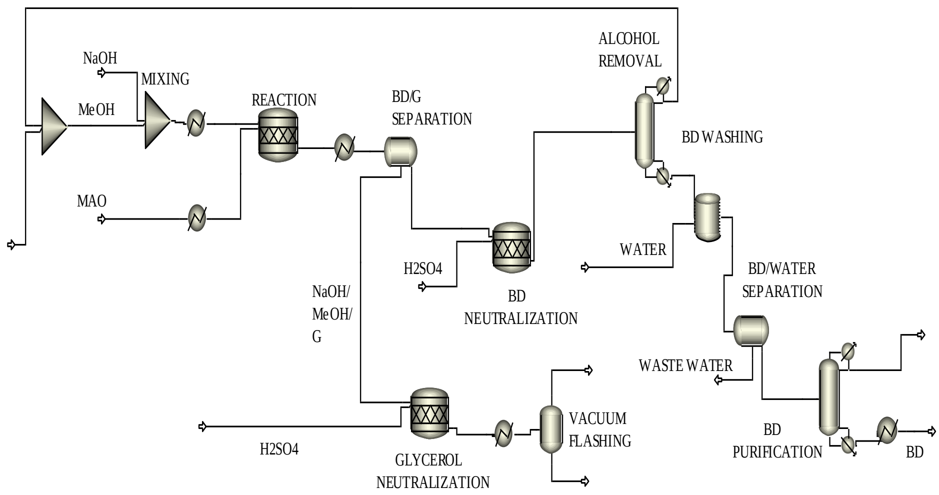

Figure 1: Process flow diagram of production biodiesel from oilgae with basic homogeneous catalysts

Waste water was sent to water treatment in order to reduce environmental impacts and for furhter reuse in the process. Finally, BD stream was sent to a distillation tower in order to remove excess water. A 3 ideal stage with total condenser, kettle reboiler, and a 1.5 reflux reatio were used to obtain a BD stream according to ASTM standards. However, since the initial composition of the microalgae oil has a high proportion of TG 18:3 (linolenic acid), the BD obtained also possess a high percentage of this component. According to the European standard pr EN 14103d a maximum of 12 % of linolenic acid methyl ester must be meet. In our case a content of 25.40 % for this fatty acid methyl esters was obtained. Despite this drawback, the BD obtained from the microalgae satisfies most of the ASTM specifications.

2.2.2. Biofuel distribution and use.
To carry out this inventory was estimated emissions from the distribution of biodiesel, B10 blend (10% v/v) as well as the combustion in a vehicle this heavy load.

Results

After having performed the analysis of inventory continued to impact assessment, which took into account the stages of classification, characterization and assessment. The methodology reported by Anton (2004) was used in the evaluation of the different impacts, and the categories studied were: climate change (CCI), acidification (AI), eutrophication (EI), photochemical smog formation (POI), respiratory effects (REI) and non-renewable energy (NRE). The percentage of participation of the studied phases in the different impact categories of the biodiesel production was calculated (Figure 2a). The environmental profile shows that the phase distribution and use of B10 blend is the most influential in the impact categories studied. In the stage of the transesterification for biodiesel production (figure 2b) showed that the major influence of emissions from each of the categories of impact was in steam production and production of raw materials.

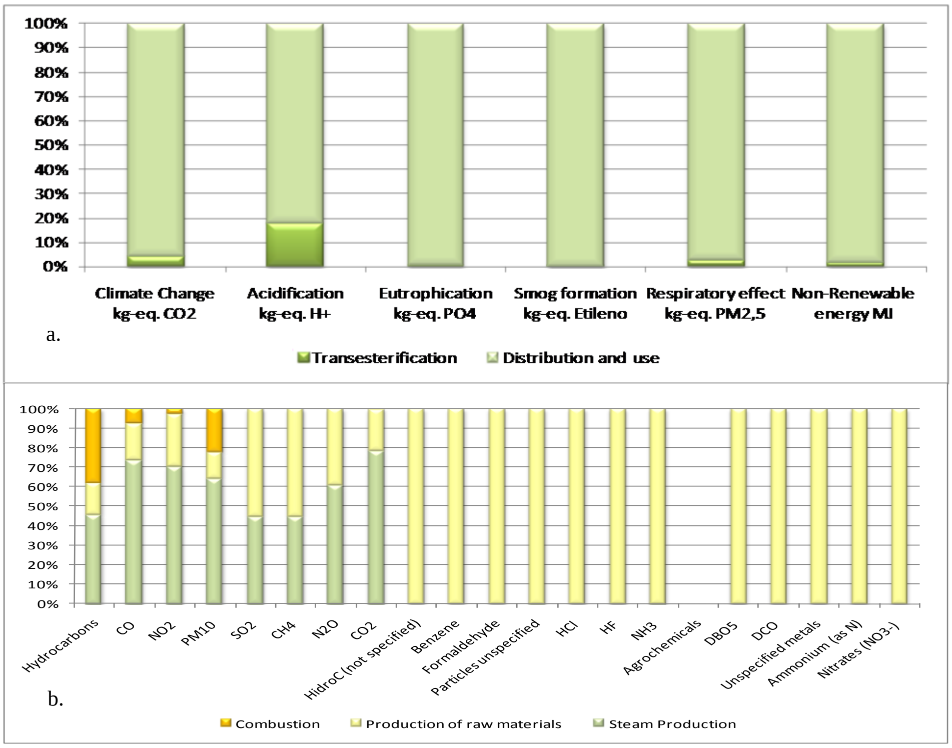

Figure 2a: Environmental profile of LCA. 2b. Emissions contribution in the stage oil transesterification (kg/y).

3. *C*onclusions

Through the quantification of input and output flows in the process of biodiesel production from microalgae oil and distribution and use of the same, it was learned more revealing emissions in each of them along with the associated energy consumption. In the transesterification for biodiesel production the highest percentage of emissions is caused primarily in the production of methanol and production of steam. The distribution and use of biodiesel in turn cause a significant environmental burden in all the pollutants considered in the study. Finally a high non-renewable energy consumption that occurs in the stages of transesterification and distribution is due to the production of raw materials involved.

5. Acknowledgements

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