

Life Cycle Assessment for Joint Production of Biodiesel and Bioethanol from African Palm

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In this paper LCA is applied to a biodiesel production process from African palm using lignocellulosic ethanol as a reagent in the transesterification reaction which is obtained from residues with high contents of cellulose resulting from the oil extraction stage. The LCA was evaluated through the biodiesel production chain starting with the land adaption stage, oil extraction, ethanol production from residual lignocellulosic biomass, transesterification of palm oil and ending with the distribution and use of the biofuel. This study was developed for Sabana de Torres (Santander - Colombia) region. The biodiesel plant was simulated by Aspen Hysys 2006.5; besides a parallel process was simulated to produce bioethanol from residual palm biomass. The last process is carried out in four steps: pretreatment of biomass, hydrolysis, fermentation and alcohol separation. The LCA was developed using SIMAPRO 7.1 software and database ECOINVENT with which the environmental profile of the system was elaborated evaluating different impact categories such as climate change (CCI), acidification (AI), eutrophication (EI), photochemical smog formation (POI), respiratory effects (REI) and non-renewable energy (NRE), among others. According to the environmental profiles obtained, the stage of distribution and use of the B10 blend (10% biodiesel) has the greatest influence in the output impact categories and the input impact category. The methodology was applied following the procedures established in the ISO 14040 and 14044 standards of 2006. This study was supported by the State Department of Science, Technology & Innovation (COLCIENCIAS), Projects CT 475-2007 and CT 272-2008, and the Ibero-American Program on Science and Technology for Development (CYTED) project 306RTO279 "New technologies for biofuels production" UNESCO codes 330303, 332205, 530603, 330999.

1. Introduction

Colombian government has encouraged the utilization of renewable biofuels for national transport sector in order to achieve several goals: diminish the volume of polluting emissions improving the air quality in Colombian cities, reduce the dependence on fossil fuels through the decrease of diesel and gasoline imports, and boost the development of Colombian rural sector, through the consolidation of agro-industrial chains for biofuels production (Cardona et al., 2009). Given the projections regarding the supply and demand for biofuels in Colombia, it is necessary to focus

efforts to improve production efficiency, so that this energy can compete with fossil fuels without the need of subsidies in the medium and long term. In this sense, the country must diversify its production alternatives in order to achieve sustainable development for the industry. Colombia is the fourth world producer of oil palm due to its favorable agro-ecological conditions. Currently, Colombia does not produce methanol and it is imported for domestic needs (Cardona et al, 2009), but in the other hand, Colombia is the second largest ethanol producer in Latin America. Considering the above mentioned, Colombia has the material basis for high-scale production of biodiesel through the transesterification reaction of palm oil with ethanol. As lignocellulose-based ethanol produced through a set of emerging conversion technologies offers promise for making progress toward both energy security and climate change mitigation goals (Spatari et al. 2009), use the lignocellulosic residues of oil palm industry to produce the ethanol for the transesterification reaction is a way to obtain a process environmental friendly.

2. LCA Methodology

2.1 Goal And Scope Definition

The purpose of this study was to evaluate the environmental sustainability of the biodiesel production from palm oil system, applying the LCA technique by means of the “well to well” 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 80.000 ton biodiesel /year. On the other hand, the temporal horizon was sixty (60) years (this temporal horizon was selected for comparative purposes), and the scenario for the analysis was the Magdalena region (east 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. Regarding the assignment rules for the extraction and transesterification stages, the hierarchy proposed by the ISO 14040 standard was followed.

2.2 Life Cycle Inventory

Environmental and energy flows for the different raw materials and processes involved in the life cycle of biodiesel production from palm oil were calculated using mass and energy balances data from the Ecoinvent software database. In order to achieve this, the life cycle of biodiesel was divided into five stages:

2.2.1 Agricultural activities:

In the agricultural activity stage, the identification and measurement of environmental and energy flows associated with fresh fruit bunches were carried out.

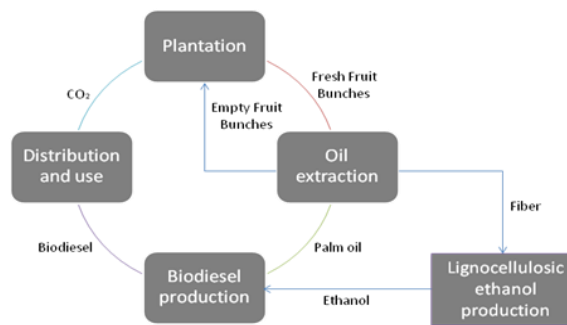


Figure 1: LCA stages

Furthermore, the effects produced by the use of agrochemicals (herbicides, pesticides, insecticides, etc.) were not included because there are not specific products for palm cultivations. In the palm oil plant cultivation stage, the integration of the carbon and nitrogen cycles was analyzed.

2.2.2 Oil Extraction.

Pressing was chosen as an extracting mechanism due to the fact that in the Magdalena region there are no plants that have additionally solvent extraction. The technological factors used were provided by a plant in operation of the zone. Required oil was estimated in 8805 kg/h from 41929 kg fresh fruit bunches/h.

2.2.3 Bioethanol production.

Raw material of this process is the fiber resulting from separation of press cake (press palm fiber, PPF) in oil extraction plant. Average composition (% w/w) of PPF was, cellulose: 24 %; hemicellulose: 14.4 %; lignin: 12.6 %; ash: 3 %; oil: 3.48 %; others: 2.52 %; moisture: 40 %. Initially, PPF was treated with saturated steam at high pressure (220°C and 22.9 atm.) and then it is suddenly decompressed to atmospheric pressure. Hemicellulose performance reaction was 60% and lignin performance reaction was 80 % (Moiser, 2005). A simultaneous saccharification and fermentation was carried out at especial operations conditions (32 °C, 101.3 kPa, and 72 h of residence time). A biological complex was added (enzymes produced by *T. reesei*, *S. cerevisiae*). Sugars (C5) fermentation was realized at 32 °C, 101.3 kPa and 36 h. Performance reactions were: cellulose saccharification, 90%; glucose fermentation, 92 %; sugars (C5), 85 % (Filho, 2007).

2.2.4 Oil Transesterification.

In this study, biodiesel production is based on the transesterification reaction of palm oil with ethanol in the presence of homogeneous basic type catalyst, NaOH (1 % Wt). Besides, the mass and energy balances of each one of these subdivisions were simulated in ASPEN HYSYS® 2006.5. In order to simplify the calculations, the pressure drop in the different equipments was neglected within this study.

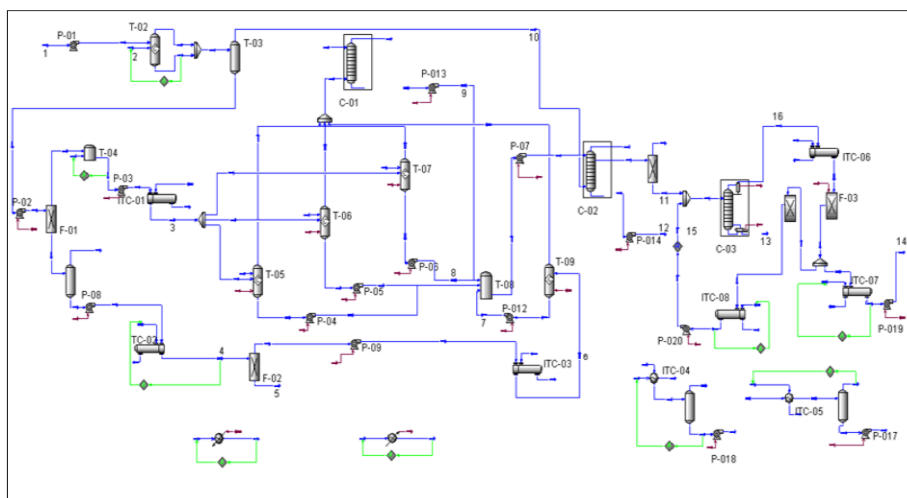


Figure 2: Process flowsheet for bioethanol production.

Components that were not found in the program library were created using the Hypo-Manager tool where hypothetical molecules were built specifying some properties known such as normal boiling point, molecular weight, acentric factor and critical properties (Knothe, 2005). Unknown properties were estimate using UNIFAC model. Due to the presence of polar components, such as ethanol and glycerol, non-random two liquid (NRTL) and UNIQUAC thermodynamic fluid packages were selected. Unknown activity model interaction parameters were estimated using UNIFAC vapor–liquid equilibrium and UNIFAC liquid–liquid equilibrium methods (Santana et al., 2009). The stecheometric relation between alcohol and the oil is 3:1. However, an excess of alcohol is usually more appropriate to improve the reaction towards the desired product (Marchetti et al., 2005). Alcohol–oil molar ratio 6:1 is used in this study giving an important conversion for the alkali catalyst without using a great amount of alcohol for recovery (Ellis et al., 2008). In this work, pre-treatment was not realized because free fatty acid (FFA) and water content of the feed is below 0.5 wt. % and 0.05 wt. %, respectively (Freedman et al., 1984). Transesterification reaction was carried out within a CSTR reactor to 60°C and 1 atm. Excess of ethanol was recycled using a distillation column and bottom stream input to other reactor where catalyst is neutralized with sulfuric acid. Two decanters were utilized for separation of glycerin following other distillation column for biodiesel purification. Biodiesel was purified to meet ASTM standard (Benjumea et al., 2008).

2.2.5 Biofuel distribution and use.

It includes the effects of the distribution of the biodiesel and the B10 blend as well as the combustion of the latter in a heavy-duty vehicle.

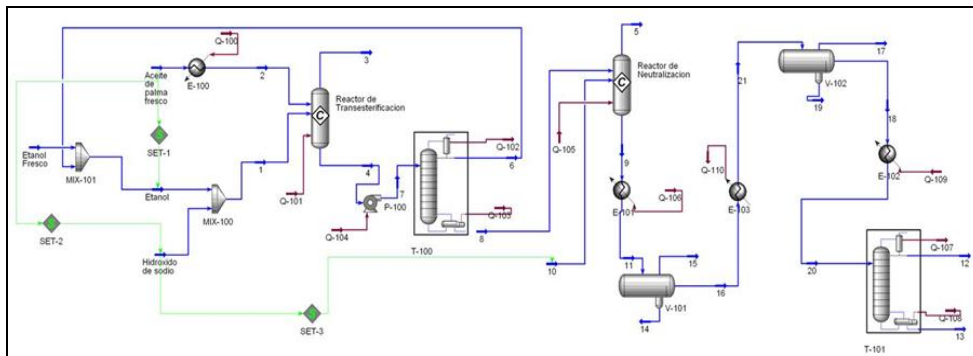


Figure 3. Process flowsheet for biodiesel production. Alkali homogeneous process.

3. Results

The percentage of participation of each of the studied phases in the different impact categories of the biodiesel production was calculated (Figure 4). 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 environmental profile indicates that biofuel distribution and use stage generates the highest environmental impacts. Whether the results obtained in this work are compared with those reported by Acevedo (2008) using the same methodology is possible to observe an average reduction of 13 % in the impacts generated by only biodiesel production stage.

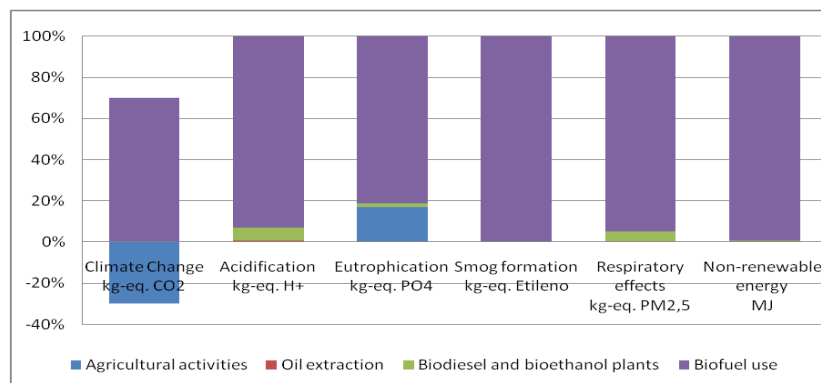


Figure 4: Environmental profile for joint production of biodiesel and bioethanol.

4. Conclusions

Biodiesel production from oil palm by a process that use ethanol produced from the solid residues of the same palm instead of methanol, offers high degree of integration and decrease of environmental impacts compared to the individual production of biodiesel and bioethanol. This option is very attractive taking into account not only the

energy consumption, but also the decrease of the solid wastes generated during the processing of oil palm. In particular, palm press fiber produced during oil extraction have a high content of lignocellulosic biomass making them very suitable materials for their conversion into ethanol.

Acknowledgments

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