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Leidy T. Vargas-Ibáñez, José J. Cano-Gómez, Peggy Zwolinski, Damien Evrard. Environmental assessment of an animal fat based biodiesel: Defining goal, scope and life cycle inventory. Procedia CIRP, 2020, 90, pp.215 - 219. 10.1016/j.procir.2020.02.053 . hal-03492256

HAL Id: hal-03492256
https://hal.science/hal-03492256

Submitted on 22 Aug 2022

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Procedia CIRP 00 (2020) 000–000

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27th CIRP Life Cycle Engineering (LCE) Conference

Environmental assessment of an animal fat based biodiesel: defining goal, scope and life cycle inventory

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Abstract

The energy crisis and environmental problems have resulted in an increase of biofuels production. However, the production cost is the biggest commercialization drawback for fuels such as biodiesel; the highest cost in its production chain is associated with the raw material. Biodiesel is usually produced from vegetable oils; nevertheless, water supplies, fertilizers and large land areas are required for its production. An alternative is to use animal fat as the most economic raw material for biodiesel production. It does not compete with food safety and reduces the environmental impact caused by an inadequate disposal. But the use of biodiesel causes damages on some different parts of unmodified diesel engines and decrease their performance. Therefore, it is necessary to study additives that modify the thermodynamic and transport properties of biodiesel such as density, viscosity or surface tension. The aim of this research is to present the goal, scope and life cycle inventory necessary to evaluate the potential environmental impacts of ternary diesel + biodiesel + additives blends, as biofuels through life cycle assessment. Mass of reagents and blends components were identified, while they have already been tested and validated from the experimental data. The life cycle scenarios will include beef tallow, biodiesel, diesel and additives production, mixing processes, and blends combustion.

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Peer-review under responsibility of the scientific committee of the 27th CIRP Life Cycle Engineering (LCE) Conference.

Keywords: Biodiesel; Ternary mixtures; Life cycle assessment, Additives.

1. Introduction

Anthropogenic pollutants are mainly greenhouse gases (GHG) emitted by activities carried out by different economic sectors such as: agriculture, industry, transport and electricity generation. Transport accounts for 14% of global GHG emissions, with most carbon dioxide emission coming from the combustion of fossil fuels [1]. In this sector, internal combustion engines are widely used due to their high efficiency, however, GHG emissions from fossil fuels burning are currently one of the main concerns worldwide due to their effects on the climate and human health.

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Peer-review under responsibility of the scientific committee of the 27th CIRP Life Cycle Engineering (LCE) Conference.
doi:10.1016/j.procir.2020.xx.xxx

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For 2013 in the European Union, 19.2% of GHG global emissions were generated by the transport sector, whereas in the United States and Mexico, transportation contributed with 27% [2] and 26% [3] of GHG emissions, respectively. This problem has increased the interest for producing alternative fuels. Recently, biofuels such as biodiesel, bioethanol, and biogas have been used because they are said to have a higher regeneration in the life cycle [4]. Also, they are meant to reduce a country's fossil fuel dependency [5].

The 95% of biodiesel is produced from vegetable resources as vegetable oils [6], these are the main raw materials because are renewables and can be produced at a large scale. Nevertheless, water supplies, fertilizers and large land areas are required for its production, and its use could threaten food security. An alternative is to produce biodiesel from waste oils or animal fats [6].

Until 2015 México was the seventh largest beef producer, with 1.8 million of ton per year and more than 1.1 million cattle ranches [7]. Tallow is classified in the international market as a waste or by-product of different industries, as examples are the leather or beef industries [8]. In the slaughtering process, beef tallow (BT) is a by-product together with hides, blood, bones and innards [9], so its use as a raw material allows to produce biodiesel at low cost and reduces environmental impact caused by an inadequate disposal. [8] [10].

In some countries like Brazil since some years ago, most BT has been used for biodiesel production, about 72% of the total tallow generated in the country [10,11]. Before of this, BT was used for cleaning and hygiene, chemical purposes, animal feed and as fuel in boilers [12]. However, most of it was frequently incinerated or disposed in landfills [9]. For that reason, BT is a potential raw material to produce biodiesel, getting high quality and good conversion rates [13]. Biodiesel has become one of the most important alternative biofuels because can be used without or with little modification in diesel engines [14]. Some advantages of biodiesel are related to its use as fuel, since it reduces the accumulation of un-burned hydrocarbons (HC) and carbon monoxide (CO) and particulate matter emissions.

In addition, it is renewable, biodegradable, nontoxic, and it has a high cetane number and flash point, which favors immediate combustion; increasing engine performance and decreasing emission of solid particles [4]. Also, biodiesel presents some disadvantages to conventional diesel; its use may increase nitrogen oxides emissions, it has less calorific value and volatility, highest cloud point and highest viscosity value, density, and surface tension [14]. These disadvantages can be overcome using alcohols as additives (AD).[4,13,15–18].

Nomenclature

GHG	Greenhouse gasses
BT	Beef Tallow
HC	Un-burned hydrocarbons
CO	Carbonmonoxide
AD	Additive
NOx	Nitrogen oxides
LCA	Life Cycle Assessment methodology
CO_2	Carbon dioxide
PM	Particulate matter
H	1-Hexanol
O	1-Octanol
B	Biodiesel
D	Diesel
DW	Distillate Water

Then additives to biodiesel can improve thermodynamic properties, but some emissions as nitrogen oxides (NOx) can increase depending on the additive, for that reason, it is necessary to compare the environmental impact generated by the production and use of biofuels blends diesel + biodiesel + alcohol and diesel.

Understanding the environmental impacts caused by the biofuels production and their use has been an important focus of research in recent years, because through a technical - economic - environmental analysis it can be evaluated the viability to implement an alternative fuel to conventional diesel. Life-cycle assessment (LCA) is an international standardized methodology for assessing the environmental impacts associated with a bioenergy system [19,20]. This technique allows the evaluation of different impact categories and the resources consumed during the generation and use of different products [21]. The purpose of this work is to present the initial steps of an ongoing environmental assessment study. It will show the goal, scope and life cycle inventory necessary to produce diesel + biodiesel + additive blends when beef tallow biodiesel is produced at laboratory scale, in order to compare the potential environmental impact of different scenarios through LCA.

2. Background

2.1. Biodiesel production from beef tallow

The main difficulty for the biodiesel commercialization is its high cost compared to diesel, between 70-90% of the cost of biodiesel is due to the production of vegetable oils that are used as raw material [22]. Therefore, the use of animal fats is an alternative to reduce the production costs of biodiesel. Some research on biodiesel from BT has been carried out, however animal fats have not been studied extensively like vegetable oils.

Banković - Ilić et al. [23] compared the properties of biodiesel produced from three large groups of raw materials: vegetable oils, animal fats and used cooking oils. They studied different transesterification methodologies for the conversion of animal fats to biodiesel, analyzing the pretreatment required and the conditions for carrying out the transesterification reaction. The authors concluded that the use of animal fats as raw material significantly decreases the cost of biodiesel and makes it competitive with fossil diesel.

Espinosa et al. [9] studied the biodiesel production in a pilot plant using BT as a raw material with methanol and potassium hydroxide as catalyst. Authors found that biodiesel quality was according with the Brazilian specifications (Resolution 42) by the National Agency of Petroleum. They concluded that economically, it is necessary to improve the methanol and glycerol recovery in order to decrease the prices and use the process at the industrial scale.

2.2. Exhaust emission characterizations of a diesel engine operating with mixtures diesel + biodiesel + alcohol as fuel

The use of alcohols as additives for biodiesel, had been associated with the reduction of carbon dioxide (CO_2) emissions and particulate matter (PM), that is the reason why a big interest exists in analysing the emissions that are being generated when biodiesel + alcohol and diesel + biodiesel + alcohol mixtures are used as fuels. Zhang et al. [24] evaluated the effect in mixing n-butanol and n-pentanol with biodiesel in 10% and 20% alcohol over the PM emissions. They conclude that all of the mixtures reduce the emissions of PM, with sizes over 50 nm, however, the particle emissions with a minor diameter than 15 nm increase for the mixtures with butanol.

Nowadays the use of 1-hexanol and 1-octanol as additives of biodiesel-diesel had been studied for the evaluation of its effect over the combustion gases emissions. Babu et al. [25] analyse the emissions generated by a diesel engine when biodiesel (B) + diesel (D) + n-hexanol (H) mixtures are used as fuels, the evaluated mixtures were B90-D5-H5 and B85-D5-H10. They found that the emissions of CO were minor for their mixtures than the diesel, meanwhile the emissions of CO2 were greater for the ternary evaluated mixtures.

2.3. Environmental evaluation of alternative fuels through life cycle assessment

Different researches have been done with the aim of evaluating the environmental impact caused by the biodiesel production from different raw materials when the life cycle assessment methodology has been used. Kaewcharoensombat et al. [26] investigated two scenarios to biodiesel production from vegetable oil. They compared two different catalysts, sodium hydroxide and potassium hydroxide, in terms of environmental impact and optimum operation. Life cycle assessment was used to estimate environmental impacts in three categories: human health, ecosystem quality and resource depletion. The authors found that the process using sodium hydroxide generate more environmental impacts on human health and the ecosystem; however, resource depletion was lower.

Another way is to produce biodiesel from non-edible raw materials, Carvalho et al [27] realized a life cycle assessment of biodiesel production from Solaris seed tobacco, they considered tobacco cultivation and harvesting, and oil extraction and transesterification assuming that the combustion of biodiesel from several plants is similar. Authors found that the greatest environmental impacts are related to the use of energy in the transesterification step. The production of Solaris tobacco seed biodiesel causes impacts similar to those that are identified for other oilseeds; however, the values were higher because the production was performed on a pilot scale.

3. Methods and results

The life cycle assessment will be performed according to ISO 14044 methodology [19,20]. The LCA consist of four steps: definition of goal and scope, life cycle inventory analysis, life cycle impact assessment and life cycle results interpretation [19,20]. The environmental impact evaluation will be made using SimaPro as a computational tool that allow to identify the different environmental impact categories.

3.1. Goal and scope

3.1.1 Goal definition

The goal of the study is to determine the potential environmental impacts and energy performance of a system to produce biodiesel from beef tallow and mixtures diesel + biodiesel + additive (cradle to gate approach). A second step will be to investigate the effect of using these mixtures as an alternative fuel when using a diesel engine.

The biodiesel production is based on the methodology proposed by Vargas-Ibáñez et al. [13]. Figure 1 shows a diagram with the methodology for biodiesel and alternative fuel production. Ternary blends will be prepared in the mass fraction range of diesel from (0.70 to 0.90) and in mass fraction range of additive and beef tallow biodiesel between (0.05 and 0.25). Densities and viscosities of ternary mixtures must be compliant with the EN 590 standard.

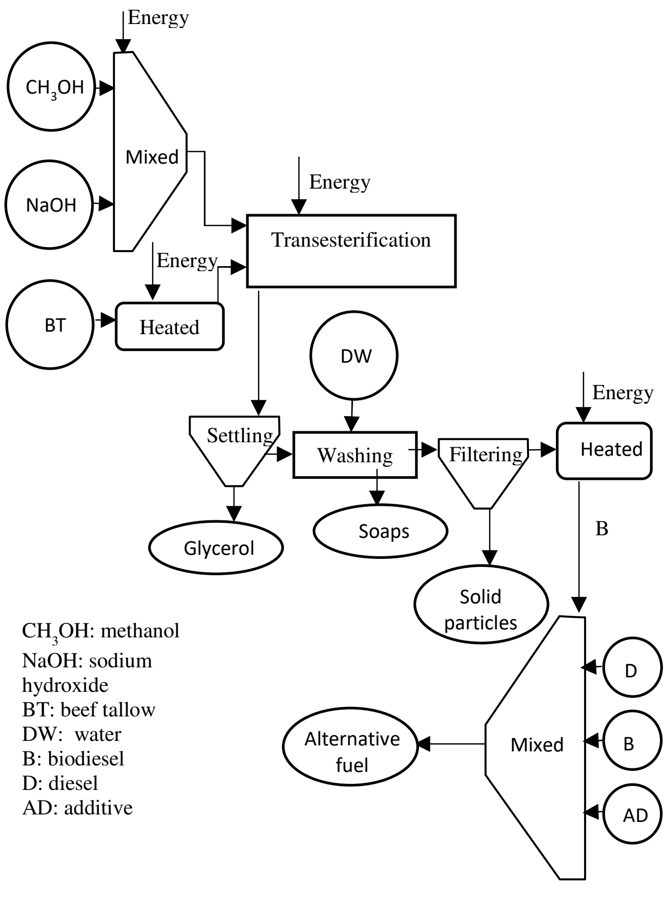

Fig. 1. Representation of biodiesel and alternative fuel production

As a first approximation, six scenarios are proposed, using 1- hexanol (H) and 1-octanol (O) as additives for diesel (D) + biodiesel (B) blends, to start the analysis, mass fraction of alcohol is established as constant. Table 1 shows the composition for different mixtures.

Table 1. Scenarios of study

Scenario	Mass fraction of biodiesel	Mass fraction of diesel
B5H5D90, B5O5D90	0.05	0.90
B15H5D80, B15O5D80	0.15	0.80
B25H5D70, B25O5D70	0.25	0.70

3.1.2. Functional unit, system boundaries, and common assumptions

The functional unit is 1 GJ of energy generated by the mixtures combustion [28]. The system that will be studied is illustrated in Fig 2. The system boundary is separated into four steps: beef tallow generation, biodiesel, diesel and additives production, mixing process and combustion of blends as biofuels. For this preliminary study supplies to produce beef tallow, as well as material goods (e.g. heating irons, reaction equipment, washing equipment) and transport were not contemplated.

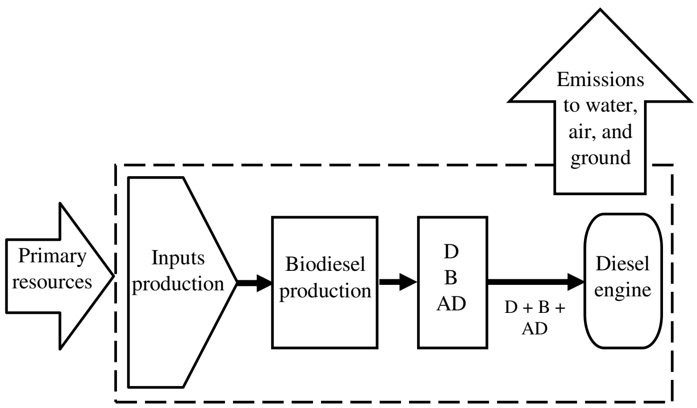

Fig. 2. System limits

3.2. Life cycle inventory analysis

For the inventory, literature data will be used for the beef tallow generation and experimental data for biodiesel production process. Ecoinvent database will be used [29]. Figure 3 shows supplies requirements for biodiesel + diesel + alcohol blends in order to produce 1 GJ of energy. Inventory of biodiesel is presented in terms of supplies for biodiesel production. For the different scenarios blends with 25% of biodiesel require approximately 5% more mass of blend to generate the same quantity of energy when 1-hexanol and 1-octanol are used as additives, this is due to the calorific value differences between diesel, biodiesel and additives. However, blends with 1-octanol as additive require 2% less mass of mixture in comparison with blends with 1-hexanol to obtain the functional unit value proposed.

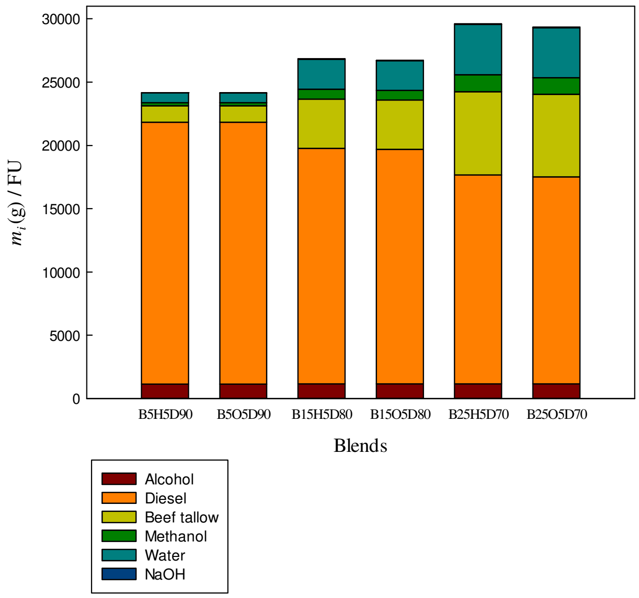

Fig. 3. Mass fraction of diesel, biodiesel and alcohol to obtain 1MJ of energy

In order to start with energy inventory, biodiesel production process was evaluated for the proposed scenarios. Figure 4 shows energy requirements in GJ to produce biodiesel from beef tallow, in this case an increase of 80% in energy consumption was observed for blends with 25% and 5% of biodiesel. This increase is related with the biodiesel mass required for the different blends.

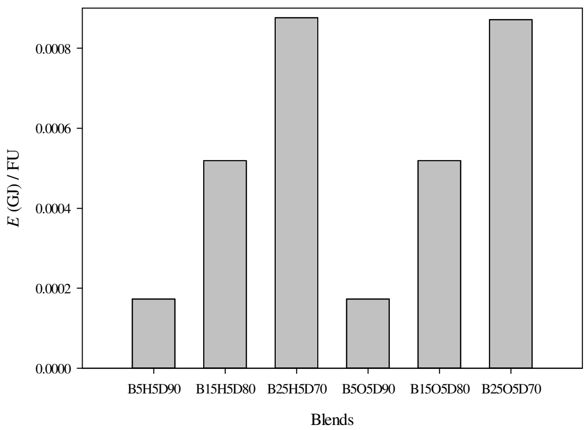

Fig. 4. Energy requirements of biodiesel production to obtain 1MJ of energy

4. Conclusions and future work

This study highlights the importance to analyze the environmental impacts in the production and use of alternative fuel produced with diesel + biodiesel from beef tallow + alcohol, to find a relationship between the variation in the mass of supplies and the generation of impacts. The first analysis done with generic data from Ecoinvent 3, using ILCD+2011, show a difference about 20% concerning the emissions generated by the different mixtures. The data and model have now to be refined, to allow the comparisons of the environmental impacts generated when an intern combustion engine is used with diesel produced from fossil fuels and with different mixtures diesel + biodiesel + alcohol. Because the current results have been establish at the laboratory scale, it will be also necessary to think about how this will be upscaled and to anticipate the impacts and rebound effects in case of a larger adoption of those new biofuels using beef tallow. The objective is to use the final LCA model to help decision making for the biodiesel but also to guide the design of the associated industrial production processes.

Acknowledgements

This work was supported by the Conseco Nacional de Ciencia and Technologic (CONACyT) [CB-2016-285320].

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