Life Cycle Assessment for the Production of Second Generation Bioethanol from Eucalyptus wood in Chile

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Abstract

The following paper deals with the life cycle assessment (LCA) for the production of second generation bioethanol from lignocellulosic material in Chile. This is, care was taken to design and assess the situation considering tree production conditions of the country and a theoretical ethanol production process based on an acid steam explosion under weak acidic conditions and a separate downstream treatment process for the resulting sugar streams. Limits of the system in the LCA included raw materials, tree production, ethanol production and use. Mixing of the ethanol in gasoline and later commercialization were not considered. The assessment was done with the software package SimaPro using EcoIndicator 99 (Hierarchical), and with the CEENE method for assessment of exergy and determination of exergetic efficiency. Results were strongly influenced by the use of fossil fuels, which increased the impact. On the other hand, use of lignin and biogas as replacement for fossil fuels in the process rendered high environmental credits. Finally, the exergetic efficiency of the process against fossil fuels was positive, which sheds light over the possibility of obtaining better efficiencies provided process optimization.

Keywords: LCA, bioethanol, lignocellulose, exergy.

Introduction

Chile has historically depended on external sources of energy to supply for internal consumption. Projections of difficulty for the supply of fossil fuels have motivated the need for alternative, renewable sources of energy, produced inside the country. For this reason, several research lines are being explored, one of thembeing the production of second generation bioethanol from lignocellulosic material, which is a readily available resource in the country. The production of second generation bioethanol is a topic of active research nowadays, with several pilot and commercial scale plants being built around the world (e.g. Iogen, Canada; Izumi, Japan; Biogasol, Denmark; Verenium, U.S.). In Chile, BioEnercel S.A. is one of the consortia dealing with the problem. This work presents the preliminary LCA for the production of bioethanol from high density *Eucalyptus nitens* plantations, as well as a proposal for a production process.

Bioethanol production requires two steps: the production of biomass, and the treatment of this biomass for the production of bioethanol. One critical stage in the process is wood pretreatment, which facilitates later fermentation by microorganisms. The processes use acids, bases, fertilizers, water and other chemical substances that can greatly affect the environment if not carefully treated. In order to assess the effects of these substances, LCA is used. This is a tool that helps to obtain an index measure of the effect a production process can cause over the environment, human health or the availability of resources, but also, it can be used as a means for discovering inefficiencies in the production process. Several methods are available for the calculation of these features, such as EcoIndicator 99[1] and CEENE[2] (Cumulative Exergy Extraction from the Natural Environment), which were used in this study. EcoIndicator is an endpoint method describing the effects caused by the discharges to the environment. On the other hand, CEENE is a resource oriented

method, so comparing both makes it possible to see the effects at both ends of the production process.

It was found that the greatest impacts were produced by the same processes in both analysis methods, and were linked to the use of fossil fuels, as in the production of fertilizers, ammonia salts, sulphuric acid and sodium hydroxide. The analysis played an important role in identifying possible sources of inefficiency in the process, shown as excessive exergy requirements or environmental impacts.

The results indicate that LCA is a useful tool when assessing the damage to the environment, and exergetic analysis is a powerful tool for finding points of inefficiency in the process.

Methods

The process was designed using information available in the literature for *Eucalyptus* or related trees, when necessary, and from information published by INFOR (Instituto Forestal – Forestry Institute).

The study considered raw and database information for the LCA. The preferred database was EcoInvent, mainly because the CEENE method is associated to it. EcoInvent was used to describe most materials in the study. Importantly, water was differentiated if coming from the natural environment or the chemical industry, depending on the stage.

A plantation density of 1.111 [trees/ha] was considered for the study. For its production purposes, 2 fertilizers, 2 herbicides and 2 fungicides, as well as plastic bags for germination, compost, and other chemicals for intermediate steps were taken into account. The consumption of CO_2 and the production of O_2 were added as credits for the process. The system boundaries can be seen in Figure 1.

The temporal limit of the system was set in 2015, mainly to avoid distortion by variations in the market and the speed of change in bioethanol production technology. The estimated consumption by the market for that year was 243.158 [m^3/y], the equivalent to a volumetric replacement of 5% on gasoline, if the energy delivered into the system were equal to that of gasoline alone.

This system was analyzed using the software SimaPro, with EcoIndicator 99 in Hierarchical mode and CEENE[2] as impact assessment methods.
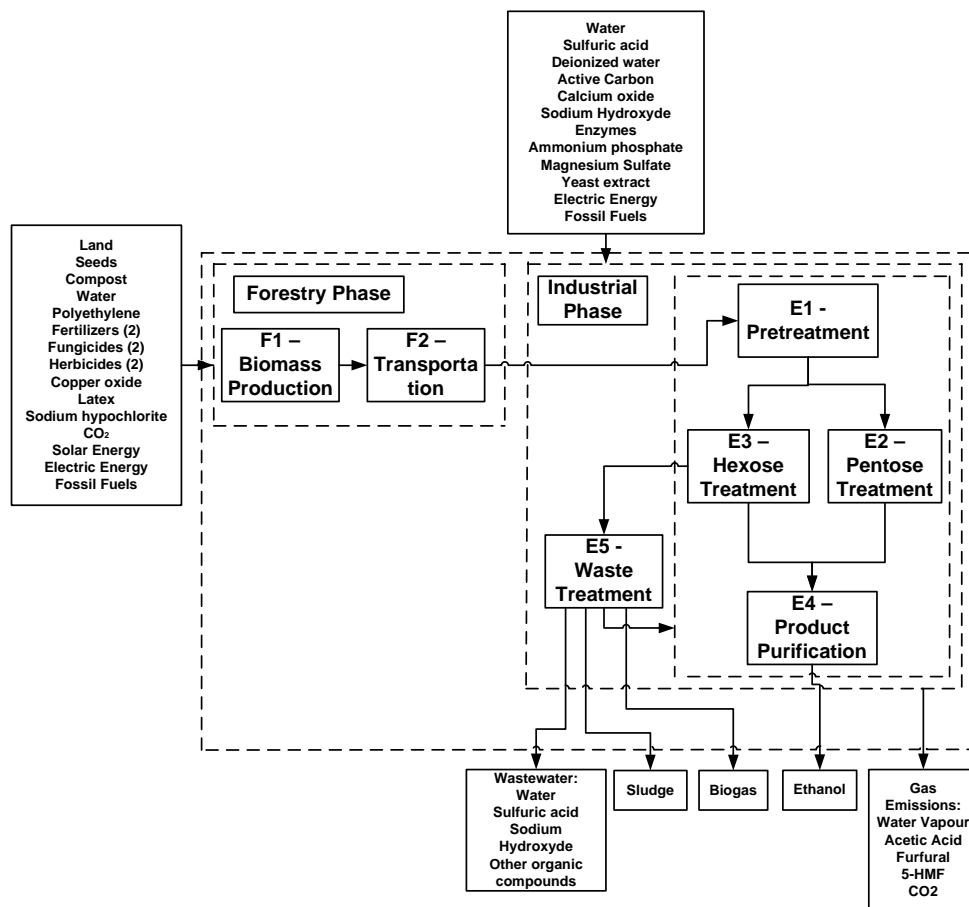
Figure 1. System boundaries.

Results and Discussion

The main aim of this study was to determine in a preliminary stage, whether the production of ethanol would make sense exergetically and environmentally. For such, a base case was designed in which the ethanol production process had a minimum of reflux and reuse flows. This would present the 'worst case scenario' for the production process, which should improve the results (i.e. decrease in the overall impact and an increase in the exergetic efficiency) when using a more efficiently designed process. However, the mixing of ethanol in gasoline and later commercialization were not considered.

In this case, the ethanol production process from wood presented an efficiency of 51.9% with respect to the theoretical maximum reported[3].

The ethanol production stage considered acid steam explosion of wood chips, followed by separate treatment of the hexose rich and pentose rich streams. Lignin was separated from the hexose rich stream and was later incinerated to generate energy for the process. The rest of the stream was fermented for the production of ethanol. A detoxification process was included for the pentose rich stream, which considered the use of membrane filtration, evaporation, lime, and charcoal. The resulting stream, comprised mainly by sugars and water, underwent fermentation for the production of ethanol. The ethanol containing streams were submitted to distillation for obtaining an ethanol rich stream which was later dehydrated in a zeolite bed. Waste water was treated in an anaerobic fermentation stage, producing biogas which was later used in the process.

Results obtained by both impact assessment methods show that the most critical stages were forestry, for the use of fertilizers, diesel-depending machinery, and soil; steam explosion, for the use of sulphuric acid; lignin extraction, for

the use of sodium hydroxide and sulphuric acid; ammonia salts used during fermentation; steel, for the production of equipment and machinery; and charcoal, mainly for the land use associated to its production. On the other hand, carbon fixation by trees, and use of biogas, lignin and ethanol as replacement for fossil fuels, were important sources of environmental credits when analyzed by the EcoIndicator 99 method. The three latter were taken as 'avoided products' compared to the use of different fossil fuels. Effects over analysis results can be seen in Figure 2.
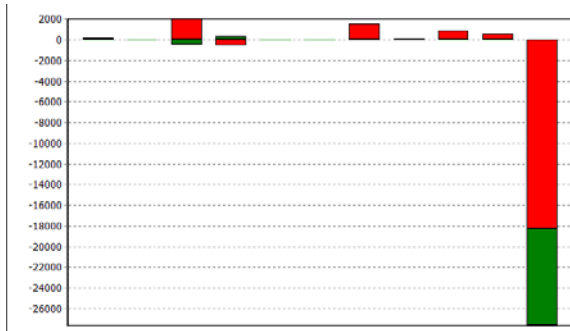

Figure 2. Normalized score, by category for the EcoIndicator 99 method. From left to right: carcinogens, respirable organics, respirable inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification / eutrofication, land +use, minerals, and fossil fuels. Red: ethanol production; Green: ethanol use.

Moreover, CEENE only measures the extraction of exergy from the natural environment, so it did not consider credits. CEENE results, broken down by category, are shown in Figure 3. The main contribution to the overall result is Land Use, with over 70% of total. Land occupation and transformation in concentrated in both the tree and charcoal production, and accounts for the extraction of solar energy, incident over such an area of soil. Fossil energy and water resources are also important, and may be reduced improving the recycling of streams in the system.
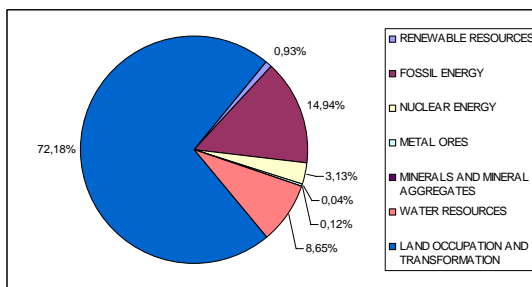

Figure 3. Contribution per category to the total CEENE score.

The exergetic efficiency of the process was found to be 15.6% [exergy obtained in ethanol/exergy extracted]. Other studies presented higher exergetic efficiencies than in this work, with different feedstock such as banana[4] or corn[5]. This may account for the greater complexity of the cellulosic matrix in *Eucalyptus* compared to the other materials. Overall efficiency *versus* fossil fuels resulted in 1.04 (this is, a 4% above the null line), which means there is greater exergy in ethanol than the exergy wasted by fossil fuels in its production. The result was considered positive, as the analysis was done over a 'worst case scenario' (most inefficient process design).

A small sensitivity analysis over the CEENE results showed that the density of plantation has a much greater effect over the extraction of exergy from the environment than does the average distance from the greenhouse to the plantation spot.

Better accuracy will be obtained as more life cycle information is made available for the region (Chile). As well, it is necessary to improve the assessment over important stages such as enzyme production of charcoal production. On the other hand new information on the tree production process is becoming available, which will improve the results on future LCA refinements.

Conclusion

It was observed that the production of bioethanol by the proposed process renders more renewable energy than invested fossil energy, which presents a promising future for more efficient processes and supports the production of bioethanol as a good alternative to fossil fuels.

Acknowledgements

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