Life Cycle Assessment for Bioethanol production from Cassava in Colombia.

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ABSTRACT

Colombia has recently started the production of Biodiesel from palm oil and Bioethanol from sugarcane. The bioethanol in Colombia replaces 8% of the national consumption of fuel for transport and it represents nearly 263.340 gallons per day. A life-cycle energy and environmental assessment was conducted for bioethanol production from cassava in Colombia. The scope covered all stages in the life cycle of bioethanol. In the Life Cycle Assessment the Impact Assessment methods used IPCC2007 GWP100a for global warming. In all stages of the life cycle there are important impacts for the use the bioethanol in a car. At other stages, the ethanol production is important for the environmental impact of the product. The carbon footprint of the bioethanol from Cassava is 65gCO2e/MJ. The energy conversion efficiency of fuel ethanol is 1.34.

1.0 Introduction

Colombia has a development policy for Biofuels which includes criteria of sustainable, agroindustrial development and energetic independence. Therefore the Colombian government has included one Law in 2001(Law 693) [1], with the rules for bioethanol use, and the economic incentives for production, commercialization and consumption. In 2003, the 180687 resolution included a blend of 10% for bioethanol with petrol in combustion in cars [2]. In 2004, a new Law for biodiesel use was developed. In 2008 the government created an Intersectorial Commission for Biofuels management conformed of five Ministries (Agriculture, Energy, Environment, Transport, Trading), this commission has approved the "Policy Guidelines to Promote Sustainable Biofuels Production in Colombia" (CONPES 3510, 2008)[3]. In 2009, the government established that from 2012 vehicles with motor 2000 cm3 manufactured, assembled, imported, distributed and marketed in Colombian, must be arranged so that their engines run Flex-fuel(E85) (Decree 1135, 2009) [4]. Since 2010, the blend with bioethanol was at 8% (Resolution 18 2367) and 7% for biodiesel (Resolution 18 2367). However, in December, 2010 the heavy rains in Colombia by the "La Niña" phenomenon, and the decrease of the productivity for sugarcane production, forced the government to reduce the blend to 0% in biofuels (Resolution 182270) [6].

Colombia was producing an average of 785.000 bbl for 2010 and has 2000 million of barrels at proved reserves of oil, it represents only seven years of reserves [7]. The decrease of the national reserves of oil, forces the government to stimulate policies for biofuels production. As a response to the policies for ethanol production, from 2005 the sugar mills included in their facilities the ethanol production for an 324,7 million of liters of ethanol per year. The ethanol capacity of production in Colombia in 2009 was 1´275.000 liters per day in six Companies [8]. The "La Niña" phenomenon had heavy rains in Colombia, it caused floods and loss of crops of sugarcane and this affected the ethanol production (average Jan- Nov 25 millions per month , 5 million on Dec) [8]. On the other hand, the increasing demand of bioethanol for blending with gasoline motivates the construction of new ethanol plants, some of them will start operations in 2011 and 2012, the new projects have a 1,5 million /day a capacity. [8]

Colombia has on cassava other great alternative source of bioethanol. The Cassava production in Colombia in 2009 was of 1´984.427 ton in 182.313 ha [9], the average productivity was 11t/ha. There are registers with productivities of 40 t/ha. Nowadays in Colombia, the Sumprocol Company is carrying on the Cantaclaro´s project for ethanol production from Cassava with a future production of 1.000.000 liters per day. At this moment the project is in pilot plant scale, with a 25.000 liter per day.

Simultaneously the Colombian government, Agriculture and Rural Development Ministry has supported researches on Cassava bioethanol production at lab scale with Universities and Research Centers. The projects had allowed to obtain ethanol concentrations in 15% v/v., with productivities at 4g/l-h and yield at 97% by simultaneously integrating enzymatic hydrolysis and fermentation, in batch and continuous mode [10]. Based in these yields and the benefits of the Cassava crops, it will be an important energetic alternative source for the bioethanol production. It will allow development of environmental policies and energetic requirements; also it is an important rural labor source for the economy in the country.

The Life Cycle Assessment is an important tool to quantify the environmental impacts in different stages of the life cycle, soil preparation, harvesting, transport, production and use for biofuels. It is based in the ISO 14040 and ISO 14044 standards, and allows the identification of hot spots in biofuels production, comparisons with another energetic sources and evaluation of some impact categories like climate change, acidification, eutrophication, ecotoxicity and photooxidants.

Thailand and China lead the world production of ethanol from cassava, such leadership is supported in the definition of public policies, studies of Life Cycle Analysis madein these countries show results that indicate the need for standardized inventory methodologies and tools, so its necessary to keep in mind that the results of an LCA study depend on the type of technology used and the amount and type of material and energy requirements.

In this sense Malakul and Papong [11] developed an environmental analysis and life cycle energy to produce ethanol from cassava in a commercial plant in Thailand and found that the production has a negative net balance. On the contrary, Dai *et al.*. (2006) [12] investigated the energy and renewable energy efficiency of cassava fuel ethanol in Guangxi which showed positive net energy and net renewable energy. Leng *et al.*. (2008) [13] concluded that cassava-based ethanol is energy efficient as indicated by an energy output: input ratio of 1.28 and a major contribution to energy consumption primarily comes from ethanol conversion phase as a result of the combustion of coal to produce energy. Nguyen et al. (2007) [14] conducted a study on the net energy balance and greenhouse gas (GHG) emissions of ethanol from cassava based on pilot plant data of the Cassava and Starch Technology Research Unit (CSTRU) and found that the energy balance is positive and net avoided GHG emission is 1.6 kg CO2 eq. per liter of ethanol. Nguyen and Gheewala 2007 [15] showed that cassava ethanol in Thailand in the form E10 reduces environmental loads compared to gasoline. Positive energy value and Net Renewable Energy value 8.80Mj/l and 9.15 MJ/l respectively, found for the Cassava fuel ethanol in Thailand proved that this energy is efficient. The analysis without co products energy credits, show Cassava fuel ethanol in Thailand is more efficient that the cassava fuel ethanol in China and corn ethanol in USA. [16] (Nguyen et al 2007)

LCA studies that has been developing in the past years, showed different results due to different input data on crop, farm energy, different conversion in ethanol technology, and co products energy credits. Its critical for the starch bioethanol process the improvement of the technology data on the inventory, due to that efficiency of the process has been increasing in the last years thanks to research projects that have improvements in the biotechnology fields. Yu and Toa (2009) [17] studied an energy efficiency of cassava-based fuel ethanol in Chinese Guangxi by the Monte Carlo method to avoid the uncertainty of data collected and showed that the energy balance is a positive net energy and energy input: output ratio of 0.7 MJ/MJ

For this reason it is necessary to evaluate the environmental impacts at the overall life cycle assessment of this product, and determine the fossil fuels intensity at ethanol production, the carbon footprint of bioethanol from Cassava, and other impacts at the Colombian conditions

2.0 METHODOLOGY

LCA methodology used in this study was based on ISO 14040 framework. The steps that the methodology applies are: goal and scope definition, inventory analysis, impact assessment and interpretation of the results

2.1 Goal and scope definition

The goal of this study is to assess the commercial bioethanol production from cassava for Colombia based on a life-cycle approach. The functional unit (FU) of this study is 1 L of 99.5% bioethanol production from cassava as octane improvement fuel. The system boundary defines the scope for the product analysis, i.e. which life cycle stages, inputs and outputs should be included in the assessment. **¡Error! No se encuentra el origen de la referencia.** shows the system boundaries with the different life cycle stages like land preparation, planting, harvest, packed, transport to ethanol plant and conversion the ethanol plant (drying chips, milling, hydrolysis and fermentation, distillation and storage)

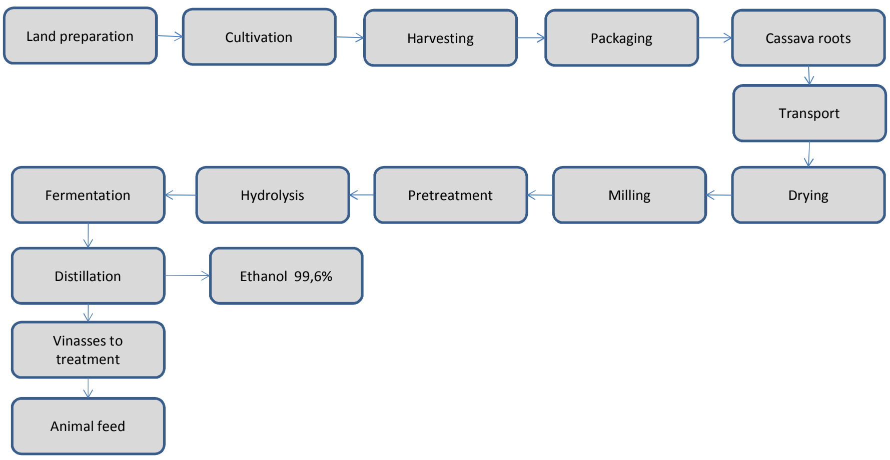

Fig. 1. System Boundaries Ethanol production from Cassava

2.2 Inventory Analysis

For this study, at the farm production, the data were collected as primary data by surveys to farmers in Urabá Colombia (PROTRACOY), and Antioquia Agriculture Secretary. These data including land preparation, cassava plantation and Cassava harvest were compiled in LCI formats. Since the first commercial production of ethanol from cassava present technical problems and could not start operations in 2010, the data were collected, for a pilot plant in CIAT belonging to the program Clayuca in Palmira, with capacity for 200-250 liters per day. These data includes raw material used and energy consumption.

The secondary data were used in this study as necessary from literatures, calculation, and ECOINVENT database for some items such as the production of fertilizers, herbicides, etc, all imported materials.

The energy for production of steam, used for distillation, is produced with wood residue combustion in Boilers

2.3 Life Cycle energy Analysis

The Net Energy Ratio (NER) was estimated by ratio Energy out/Energy in. The inventory analysis allowed measure the energy flows based on energy output and input for 1 liter of 99.5% bioethanol from cassava.

2.4 Carbon footprint

Carbon footprint methodology for this study was calculated using in the PAS2050 (BSI, 2008) and the ISO14040 and ISO14044 framework. The PAS2050 Methodology consists of five steps forcalculating the carbon footprint: process map, boundaries and priorization, data, calculation and uncertainty.

2.5 Life Cycle impact assessment

The inventory data (primary and secondary) of each step were introduced in SimaPro v7.22 to evaluate the environmental impacts using a methods CML 2000, for eutrophication, acidification, photochemical oxidation, human toxicity, ozone layer depletion, abiotic depletion and methods IPCC2007 GWP100a for global warming. The following considerations were taking into account:

-not including indirect formation of dinitrogen monoxide from nitrogen emissions.
-not accounting for radioactive forcing due to emissions of NOx, water, sulphate, etc. in the lower stratosphere + upper troposphere.
-not considering the range of indirect effects given by IPCC.

For this study biogenic CO2 uptake as negative impact was not considered, because the cassava is a temporal crop.

3.0 RESULTS AND DISCUSSION

3.1 Results of Inventory analysis

Table 1 presents the Life Cycle Inventory to produce 1kg of Cassava in Colombia, and Table 2 presents the Life Cycle Inventory to produce 1kg of Ethanol in Colombia

Table 1. Life Cycle Inventory to produce 1kg of Cassava in Colombia.

Material	Amount	Unit
	INPUT	
vegetative Seed	0,77	seed
Fertilizer N	2,3 E-03	Kg
Fertilizer P_2O_5	4,6 E-03	Kg
Fertilizer K_2	4,6 E-03	Kg
Alaclor	2,3 E-04	Kg
Glyphosato	1,5 E-04	Kg
Paraquat	2,3 E-4	Kg
Diurón	8,3 E-05	Kg
Fungicida-Insecticida	7,7 E-05	Kg
Polypropylene bags	2,59E-4	kg
Transport of raw materials	6 E-8	tkm
Transport of tubers	0,8076	tkm
	OUTPUT	
Cassava	1	Kg
Reject	0,135	Kg
N_2O $_{synthetic\ fertilizer}$	3,6 E -05	Kg
N_2O $_{tuber\ reject}$	2,5 E -05	Kg
Dangerous residues	2,2 E-05	Kg
Bags to landfill	2,59E-4	kg

Table 2. Life Cycle Inventory to produce 1kg of Ethanol from Cassava in Colombia

Material	Amount	Unit
	INPUT	
Dirty cassava	13,2	Kg
Clean water	1651,0	Kg
HCl (36%)	3,7E-02	Kg
Enzymes	1,9E-02	Kg
Yeast	1,3E-02	Kg

Material	Amount	Unit
Úrea (46%)	9,4E-03	Kg
Vapor	11,0	Kg
Electricity	4,9E-01	kWh
OUTPUT		
EtOH 96%	1,0	Kg
Residual water	1,7	Kg
Husk and impurities	6,6E-01	kg
Evaporated water	8,1	kg
Gravel	1,1	kg
CO_2 produced	1,0	kg
Stillage	3,1	kg
Condensed	11,0	kg

3.2 Energy Analysis

The results show that the energy conversion efficiency of Fuel ethanol was 1.34, it means is possible to obtain 1, 34 energy units per every energy unit necessary to obtain cassava bioethanol at Colombian conditions. These results are in accordance with Leng *et al.*, (2008) [13] and You and Tao [17], who concluded that cassava-based ethanol is energy efficient as indicated by an energy output: input ratio of 1.28. and 1.43 respectively. Nguyen *et al.*, (2007) [14] showed in a study on the net energy balance of ethanol from cassava based on a pilot plant data of the Cassava and Starch Technology Research Unit (CSTRU) found that the energy balance is positive.

3.3 Carbon footprint of cassava ethanol

The carbon footprint of cassava ethanol is 0.395kg CO2e per kg of ethanol, this means 75 g CO2eq/MJ, allowed a net reduction of 13.5 g CO2 e/MJ GHG emission compared to conventional gasoline[18]. In a similar study Nguyen *et al.*, (2007) [14] found a net avoided GHG emission is 1.6 kg CO2 eq. per liter of ethanol (2.05 Kg CO2 /kg etanol i.e. 72 g CO2 e/ MJ), a higher value that the reported in this study. Figure 2 shows the operation produces 90% of the GHG emission, and the cassava farming and ethanol production only contribute with 7.6 and 2.4% respectively.

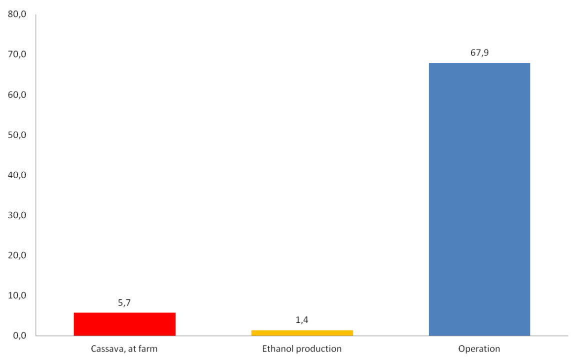

Figure 2. Carbon foot printer for bioethanol from cassava in Colombia g CO2 e /MJ

4.0 CONCLUSIONS

The ethanol from cassava will be an alternative for the Biofuel production in Colombia, this crop does not compete with the food security and creates jobs with unskilled labor.

The carbon footprint of the cassava ethanol is lower than fossil fuels, with 20% lower footprint

The energy conversion efficiency of Fuel ethanol was 1.34 this means it's possible to obtain 1,34 units of energy per every unit of energy necessary to obtain cassava bioethanol

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References

[1]http://www.mincomercio.gov.co/eContent/Documentos/Normatividad/resoluciones/2003/R_180687_2003.pdf (Accessed 10.04.2011)
[2] http://www.fedebiocombustibles.com/files/182368.pd (Accessed 02.04.2011)
[3]http://www.dnp.gov.co/PortalWeb/Portals/0/archivos/documentos/Subdireccion/Conpes/3510.pdf (Accessed 15.03.2011)
[4]http://web.presidencia.gov.co/decretoslinea/2009/marzo/31/dec113531032009.pdf, (Accessed 15.03/2011)
[5]http://www.avancejuridico.com/actualidad/documentosoficiales/2008/47211/r_mme_182367_2008.html, (Accessed 02/03/2011)
[6] http://www.fedebiocombustibles.com/files/182367.pdf, (Accessed 05.03.2011)
[7] http://www.acolgen.org.co/article.php?sid=1443 (Accessed 07.03.2011)
[8]http://www.fedebiocombustibles.com/files/Cifras%20Informativas%20del%20Sector%20Biocombustibles%20-%20ETANOL(20).pdf, (Accessed 10.03.2011)

[9]http://www.agronet.gov.co/agronetweb/AnalisisEstadisticas/tabid/73/Default.aspx, (Accessed 16/03/2011)

[10]http://www.agronet.gov.co/agronetweb/Búsqueda/tabid/81/Default.aspx?cx=partner-pub-1752189363943883%3Arddvua-ftff&cof=FORID%3A11&ie=ISO-88591&q=Yuca+etanol&sa=Buscar+en+Agronet&siteurl=www.agronet.gov.co%2Fagronetweb%2Finclude.htmlAgronet. Reporte de los Proyectos de Biocombustibles MADR, (Accessed 10/03/2011)

[11] Papong S, Malakul P. Life-cycle energy and environmental analysis of iotehanol production from cassava in Thailand , Biosources Technology.101,2010, S1 12-S1-18

[12] Dai, D., Hu, Z., Pu, G., Li, H., Wang, C, Energy efficiency and potentials of cassava fuel ethanol in Guangxi region of China. Energy Conversion and Management 47,2006, 1686–1699.

[13] Leng, R., Wang, C., Zhang, C., Dai, D., Pu, G.,. Life cycle inventory and energy analysis of cassava-based fuel ethanol in China. Journal of Cleaner Production 16, 2008, 374–384.

[14] Nguyen, T.L.T., Gheewala, S.H., Garivait, S. Full chain energy analysis of fuel ethanol from cassava in Thailand. Environmental Science and Technology 41, 2007, 4135–4142.

[15] http://dx.DOI.org.10.1065/lca2007.06.343 , (Accessed 25/03/2011)

[16] Nguyen, T.L.T., Gheewala, S.H., Garivait, S. Energy balance and GHG abatement cost of cassava utilization for fuel ethanol in Thailand. Energy Policy 35,2007, 4585–4596.

[17] Yu, S., Toa, Jing..Energy efficiency assessment by life cycle simulation of cassava-based fuel ethanol for automotive use in Chinese Guangxi context. Energy 34,2009, 22–31

[18] Fritshe 2008