EMERGY LIFE CYCLE ASSESSMENT OF FUEL ETHANOL IN BRAZL

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ABSTRACT

The Life Cycle Assessment (LCA) and the emergy evaluation present many common areas, like applications to determine environmental performance, to value consumed resources, among common features, like the search to determine the environmental performance and the use of resources of a given product or process. This paper presents a possible application of emergy analysis to support LCA, providing indicators to assess the resource use or resource depletion in LCA. A case study focusing the fuel ethanol life cycle, from sugar cane in Brazil, is presented. The scope of LCA is wider than traditional emergy analysis because it involves beyond the production system, it includes also the product distribution, the product use and the product after use activities. The results of the emergy life cycle assessment of fuel ethanol in Brazil indicate the Life Cycle Transformity is $2,23.10^{13}$ sej/kg, the Life Cycle Environmental Load Rate is 45,23, the Life Cycle Renewability is 2%, the Life Cycle Emergy Investment Rate is 31,77, the Life Cycle Emergy Yield Rate is 1,03 and the Life Cycle Sustainability is 0,02.

1. INTRODUCTION

With the aim of reducing environmental impacts caused by the production systems or by the anthropogenic systems, the search of sustainability must consider environmental, social and economic aspects. Thus, emergy analysis is suitable to evaluate sustainability as it incorporates all the aspects in terms of the product formation, quantified by the equivalent solar energy. Thus, it becomes an adequate form to evaluate the sustainability of products and services. Sugar cane is one of the main agricultural resources in Brazil. In 2004 this culture occupied 5,415,090 hectares of the territory [1], with an expected harvest of 395,558,195 t of cane. In Brazil, there are 3.5 million motor-vehicles powered by ethanol, and in the 2000 harvest 316 distilleries transformed 300 million ts of cane into 17.6 million t of sugar and 13 billion liters of ethanol. The State of São Paulo being produces 8.5 billion liters of alcohol [2]. Therefore, the importance of fuel alcohol for the São Paulo State is very high regarding economical and social terms. As a renewable and alternative fuel to fossil fuel, it presents great potential as an adequate environmental alternative for use in vehicles.

Some exact reasons for the assessment of the life cycle of ethanol from sugar cane are:

- Ethanol from sugar cane can substitute fossil fuel;
- Ethanol fuel can be more environmentally adequate but maybe not renewable (according emergy analysis);
- Ethanol produce a lower amount of pollutant gases during its combustion in comparison to fossil fuels;
- There is a felt need to evaluate environmental impacts of fuel alcohol life cycle.
- The electricity co-generation from its sub-products is not currently used and;
- The possibility to transform the Sugar and Alcohol Industrial Complex into a more efficient energetic system.

Emergy is founded in Systems Ecology, and it considers the energy used, direct or indirect, for the production of a new resource. This methodology has a great application to evaluate the inputs in life cycle evaluations. The objective of this work is to show

how to incorporate emergy in LCA and to present the results of Emergy Life Cycle Assessment (EmLCA) for fuel alcohol produced from sugar cane in Brazil.

2. LIFE CYCLE ASSESSMENT AND EMERGY

By definition, LCA is an evaluation process of the effects that a product, process or activity (or the function that it is projected to develop) has on the environment, considering all the life cycle of the system in question. Yet, a systematic process to assess the environmental load associated to a product, process or activity, through identification and quantification of energy consumption, used material and disposed residual in the environment, and consequently evaluate the impact coming from this energy consumption, used material and subsequent disposal in the environment, identifying and assessing environmental improvement opportunities [3]. This analysis includes the entire product, process or activity life cycle, comprehending the extraction, raw material processing, production, distribution, use, reuse, maintenance, recycling and final disposal.

Emergy considers the energy memory to produce a service or product [4]. In due course, emergy quantifies the needed energy to form a determined product or service, since the formation of natural elemental resources, based on the energy sources of the Earth: solar, deep heat internal energy and tidal energy. The emergy application on Life Cycle Assessment (LCA) is an extension of the traditional emergy evaluation, in order to include the distribution, use and waste treatment after use of the product, but up to now, the emergy assessment does not include emissions, as the traditional LCA. LCA and emergy evaluation present similarities: both give subsides for environmental evaluations; Thermodynamics guides the assessment through evaluation of energy used in product formation. They both allow comparing processes, according with environmental performance, or according resource consumption. Both contribute to a new branch of science called Industrial Ecology.

The applications of LCA that can be extended to emergy evaluations are:

- Identification of opportunities for environmental improvement;
- Assistance for decision making in industry, government and non-profit organizations in strategic planning and project development;
- Assistance in decision making by consumers;
- Offering of environmental performance indicators;
- Marketing (product comparison, certifications, labeling and declarations);
- Compare functionally between equivalent products;
- Compare projects objecting the minimization of resource consumption;
- Identify processes and materials that cause high resource consumption;
- Subsidy for regulations and laws;
- Gather environmental information.

Therefore, there is a great possibility for emergy to approximate the life cycle assessment. Based on the definition of emergy, as being emergy memory of a product or service, the application of emergy in life cycle studies is more indicated for the qualification and quantification of consumed resources during the whole life cycle of the product. To make it different from the Traditional Emergy Assessment, all the indexes of this analysis will have the denomination "life cycle" added to their names. Hence, the indexes for the life cycle will be indicated as:

- Life Cycle Transformity;
- Life Cycle Environmental Load Rate;
- Life Cycle Renewability;
- Life Cycle Emergy Investment Rate;
- Life Cycle Emergy Yield Rate
- Life Cycle Sustainability.

3. RESULTS

The fuel ethanol life cycle are divided on nine activities and presented at the figure 1:

Activity 1: Soil Preparation;
Activity 2: Sugar Cane Planting;
Activity 3: Pesticides Application;
Activity 4: Sugar Cane Harvesting;
Activity 5: Industrial Process of Alcohol;
Activity 6: Steam and Electric Energy Generation;
Activity 7: Irrigation with vinasse (subproduct);
Activity 8: Alcohol Storage and Transportation;
Activity 9: Use of Fuel Alcohol

Activity 5 is subdivided in unit operations and processes: cane milling, juice treatment, fermentation and distillation. The products from the sugar cane milling are the broth, the filter cake and the bagasse. The fermentation of broth gives alcohol; the filter cake is used as fertilizer together with vinasse. For the emergy life cycle assessment of alcohol in Brazil, some considerations were made: (a) Useful lifetime of 15 yrs for all equipment; (b) The data were collected "in loco"; (c) if the used input is a recycled internal product, it was not accounted for the life cycle total emergy, so there would not be double accounting.
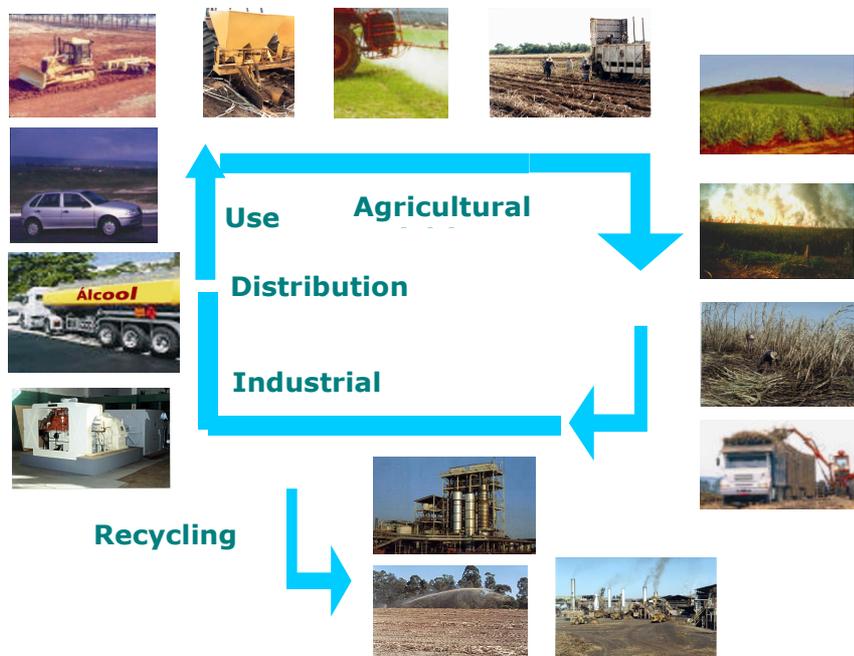
Figure 1. Fuel ethanol life cycle activities

The traditional emergy analysis usually includes only agricultural and industrial production. The EmLCA also includes the distribution, consumption and recycling activities, as shown in Figure 1. The emergy flows of ethanol complete cycle were calculated in spreadsheet shown in Table 1 (see Appendix of this paper). Through Tables 1 and 2, it can be observed that the highest emergy consumption of alcohol life cycle is due to materials, mainly by the intense use of chemicals used as pesticides and herbicides and by the consumption of diesel oil. Therefore, a decrease in the use of chemical products and fossil fuels is fundamental to improve the cycle activity efficiency. The high expenditure of water, contributed for the Renewable resources to be the second higher contribution.

Table 2. Emergy quantification of fuel alcohol life cycle resources

Resources	Emergy (sej/ha/year)	Emergy (sej/t ethanol)	Percent (%)
Renewable	$3,28.10^{15}$	$4,83.10^{14}$	2,16
Non-Renewable	$8,26.10^{14}$	$1,98.10^{14}$	0,89
Natural Resources	$4,10.10^{15}$	$6,81.10^{14}$	3,05
Materials	$4,41.10^{16}$	$2,16.10^{16}$	96,85
Services	$1,25.10^{14}$	$2,32.10^{13}$	0,10
Economical	$4,42.10^{16}$	$2,16.10^{16}$	96,95
Total	$4,83.10^{16}$	$2,23.10^{16}$	100

A great amount of sugar cane (15.6 t) is used for the production of 1 t of alcohol. The results from LCA emergy indices for 1 t of ethanol are shown in Table 3. The words "Life Cycle" were used to differentiate indices of emergy LC analysis from those of traditional emergy analysis.

Table 3. Fuel alcohol life cycle resource emergy

Indices	Value	Unit
Life Cycle Transformity	$2,23.10^{13}$	sej/kg
Life Cycle Environmental Load Rate	45,23	-
Life Cycle Renewability	2,0	%
Life Cycle Emergy Investment Rate	31,77	-
Life Cycle Emergy Yield Rate	1,03	-
Life Cycle Sustainability	0,02	-

1) Life Cycle Transformity: The value of $2.23x10^{13}$ sej/kg found for life cycle alcohol transformity is higher than alcohol transformity ($6.7x10^{12}$ sej/kg), due to inclusion of more steps in the chain of activities.

2) Life Cycle Environmental Load Rate: The environmental load rate found is 45, which is considered extremely high due to the large quantity of pesticides used and the high emergy value of cars.

3) Life Cycle Renewability: The cycle's renewability is only 2%, indicating that despite alcohol being considered a renewable fuel, its life cycle is extremely dependent on non-renewable inputs from the economy, because of the large use of agro-chemicals, fossil fuels and steel machinery.

4) Life cycle emergy investment rate: Alcohol life cycle emergy investment rate is almost 32, demonstrating that the emergy inputs coming from economy are 32 times bigger than resources from nature, due to high consumption of agro-chemicals, fossil fuels and steel machinery.

5) Life Cycle Emergy Yield Rate: The yield of 1.03 means that ethanol life cycle adsorbs almost all solar energy captured.

6) Life cycle sustainability: The index of 0.02 was found, meaning that the non renewable energy demand is much bigger than the natural renewable emergy income. Consequently, many improvements must be carried out to increase cycle's sustainability, such as the reduction of chemicals and fossil fuel use.

The results of the emergy assessment of fuel alcohol life cycle are in Table 2 and 4. Table 4 compares the emergy index values of alcohol life cycle with its own agro industrial production. This comparison shows a great difference between the results of both analyses, because when we are assessing products, we must always assess them by their total life cycle and not only by their productive process. The sustainability index is just a indication of the resource consumption sustainability based on emergy analysis and does not include all aspects that would be necessary for a whole sustainability analysis as cultural, spatial, emissions impacts aspects and others.

Table 4. Comparison of fuel alcohol production indexes to fuel alcohol life cycle

Indices	Production (1t. of ethanol)	Life Cycle (1t. of ethanol)
Life Cycle Transformity	$6,7 . 10^{12}$ sej/kg	$2,23.10^{13}$
Life Cycle Environmental Load Rate	2,46	45,23
Life Cycle Renewability	29%	2%
Life Cycle Emergy Investment Rate	2,42	31,77
Life Cycle Emergy Yield Rate	1,41	1,03
Life Cycle Sustainability	0,57	0,02

4. CONCLUSIONS

Traditionally, emergy is applied to the productive process of a good or service, thus not assessing for all its life cycle. This work shows that emergy assessment can be applied to LCA, specifically to account for life cycle assumes of the all activities of the product life cycle. In the case of fuel alcohol, to increase sustainability, a lower use of agro-toxics, substitution of fossil fuel used in agricultural equipment and in transport for fuel alcohol, decrease the use of agricultural machinery, incorporation of green areas and better social conditions are all indicated. To assess a determined product, the indexes of emery life cycle assessment of products strongly differ from the one for the productive process assessment, including all activities of the product life cycle, since the raw material extraction until the product use and after use activities. Therefore, the emergy life cycle assessment is indicated as a way to assess the resource consumption during the whole life cycle of products and services.

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APPENDIX

Memorial of calculations of the emergy spreadsheet.
The numbers in front of the presented resources agree to the ones presented in the emergy spreadsheet (Table 1). The calculus memorial for all the analyzed inputs is represented by the first activity where it was used.

1. Rain Water
Rain: 1500 mm/m^2/year (www.fea.unicamp.br)
Gibbs free energy for water: 4,940 J/kg, [4] Rain water transformity: 1.83 x10^4 sej/J, [4]
Energy = 1.5m^3 / m$^{2.}$ year * 10,000 m^2/ha * 1,000 kg/m^3 * 4,940 J/kg = 7.42x10^{10} J/ha/year.
Emergy = Energy * Transformity = 7.42x10^{10} J/ha/year * 1.83x10^4 sej/J = 1.35x10^{15} sej/ha/year

2. Soil Loss
According to [5], the soil loss for all agricultural activities for the culture of sugar cane is around 12.4 t/ha/year and the quantity of calorie contained in 1 kg is around 216 cal.
Soil Transformity = 7.38 E04 sej/J.
So: Energy =12.4 t/ha/year * 216 cal * 4186 Joules/cal = 1.12x10^{10} J/ha/year.
Emergy = Energy * Transformity = 1.12x10^{10} J/ha/year * 7.38x10^4 sej/J = 8.26x10^{14} sej/ha/year.

3. Fuels
The emergy calculus memorial for fossil fuels, in this case diesel oil, is presented, next, for activity 1. For further activities that use diesel oil, the calculus form is the same, changing the amount of used fuel.
For activity 1, the used amount of diesel oil is 3.98 kg/t. Diesel oil transformity, according to [4] is of 6.6x10^4 sej/J and its calorific power, according to [5], is of 27,570 kJ/kg. So:
Diesel oil Emergy = 3.98 * 27,570,000 * 6.6x10^4 = 7.25x10^{12} sej/t alcohol.

4. Pesticides or Chemicals
The pesticides use at activity 1 is 0.1 kg/t of alcohol. The transformity of the chemical products is of 4.1x10^{14} sej/kg, [4].
Thus: Pesticides Emergy = 0.1 kg/ t alcohol x 4.10.10^{14} sej/kg = 3.64.10^{13} sej/t alcohol.

5. Fertilizers and Liming or auxiliaries inputs
The amount of fertilizers, liming and other auxiliaries inputs used in each activity of the life cycle is specified in the table 02, but the transformity value to calculate their emergy is the same. 96 kg lime is used for each ton of alcohol. The transformity of the chemical products is of 3.8 x10^{12} sej/kg, [4]. Therefore: Lime Emergy = 96 kg/t alcohol * 3.80 x10^{12} = 3.65x10^{14} sej/t alcohol.

6. Equipment
The calculations regarding equipment were obtained from their mass and the respective transformity.
For the soil preparation, the primary data are:
   - Equipment mass per hectare = 1.33 kg/ha/year,
   - Life cycle of used equipment = 15 yrs.
   - Equipment transformity = 6.7x10^{12} sej/kg, [5];
   - Corresponding area for activity 1: 0.048ha.

Hence, Equipment emergy = 1.33 Kg/ha/year/15 years * 6.7 $\times 10^{12}$ sej/kg = 8.9×10^{12} sej/ha/year.

7. Manual Labor

The number of working people is considered, for each activity, according to the inventory analysis results. For the conventional preparation of soil, there is:
- Relative number of employees for 1 t of alcohol = 0.003 people
- Daily work hours = 8 hours;
- Work days per year = 120 days;
- Daily employee energetic consumption = 3200 Calories, [4];
- Conversion factor = 1 cal is equal to 4186 Joule [6];
- Employee Transformity = 4.0010^5 sej/J, for Brazil in 1998 [8];

Therefore, Energy = 0.003*8/24*120*3200*4186 = 1.47×10^5 J/t alcohol

Emergy = Energy * Transformity = 5.88×10^{10} sej/t alcohol

8. Sugar Cane

The amount of sugar cane that would be planted, considering that the activity is running, it is at 0,048ha, which corresponds at 672kg.

Sugar cane transformity was calculated by the interactive method in the emergy spreadsheet according to the following:

Sugar Cane Transformity = Total emergy of the agricultural part for 1 t of alcohol / 15,720 kg of sugar cane/t alcohol

Consequently: Sugar Cane Transformity = 1.78×10^{15} sej/t alcohol / 15,720 kg/t alcohol = 1.13×10^{11} sej/kg.

Then, Sugar cane Emergy = Mass * Transformity = 672 kg cane/t alcohol * 1.13×10^{11} sej/kg = 7.59×10^{13} sej/t alcohol.

21. Buildings

The facilities used for all agricultural activities were accounted at the harvesting activity. The size of buildings were obtained by primary data from the autonomous distillery averages visited in the region of Ribeirão Preto, SP – Brazil. The data below from [4] is from. Data:

Constructed Area = 4100 m^2 Construction Cost = R$ 700.00 / m^2, [7]

"Emergy Money Ratio" = 4.82×10^{12} sej/dollar, for Brazil in 1995 [8].

Exchange Rate: 1US$ = R$ 3.00, 07/03/2004

Agricultural area size = 22,000 hectares

Period: 15 yrs

Cost in dollar per hectare and per year = (4,100 * 700/3) / (35,000 *15) = 1.8 US$/ha,

Emergy = Cost * "Emergy Money Ratio" = 1.8 US$/ha.* 4.82×10^{12} sej/dollar = 8.78×10^{12} sej/ha.

23. Specialized Manual Labor

The number of people working in specialized manual labor is considered according to the inventory analysis results. The technical professionals from the agricultural area were moved to the sugar cane harvesting. Therefore, we have:
- Relative number of employees for 1 t of alcohol = 0.0005 people
- Daily work hours = 8 hours;
- Work days per year = 315 days;
- Daily employee energetic consumption = 2,500 Calories, [4];
- Conversion factor = 1 cal is equal to 4186 Joule [6];
- Specialized employee transformity = 4.0×10^6 sej/J, for Brazil in 1998 [8];

Thus, Energy = 0.0005*8/24*315*2500*4186 = 5.99×10^5 J/t alcohol

Emergy = Energy * Transformity = 5.99×10^5 J/t alcohol * 4.0×10^6 sej/J = 2.4×10^{12} sej/t alcohol

24. Water

According to [4], Gibbs free energy for water is 4,940 J/kg and its transformity is of 110 000 sej/J. Since 1.29×10^5 kg per t of alcohol is used, its emergy is equal to: 1.29×10^5 kg /t alcohol * 4,940 J/kg * 110 000 sej/J = 7.02×10^{13} sej/t alcohol.

44. Automobile

The emergy of a vehicle was calculated by [9] and its value is of 1.54×10^{16} sej/year.

Table 1: Emergy spreadsheet of fuel alcohol life cycle

Notes	Activity 1- Conventional preparation of the soil	Flow Value	Flow (Standard) Units	Energy Mass or Money flows	Unit	Transformity sej/J or sej/kg	Emergy Flow sej/ha/year	Emergy Flow Sej/t Alcohol
	Renewable Resources						**1.35E+15**	**3.25E+14**
1	Rain Water	1.5	m³/m².year	7.41E+10	J/ha/year	1.83E+04	1.35E+15	3.25E+14
	Non-renewable Resources						**8.26E+14**	**1.98E+14**
2	Soil loss	12.4	t/ha/year	1.12E+10	J/ha/year	7.38E+04	8.26E+14	1.98E+14
	Materials						**9.18E+14**	**4.40E+13**
3	Fuels	3.98	kg/t alcohol	1.10E+08	J /t alcohol	6.60E+04	1.51E+14	7.25E+12
4	Pesticides	0.1	kg/t alcohol	0.09	kg/t alcohol	4.10E+14	7.58E+14	3.64E+13
5	Liming	96.0	kg/t alcohol	96.00	kg/t alcohol	3.80E+15	7.60E+15	3.65E+14
6	Equipment	1.3	kg/ha/year	1.3	kg/ha/year	6.70E+12	8.90E+12	4.27E+11
	Services						**1.22E+12**	**1.13E+10**
7	Manual Labor	0.000274	person/t alcohol	1.47E+05	J /t alcohol	4.00E+05	1.22E+12	5.88E+10
	Activity 1 emergy						**3.10E+15**	**5,67E+14**
	Activity 2 – Sugar cane Planting							
	Renewable Resources						**1.58E+15**	**7.59E+13**
8	Sugar Cane	6.72E+02	kg/t. alcohol	6.72E+02	Kg/t. Alcohol	1.13	1.58E+15	7.59E+13
	Materials						**2.64E+15**	**1.27E+14**
9	Fuels	3.24	kg/t. Alcohol	8.94E+07	J /t. Alcohol	6.60E+04	1.23E+14	5.90E+12
10	Pesticides	0.2	kg/t. Alcohol	0.15	kg/t. Alcohol	4.10E+14	1.31E+15	6.30E+13
11	Fertilizers and Liming	15.1	kg/t. Alcohol	15.12	kg/t. Alcohol	3.80E+12	1.20E+15	5.75E+13
12	Equipment	1.5	kg/ha/year	1.5	kg/ha/year	6.70E+12	1.01E+13	4.85E+11
	Services						**1.71E+13**	**8.23E+11**
13	Manual Labor	0.004	person/t. alcohol	2.06E+06	J /t. alcohol	4.00E+05	1.71E+13	8.23E+11
	Activity 2 emergy						**4.3E+15**	**2.04E+14**

Notes	Activity 3 – Pesticides Application	Flow Value	Standard Units	Energy flow mass or money	Unit	Transformity sej/J or sej/kg	Energy Flow sej/ha/year	Emergy Flow Sej/t Alcohol
	Materials						**3.77E+15**	**9.05E+14**
14	Fuels	2.28	kg/t. Alcohol	6.30E+07	J /t. Alcohol	6.60E+04	1.73E+13	**4.15E+12**
15	Pesticides	0.8	kg/t. Alcohol	0,82	kg/t. Alcohol	4.10E+14	1.4E+15	**3.36+E14**
16	Fertilizers and Liming	148.3	kg/t. Alcohol	148.32	kg/t. Alcohol	3.80E+12	2.35E+15	**5.64E+14**
17	Equipment	0.3	kg/ha/year	0.3	kg/ha/year	6.70E+12	2.14E+12	**5.15E+11**
	Services						**6.43E+12**	**1.54E+12**
18	Manual Labor	0.007	person/t. alcohol	3.86E+06	J /t. alcohol	4.00E+05	6.43E+12	**1.54E+12**
	Activity 3 emergy						**3.8E+15**	**9.08E+14**
	Activity 4 – Harvest							
	Materials						**3.54E+14**	**8.49E+13**
19	Fuels	31	kg/t. alcohol	8.64E+08	J /t. alcohol	6.60E+04	2.38E+14	**5.70E+13**
20	Equipment	16.0	kg/ha/year	16.0	kg/ha/year	6.70E+12	1.07E+14	**2.57E+13**
21	Building	1.8	US$/ha/year	1.8	US$/ha/year	4.82E+12	8.78E+12	**2.11E+12**
	Services						**2.9E+13**	**7.03E+13**
22	Manual Labor	0.090	Person/ha/year	4.83E+07	J /ha/year	4.00E+05	1.93E+13	**4.63E+12**
23	Specialized Manual Labor	0.0005	person/t alcohol	5.99E+05	J /t. alcohol	4.00E+06	9.99E+12	**2.40E+12**
	Activity 4 emergy						**3.8E+14**	**9.19E+13**
	TOTAL EMERGY OF THE AGRICULTURAL PART						**1.15E+16**	**1.77E+15**

Activity 5 –Industrial Production of Alcohol			Energy Flow, Mass or money	Unit	Transformity	Emergy Flow	Emergy Flow Sej/t
Notes	Flow Value	Standard Units			sej/unit	sej/ha/year	Alcohol
Renewable Resources						**2.93E+14**	**7.02E+13**
24 Water	1.29E+05	kg/t. alcohol	6.38E+08	J /ha/year	1.10E+05	2.93E+14	**7.02E+13**
Materials						**2.03E+16**	**4.87E+15**
25 Chemicals	11.68	kg/t. alcohol	11.68	kg/t. alcohol	4.10E+14	2.00E+16	**4.79E+15**
26 Other inputs	1.28E-01	kg/t. alcohol	0.13	kg/t. alcohol	3.80E+12	2.03E+12	**4.86E+11**
27 Equipment	1.6	kg/ha/year	1.6	kg/ha/year	6.70E+12	1.07E+13	**2.57E+12**
28 Buildings	65.9	US$/ha/year	65.9	US$/ha/year	4.82E+12	3.18E+14	**7.63E+13**
Service						**7.2E+12**	**1.73E+12**
29 Manual Labor	0.004	person/ha/year	2.30E+06	J /ha/year	4.00E+05	9.19E+12	**2.20E+11**
30 Specialized Manual Labor	0.001	person/ha/year	1.57E+06	J /ha/year	4,00E+06	6.28E+12	**1.51E+12**
Activity 5 emergy						**2.10E+16**	**4.94E+15**
CYCLE EMERGY UP TO ALCOHOL PRODUCTION						**3.21E+16**	**6,71E+15**
Activity 6 – Energy Generation							
Renewable Resources						4.92E+13	**1.18E+12**
31 Water	21725	kg/t. alcohol	1.07E+08	J /t. alcohol	1.10E+05	4.92E+13	**1.18E+12**
Materials						**8.62E+13**	**2.07E+13**
32 Equipment	3.3	kg/ha/year	3.3	kg/ha/year	6.70E+12	2.20E+13	**5.27E+12**
33 Buildings	13.3	US$/ha/year	13.3	US$/ha/year	4.82E+12	6.43E+13	**1.54E+13**
Service						**2.94E+12**	**7.06E+11**
34 Manual Labor	0.002	person/ha/year	1.07E+06	J /ha/year	4.00E+05	4.29E+11	**1.03E+11**
35 Specialized Manual Labor	0.0006	person/ha/year	6.28E+05	J /ha/year	4.00E+06	2.51E+12	**6.03E+11**
Activity 6 emergy						**1.4E+14**	**3.32E+13**
CYCLE EMERGY UP TO COGENERATION						**3.2E+16**	**6.74E+15**

Notes	Flow Value	Standard Units	Energy Flow, Mass or money	Unit	Transformity sej/unit	Emergy Flow sej/ha/year	Emergy Flow Sej/t Alcohol
Activity 7 - Recycling – Irrigation with Sub-Products							
Renewable Resources						**4.09E+11**	**9.83E+10**
36 Water	180.82	kg/t. alcohol	8.93E+05	J /ha/year	1.10E+05	4.09E+11	**9.83 E+10**
Materials						**7.33E+14**	**1.76E+14**
37 Fuels	6	l/t. alcohol	1.29E+08	J /ha/year	6.60E+04	3.54E+13	**8.51E+12**
38 Fertilizers and Liming	42.3	kg/t. alcohol	42.34	kg/ha/year	3.80E+12	6.70E+14	**1.61E+14**
39 Equipment	4.0	kg/ha/year	4.0	kg/ha/year	6.70E+12	2.70E+13	**6.47E+12**
Service						**3.06E+11**	**7.35E+10**
40 Manual Labor	0.001	person/ha/year	7.65E+05	J /ha/year	4.00E+05	3.06E+11	**7.35E+10**
Activity 7 emergy						**7.3E+14**	**1.76E+14**
CYCLE EMERGY UP TO IRRIGATION WITH SUB-PRODUCTS						**3.30E+16**	**6.92E+15**
Activity 8 - Distribution							
Materials						**1.01E+13**	**2.43E+12**
41 Fuels	2	l/t. alcohol	3.66E+07	J /ha/year	6.60E+04	1.01E+13	**2.42E+12**
42 Equipment	0.006	Kg/ha/year	0.0	kg/ha/year	6.70E+12	3.95E+10	**9.48E+09**
Service						**6.12E+11**	**1.47E+11**
43 Manual Labor	0.003	Person/ha/year	1.53E+06	J /ha/year	4.00E+05	6.12E+11	**1.47E+11**
Activity 8 emergy						**1.1E+13**	**2.57E+12**
Total Emergy (up to storage)						**3.30E+16**	**6.92E+15**
Activity 9 – Ethanol use							
Material						**1.54E+16**	**1.54E+16**
4 Car	*					1.54E+16	**1.54E+16**
Activity 9 emergy						**1.54E+16**	**1.54E+16**
TOTAL EMERGY OF FUEL ETHANOL						**4.8E+16**	**2.23E+16**