EMERGY SYNTHESIS:
Theory and Applications of the Emergy Methodology

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Emergy Analysis And Trends For Ethanol Production In Brazil

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ABSTRACT

The sugarcane industry has always been an important economic activity in Brazil. This agro-industry showed its major growth during the last three decades due to the establishment in 1975 of the National Program for Alcohol Production to face the world energy crisis. This industry has produced great environmental damage and nowadays, is still generating problems, but new technologies with a different kind of social and ecological impact may establish a new outlook. On the other hand, the international market prices for raw materials and fossil oil are putting this activity under siege. This research presents the emergy analysis of a typical alcohol distillery - sugarcane plantation system in the State of São Paulo and identifies tendencies that will affect this industry. Emergy indices obtained for ethanol production are Transformity=2,000,000 sej/J, Renewability=14%, Emergy Yield Ratio=1.21, Emergy Investment Ratio=4.72, Environmental Loading Ratio=8.21 and the Emergy Exchange Ratio=3.17.

INTRODUCTION

The State of São Paulo produces 200 x 10^6 tons of sugarcane on 2.5 x10^6 ha (33% of its arable land). The value corresponds to 50% of Brazil's sugarcane production, generating jobs for 3 millions inhabitants. The sugarcane industry has been responsible for several negative environmental impacts, such as destruction of native forests, loss of rural production diversity and the release of effluents into rivers. Nowadays the environmental load is aggravated by a set of problems such as soil erosion, pollution of soils and aquifers with pesticides, air pollution resulting from the burning process during sugarcane harvesting, destruction of the remaining biodiversity, elimination of the small and medium agriculture farms, human exodus from rural areas, etc. The purpose of this study is to make an emergy analysis of the sugar and ethanol industry in the State of São Paulo and to provide ideas on the possible trends that will affect distilleries in the future.

MATERIAL AND METHODS

The factory studied is located in the best area for sugar cane production in the North East of São Paulo State. It uses, on a yearly basis, 1.87 x 10^6 tons of sugar cane obtained from 25,490 ha of plantation lands. Its milling capacity is close to 10,000 tons of cane/day. The production ratios are 32.2 liters of ethanol / ton of cane, 92.05 kg of sugar / ton of cane. The extraction efficiency is near to 99% due to the use of 6 mills and intense watering in the milling process. The alcohol produced is concentrated up to 99.5 %. The factory uses the bagasse for electric power generation fulfilling all its needs, with no surplus for local sale. By-products such as filter cake and vinasse are used as fertilizers, diminishing the use of synthetic chemical fertilizers.

Brief Explanation of Emergy Indices

Transformity (Tr=Y/Qp): the ratio obtained dividing the total of emergy, of one type, required to make a product (Y) by the energy of one kind contained in the product (Qp).

Emergy Yield Ratio (EYR=Y/F): measures the ecosystem contribution to the economy. It is calculated dividing the total emergy used (Y) by the emergy of Feedback from economy (F).

Emergy Investment Ratio (EIR=F/I)): measures the intensity of the economic development. It is calculated dividing the economic Feedback emergy (F) by the environment emergy (I).

Environmental Loading Ratio (ELR=(N+F)/R): measures the environmental impact. It is calculated by dividing the sum of non-renewable resources (free and purchased) by the renewable resources emergy.

Emergy Exchange Ratio (EER= Y/[$.(sej/$)]): is calculated dividing the solar emergy flow of product (Y) by the solar emergy of the money received (sej/$) in the sale of product ($).

Renewability (%R=100*R/Y): shows the ratio of renewable resources to total resources used, considering both flows in terms of emergy.

RESULTS

The emergy analysis of the alcohol production begins with a description of the system. The data of a typical distillery were obtained from farmers and the production process is showed in Figures 1 and 2. The second step is to obtain the emergy flows. Table 1 shows the energy, material and monetary flows, the use of transformities for the conversion of units and finally the emergy flows. The data is arranged according to its characteristics: nature contributions, materials and services from economy. The third step is to calculate emergy indices and to evaluate ethanol production according with methodology (Odum, 1996). Table 2 shows some indices of production and Table 3 shows emergy indices.

The following trends were identified:

(a) New environmental laws were emitted to eliminate pre-harvest burning of sugarcane plantations. As a result, mechanical harvesting was introduced and people become unemployed;

(b) The use of sugarcane by-products (vinasse and some others) in sugarcane plantations;

(c) Difficulties in establishing new industrial processes to use sugarcane or its by-products;

(d) Discovery of nitrogen fixation in sugarcane;

(e) Adoption of SIG and GPS techniques on some farms;

(f) An international scenario presenting great oscillations concerning prices of sugarcane, ethanol and fossil oil;

(g) International regulations for production, commercialization and quality certification;

(h) Adoption of organic production technologies;

(i) Agrarian reform.

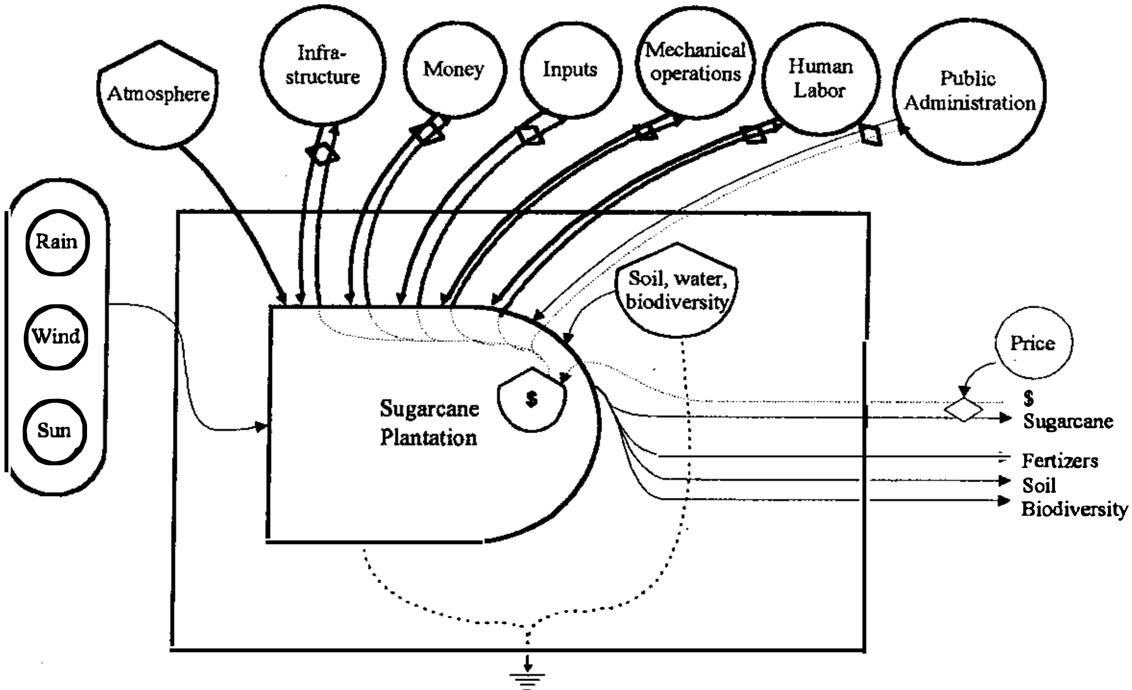

Figure 1. *Energy flow diagram for sugarcane production*

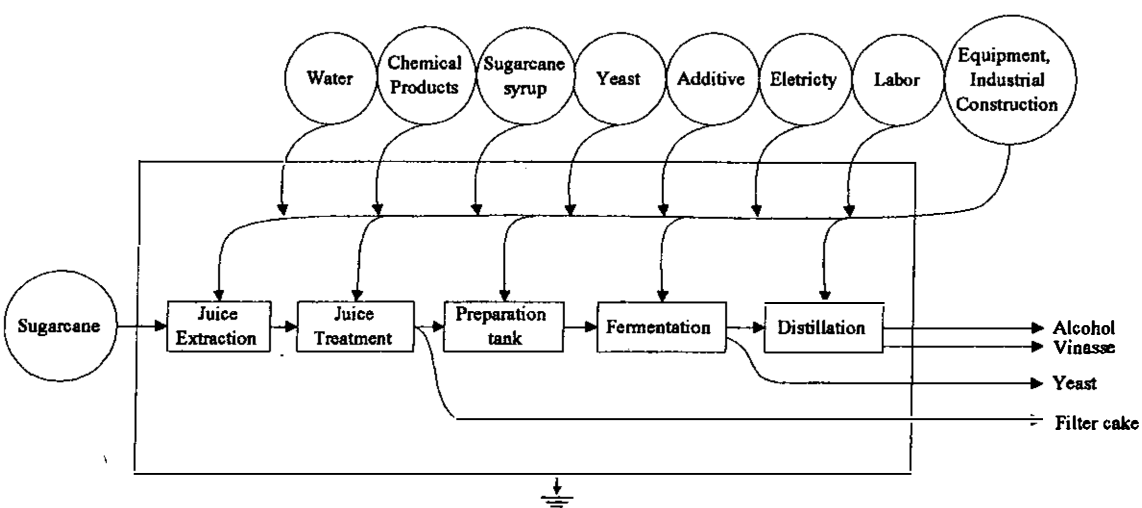

Figure 2. *Energy flow diagram for alcohol production*

Table 1. Emergy analysis of ethanol production from sugarcane

Notes		energy (J/ha.y) mass (kg/ha.y) money ($/ha.y)		Transformity	Emergy Flows sej/ha.y	%
	Natural Resources				**2,18E+15**	**17,49**
	Renewable				**1,36E+15**	
1	Rain	7.41E+10	J/ha.y	1.83E+04	1.35E+15	**10,8**
2	Water	3.34E+08	J /ha.y	1.10E+05	3.67E+12	**0,0**
	Nou-Renewable					
3	Soil loss	1.12E+10	J/ha.y	7.38E+04	8.27E+14	**6,6**
	Total Economy Resources				**9.21E+15**	**73,82**
		Agricultural production				
	Materials				**6.85E+15**	**54,86**
4	Seedlings	270.00	$/ha.y	3.70E+12	9.99E+14	**8,0**
5	Lime	200	kg/ha.y	1.00E+12	2.00E+14	**1,6**
6	Herbicide	4.30	kg/ha.y	8.24E+14	3.54E+15	**28,4**
7	Fertilizers	421	kg/ha.y	3.80E+12	1.60E+15	**12,8**
8	Fuels	7.67E+09	J /ha.y	6.60E+04	5.06E+14	**4,1**
	Services				**2.4E+15**	**18,96**
9	Manual Operation	3.09E+08	J /ha.y	1.00E+05	3.09E+13	**0,2**
10	Mechanical Operation	3.42E+08	J /ha.y	5.00E+06	1.71E+15	**13,7**
11	Administration	12.00	$/ha.y	1.00E+07	1.20E+08	**0,0**
12	Depreciation	78.00	$/ha.y	3.70E+12	2.89E+14	**2,3**
13	Taxes	91.60	$/ha.y	3.70E+12	3.39E+14	**2,7**
		Industrial production				
	Materials				**1.1E+15**	**8,7**
14	Chemical Products	66.35	kg/ha.y	3.80E+12	2.52E+14	**2,0**
15	Electricity	2.50E+08	J /ha.y	6.72E+04	1.68E+13	**0,1**
16	Equipment	7.75	kg/ha.y	1.80E+12	1.40E+13	**0,1**
17	Industrial Construction	217.0	$/ha.y	3.70E+12	8.03E+14	**6,4**
	Services				**1.17E+10**	**0.0**
18	Labor	2.43E+04	J /ha.y	5.00E+05	1.17E+10	**0.0**
	Total Emergy				**1.2E+16**	**100**

Agricultural Production	
Sugarcane produced	1,358,000 t/y
Sugarcane purchased form external growers	513,000 t/y
Total sugarcane used	1,871,000 t/y
Total area of sugarcane	25,490 ha
Sugarcane productivity	73.5 t/ha.y
Price	14.5 $/t

Footnotes can be found at end of chapter

Table 2: Emergy indices for ethanol production in São Paulo, Brazil.

	Total quantity	Industrial Production Conversion	Quantity produced per ton of sugar-cane
Sugar	2.87 e06 sacs	(2.87 e06/1871000) x 60	92.05 kg
Alcohol	7.51 e07 liters	(7.51 e07/1871000)	32.12 kg
Bagasse	5.41 e08 kg	(5.41 e08/1871000)	289.28 kg
Vinasse	9.02 e08 liters	(9.02 e08/1871000)	481.84 kg
Filter cake	7.71 e07 kg	(7.71 e07/1871000)	41.19 kg
Ash	7.87 e05 kg	(7.87 e05/1871000)	0.42 kg
Sludge	3.93 e08 kg	(3.93 e08/1871000)	209.89 kg
Electricity	2.17 e07 kWh	(2.17 e07/1871000)	11.59 kWh
Steam	1.19 e09 kg	(1.19 e09/1871000)	636.41 kg

Table 3: Table of emergy indices

R	1.36E+15	Tr = Y/Qp	2.0E+06	Transformity
N	8.27E+14	EYR = Y/F	1.21	Emergy Yield Ratio
I	**2.18E+15**	EIR=F/I	4.72	Emergy Investment Ratio
M	7.93E+15	ELR=(N+F)/R	8.21	Environment Loading Ratio
S	2.37E+15	%R = R/Y	0.11	Renewability (%)
F	**1.03E+16**	EER=Eprod/E$	3.17	Emergy Exchange Ratio
Y	**1.25E+16**	ESI = EYR/ELR	0.26	Emergy Sustainability

DISCUSSION

The Transformity obtained for ethanol (2,000,000 sej/J) shows a relatively low value due to the great efficiency of sugarcane in capturing solar energy.

The Emergy Yield Ratio (1.21) shows that ethanol production from sugarcane fixes solar energy; therefore, it can be considered as an energy crop, not being, however, as efficient as a forest (2.0).

The Emergy Investment Ratio (4.72) is similar to the average values of agriculture products (3.0-7.0) but lower when compared to urban industrial values.

The low value for renewability (0.11) indicates that this system uses greater amounts of non-renewable resources in comparison to nature's renewable resources.

The Emergy Exchange Ratio of 3.17 shows that the sugarcane agricultural system delivers to urban consumers much more energy than it receives from them.

The Environment Loading Ratio (8.21) and Emergy Sustainability Index (0.26) show intermediate values.

The next step will be the preparation of emergy tables with new values for the inputs and outputs, corresponding to each trend detected, and also the discussion of the emergy indices changes.

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Table 1 Footnotes: Calculations for Emergy Analysis

Year: 1999 Emergy/dollar = 3.7 E 12 sej/dollar

Notes	Item	Flow	CONVERSION	Total	Unit
			Agricultural production natural resources		
Renewable resources					
1	Rain	1,5 m3/m2.ha.y	1000*10000*4940	7.41E+10	J/ha.y
2	Water	1700000 m3	1700000 m³/t. cane x 73.5 t/ha x 1000 x 5000 18710000 t sugarcane x 1 ha	3.34E+07	J/ha.y
Non-renewable Resources					
3	Soil loss	12.4 t/ ha.y	1000*0.04*5400*4186	1.12 E+10	J/ha.y
Agricultural materials from Economy					
4	Seeding	12 t/ha.y	12t x $22.5t	**270**	$/ha.y
5	Lime	3700 t/ha.y	(3700/18500)*1000kg	**200**	kg/ha.y
6	Herbicide			**4.29**	kg/ha.y
	Roundup	1.56 l/ha.y	1.56 l x 0.75 kg ha.y 1 liter	1.17	kg/ha.y
	Perflom	0.12 kg/ha.y		0.12	kg/ha.y
	Gamit	0.11 l/ha.y	0.11 l x 0.75 kg ha.y 1 liter	0.08	kg/ha.y
	Velpar	0.58 kg/ha.y		0.58	kg/ha.y
	Gesepar	2.73 l/ha.y	2.73 l x 0.75 kg ha.y 1 liter	2.05	kg/ha.y
	Agritin	0.39 l/ha.y	0.39 l x 0.75 kg ha.y 1 liter	0.29	kg/ha.y
7	Fertilizer			**421.00**	kg/ha.y
	8.25.25	0.087 t /ha.y	0.087 t x 1000 kg	87.00	kg/ha.y
	12.00.36	0.0984 t/ha.y	0.0984 t x 1000 kg	98.40	kg/ha.y
	8.8.32	0.068 t/ha.y	0.068 t x 1000 kg	68.00	kg/ha.y
	18.05.27	0.0908 t/ha.y	0.0908 t x 1000 kg	90.80	kg/ha.y
	17.05.24	0.0768 t/ha.y	0.0768 t x 1000 kg	76.80	kg/ha.y
8	Fuels			**7.67E+9**	J /ha.y
	Transport of inputs	120 l/ha.y	120 l x 0.7 kg x 10000 kcal x 4186 J ha.y 1 liter kg 1kcal	3.52E+9	J /ha.y
	Sugarcane transport	46.4 l/ha.y	46.4 l x 0.7 kg x 10000 kcal x 4186 J ha.y 1 liter kg 1kcal	1.36E+9	J /ha.y
	Field Operations	95.35 l/ha.y	95.35 l x 0.7 kg x 10000 kcal x 4186 J ha.y 1 liter kg 1kcal	2.79E+9	J /ha.y
Services from Economy					
9	Manual Operations	0.024 ind./ha.y	0.024 p. x 8h x 120 days x 3200 kcal x 4186 J ha p. year day 1 kcal	**3.09E+8**	J /ha.y
10	Mechanical. Operations	0.034 ind./ha.y	0.034 p. X 8h x 120 days x 2500 kcal x 4186 J ha p. Year day 1 kcal	**3.42E+8**	J /ha.y
11	Administration	12 $/ha.y		12	$/ha.y
12	Depreciation	78 $/ha.y		78	$/ha.y
13	Taxes	91 $/ha.y		91	$/ha.y
Industrial production					
14	Chemicals			**66.35**	kg/ha.y

	Sulfuric Acid	8252731	8252731 x 73.5 t cane x 1.83 / 1871000 t cane 1 ha	59.33	kg/ha.y
	C_6H_{12}	90100 l	90100 l x 73.5 t Ana x 0.779 / 1871000 t cane 1 ha	2.76	kg/ha.y
	Sodium Hydroxide	56000 kg	56000 l x 73.5 t cane / 1871000 t cane 1 ha	2.20	kg/ha.y
	Lubricants	70213 l	70213 l x 73.5 t cane x 0.75 / 1871000 t cane 1 ha	2.07	kg/ha.y
15	Electricity Produced			**2.48E+08**	
	kWh	21682042 kWh	21682042 kWh x 73.5 t cane x 1000 x 60 x 60 / 1871000 t sugarcane 1 ha	3.07E+09	kWh/ha.y
Purchased					
	kWh	1750505 kWh	1750505 kWh x 73.5 t cane x 1000 x 60 x 60 / 1871000 t sugarcane 1 ha	2.48E+08	kWh/ha.y
16	Equipment			7.75	kg/ha.y
	Sugarcane processing track	0.44 kg		0.44	kg/ha.y
	Bagasse processing track	1.76 kg		1.76	kg/ha.y
	Washing equipment	0.41 kg		0.41	kg/ha.y
	Millstone	1.07 kg		1.07	kg/ha.y
	Steam turbine	0.24 kg		0.24	kg/ha.y
	Boiler	1.51 kg		1.51	kg/ha.y
	Distillery Stainless Steel	0.37 kg		0.37	kg/ha.y
	Distillery Steel	1.95 kg		1.95	kg/ha.y
17	Industrial Construction				
	Industrial Construction	10800 m²		217.00	$/ha.y
	Industrial Building	5000 m²	5000 m² / 18500 ha x R$ 200 / (m² x $ 1.82)	100.54	$/ha.y
	Offices	300 m²	300 m²/ 18500 ha x R$ 200 / (m² x $ 1.82)	6.03	$/ha.y
	Factory and laboratory	1500 m²	1500 m² / 18500 ha x R$ 200 / (m² x $ 1.82)	30.16	$/ha.y
	Tank	4000 m²	4000 m² / 18500 ha x R$ 200 / (m² x $ 1.82)	80.43	$/ha.y
18	Labor	355	355 ind. x 75 t cane x 1/8 x 3200 x 4186 / 1871000 t sugarcane 1 ha	2.41E+05	pers/ha.y