EMERGY SYNTHESIS 2:
Theory and Applications of the Emergy Methodology

Proceedings from the Second Biennial Emergy Analysis Research Conference, Gainesville, Florida, September, 2001.

Edited by
Mark T. Brown
University of Florida
Gainesville, Florida

Associate Editors
Howard T. Odum
University of Florida
Gainesville, Florida

David Tilley
University of Maryland
College Park, Maryland

Sergio Ulgiati
University of Siena
Siena, Italy

December 2003

The Center for Environmental Policy
Department of Environmental Engineering Sciences
University of Florida
Gainesville, FL

The Center for Environmental Policy
P.O. Box 116450

21

Emergy Comparison of Ethanol Production in Brazil: Traditional Versus Small Distillery With Food and Electricity Production

Ortega, E., Ometto A. R., Ramos P.A.R.;
Anami, M.H., Lombardi G., Coelho, O.F.

ABSTRACT

The Conventional Production Model (CPM) of ethanol production in Brazil is characterized by extensive sugarcane plantations (between 20,000 and 30,000 ha) that are burned before harvest, use of large quantities of agro-chemicals, and seasonal jobs. An alternative, the Medium size Integrated and Diversified Ethanol Distillery (MIED) project involves 2 060 ha to produce ethanol, electricity, and food (meat, milk, leather and cereals) with permanent jobs. These two systems have been compared using emergy analysis and the results were favorable to the MIED project. Some features prove the advantages of the MIED proposal over CPM: better waste recycling, creation of permanent jobs at the lowest cost possible to maintain or establish populations in rural areas, contribution to electric power generation. This is an important issue considering that the area covered by sugarcane in Brazil is 5 million ha.

INTRODUCTION

The twentieth century was characterized by a huge growth of industry and transportation based on petroleum that led to important environmental and public health hazards. It took many years to discover oil in Brazil. During World War II the University of São Paulo (USP) created a commission to promote the production of alternative fuels, among them ethanol which then was produced as by-product in the sugar industry. Some years after, the studies about ethanol production promoted a large agro-industrial activity based on solar energy and industrial inputs.

The expansion of the Ethanol Agribusiness started in 1970, with support from the Brazilian Ethanol Production Program (Pró-Álcool) that subsidized the installation of hundreds of new large-scale distilleries. Ethanol was used mainly as a motor fuel. Although it has a lower calorific value than gasoline, a larger thermodynamic combustion efficiency and better environmental qualities (1, 2) offset this. In the decades of 1980 and 1990 the ethanol production moved from hydrated motor fuel (92%) to absolute alcohol (99%) used as gasoline additive (up to 20%) in replacement for toxic lead products. Sugarcane areas, as well as sugar and ethanol industries, increased very fast. Nowadays, after 30 years of depreciation, the Pró-Álcool Program demands equipment substitution and reactivation. New economic trends and improvements in ethanol technology allow the expansion of its use in car engines and demand for increase of its production. It is the right time to discuss the several proposals to implement this new Pró-Álcool stage. The electrical energy shortage in the State of São Paulo may put an additional pressure on Pró-Álcool for new objectives (Electricity Production) as well as public policies with concerns for human employment and agrarian reform.

Table 1. MIED Emergy Analysis Table

Inputs %	Values	Units	Energy Mass Money		Transformity		Emergy sej/ha/y	Flows
Natural Resources (I)							1.69E+15	22.68
Renewable (R)							1.36E+15	18.23
Rain on land	1.20E+00	m3/m/y	5.94E+10	J/ha/y	1.82E+04	sej/J	1.08E+15	14.48
Nutrients (nature)	1.80E+01	kg/ha/y	1.80E+01	kg/ha/y	3.00E+12	sej/kg	5.40E+13	0.72
Nitrogen (atmosphere)	7.00E+00	kg/ha/y	7.00E+00	kg/ha/y	4.61E+12	sej/kg	3.23E+13	0.43
Biological control - forest	6.80E-01	t/ha/y	3.84E+09	J/ha/y	2.46E+04	sej/J	9.45E+13	1.27
Groundwater - irrigation	5.00E-01	m3/ha/y	2.47E+06	J/ha/y	1.10E+05	sej/J	2.72E+11	0.00
Biodiversity gain	2.00E+03	kg/ha/y	2.24E+09	J/ha/y	4.43E+04	sej/J	9.90E+13	1.33
Nonrenewable (N)							3.32E+14	4.45
Soil loss	1.82E+02	J/ha/y	4.11E+09	J/ha/y	7.38E+04	sej/J	3.03E+14	4.06
People loss	1.80E-02	p/ha	2.89E+07	J/ha/y	1.00E+06	sej/US$	2.89E+13	0.39
Economy Resources (F)							5.77E+15	77.32
Agricultural production							1.41E+15	18.93
Materials (M)							8.29E+13	1.11
Seedlings	4.24E+01	kg/ha/y	4.24E+01	kg/ha/y	1.47E+12	sej/kg	6.23E+13	0.83
Crop Protection	3.00E+00	L/ha/y	1.99E+00	kg/ha/y	1.48E+12	sej/kg	2.95E+12	0.04
Equipment	9.85E+00	kg/ha/y	9.85E+00	kg/ha/y	1.80E+12	sej/kg	1.77E+13	0.24
Services (S)							1.33E+15	17.81
Unqualified labor	6.31E-03	p/ha/y	2.66E+07	J/ha/y	7.66E+05	sej/J	2.04E+13	0.27
Qualified labor	9.71E-04	p/ha/y	3.20E+06	J/ha/y	7.66E+06	sej/J	2.45E+13	0.33
Fuel (diesel)	6.05E+02	L/ha/y	1.90E+10	US$/ha/y	6.60E+04	sej/US$	1.25E+15	16.79
Maintenance	6.39E+00	US$/ha/y	6.39E+00	US$/ha/y	3.70E+12	sej/US$	2.37E+13	0.32
Taxes and rates	2.14E+00	US$/ha/y	2.14E+00	US$/ha/y	3.70E+12	sej/US$	7.93E+12	0.11
Cattle production							6.20E+14	8.31
Materials (M)							5.87E+13	0.79
Livestock purchase	3.13E+00	kg/ha/y	2.33E+07	J/ha/y	1.73E+06	sej/J	4.03E+13	0.54
Milky factory	2.35E+00	US$/ha/y	2.35E+00	US$/ha/y	3.70E+12	sej/US$	8.68E+12	0.12
Corrals	1.42E+00	US$/ha/y	1.42E+00	US$/ha/y	3.70E+12	sej/US$	5.24E+12	0.07
Slaughterhouse	5.50E-01	US$/ha/y	5.50E-01	US$/ha/y	3.70E+12	sej/US$	2.04E+12	0.03
Fermentation tanks	6.47E-01	US$/ha/y	6.47E-01	US$/ha/y	3.70E+12	sej/US$	2.39E+12	0.03
Leather tanner center	3.20E-02	US$/ha/y	3.20E-02	US$/ha/y	3.70E+12	sej/US$		
1.18E+11	0.00							
Services (S)							5.61E+14	7.52
Unqualified labor	3.40E-03	p/ha/y	1.43E+07	J/ha/y	7.66E+05	sej/J	1.10E+13	0.15
Qualified labor	9.71E-04	p/ha/y	3.20E+06	J/ha/y	7.66E+06	sej/J	2.45E+13	0.33
Animal husbandry	1.14E+02	US$/ha/y	1.14E+02	US$/ha/y	3.70E+12	sej/US$		
4.21E+14	5.63	Maintenance		9.59E+00	US$/ha/y	9.59E+00		US$/
ha/y	3.70E+12	sej/US$	3.55E+13	0.48	Taxes and rates		1.89E+01	US$/
ha/y	1.89E+01	US$/ha/y	3.70E+12	sej/US$	6.99E+13	0.94		
Industrial production							2.98E+15	39.91
Materials (M)							1.82E+14	2.44
Chemical inputs	4.09E+01	l/ha/y	3.27E+01	kg/ha/y	3.80E+12	sej/kg	1.24E+14	1.66
Equipment - infrastructure	7.16E+00	kg/ha/y	7.16E+00	kg/ha/y	6.70E+12	sej/kg	4.80E+13	0.64
Construction	2.69E+00	US$/ha/y	2.69E+00	US$/ha/y	3.70E+12	sej/US$	9.97E+12	0.13
Services (S)							2.80E+15	37.47
Unqualified labor	1.41E-02	p/ha/y	5.94E+07	J/ha/y	7.66E+05	sej/J	4.55E+13	0.61

Table 1 continued. MIED Emergy Analysis Table

Inputs			Energy Mass		Transformity		Emergy	Flows %
Qualified labor	5.34E-03	p/ha/y	1.76E+07	J/ha/y	7.66E+06	sej/J	1.35E+14	1.81
Administration labor	3.40E-03	p/ha/y	1.12E+07	J/ha/y	5.00E+06	sej/J	5.60E+13	0.75
Laboratory labor	2.43E-03	p/ha/y	8.00E+06	J/ha/y	5.00E+07	sej/J	4.00E+14	5.36
Biological control - laboratory	6.80E-01	t/ha/y	5.10E+02	J/ha/y	2.46E+04	sej/J	1.25E+07	0.00
Manufacturing	4.61E+02	US$/ha/y	4.61E+02	US$/ha/y	3.70E+12	sej/US$	1.71E+15	22.86
Maintenance	9.06E+01	US$/ha/y	9.06E+01	US$/ha/y	3.70E+12	sej/US$	3.35E+14	4.49
Taxes and rates	3.22E+01	US$/ha/y	3.22E+01	US$/ha/y	3.70E+12	sej/US$	1.19E+14	1.60
Complementary Services							7.59E+14	10.17
Waste treatment and recycling	1.74E+02	US$/ha/y	1.74E+02	US$/ha/y	3.70E+12	sej/US$	6.42E+14	8.60
Equipment - infrastructure	3.16E+01	US$/ha/y	3.16E+01	US$/ha/y	3.70E+12	sej/US$	1.17E+14	1.57
Total Emergy (Y)							7.46E+15	100.00

The data were obtained from Ramos (6), Lanzotti, Ortega, Guerra (9) and Ortega & Miller (10).

The Conventional Production Model (CPM) adopted in Brazil is generally based on a plantation system with extensive use of agricultural land, biodiversity destruction by use of single-culture techniqueswith intensive use of fertilizers, pesticides, water and fire (5). Guivant comments (4) that since 1985 the world's agricultural productivity has declined due to environment degradation: soil loss due to erosion, salt deposition, acid rain, leaching, etc. Elliot and Colle comment that somehow this represents nature'sanswer to capitalistic agricultural systems with land concentration and intensive use of machinery, agro-chemicals and fossil fuels (3). According to World Resources (7), during the last 50 years, approximately 66% of the world's agricultural soils were degraded. This motivates the search for a cleaner production model for the Pró-Álcool System.

Recently, the agricultural and industrial activities of the CPM were analyzed (5) to identify the environmental impacts they cause. Major objections to the Pró-Álcool Program are: (a) culture based solely on sugarcane; (b) large-scale production techniques, often resulting in job losses; and (c) pollution of water sources by farm and distillery effluents. To overcome these problems, new approaches have been proposed, and these are embodied in the MIED concept. The MIED project is based on 40 years research at several institutions within USP (ESALQ, EP, IF, IPT, IPAI, EESC) that now gain the collaboration of Unicamp (Brazil) and "Jose Antonio Echeverria" Polytechnic Institute of Havana, Cuba.

CPM environmental and social impacts

Among CPM environmental impacts, some stand out for the magnitude of their negative externalities: the practice of burning cane areas before the harvest, the intensive use of pesticides, the excessive mechanical tillage of soil, the exploitation of rural workers (low wages and extenuating work), the concentration of land and income through unfair land tenancy, the inadequate use of distillery effluents.

The Sugar-Industrial Complex continuously tends to amplify its area in order to increase economic profits. Evidently this leads to larger plantations and fewer owners. The CPM system is limited to work around 120 to 167 days a year when based only on sugarcane as the raw material. The agricultural labor, generally from other regions, is concentrated during cane harvest. Finding parallel activities between crops could minimize these problems. The transportation of cane over long distances (50 kilometers mean) increases production costs; this is done in trucks with two trailers on sinuous roads, thus deteriorating

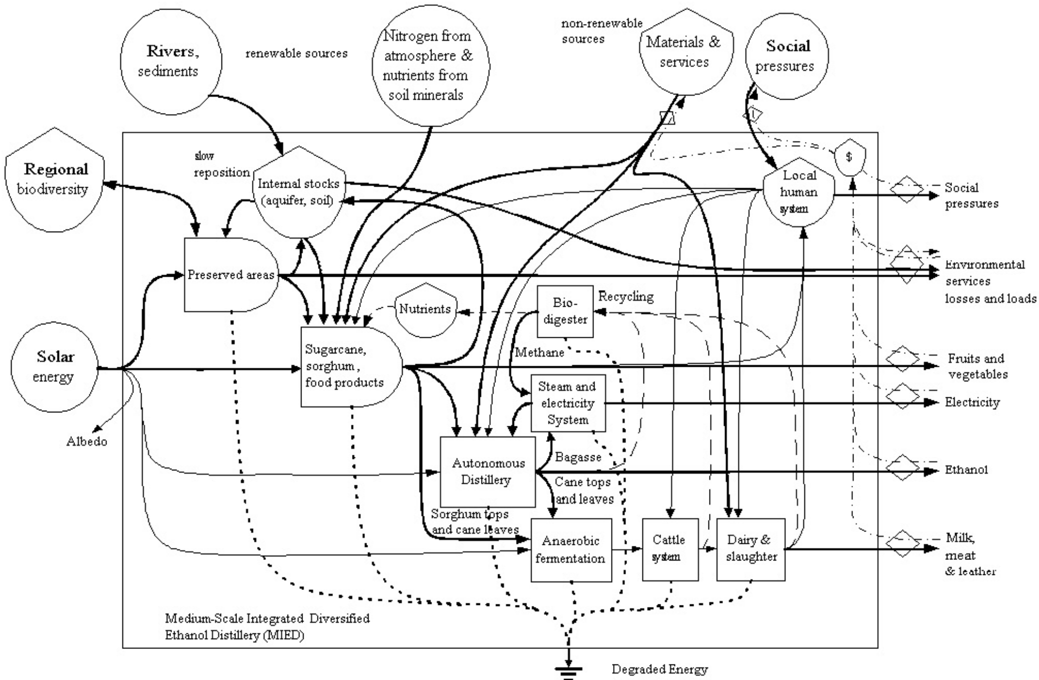

***Figure 1.** Energy flows diagram of Medium size Integrated Ethanol Distillery (MIED)*

highways and increasing the risk of accidents.

Agricultural and industrial research conducted in Brazil (1, 2, and 6) has resulted in MIED proposals, an innovative approach to ethanol production. Through the effective integration of the processes that constitute the biomass-based chain of ethanol production, the MIED system becomes feasible. The main contribution of the MIED will be to avoid the social and economical problems associated with large-scale agro-industrial complexes, allowing the activities to take place on a scale that is suited to labor intensive operation and small entrepreneurs investment capabilities or rural cooperatives. The MIED concept may be implemented at various capacities, ranging from 20 000 to 80 000 liters/day.

If we compare solely the industrial systems (MIED of 2000 ha and CPM of 20 000 ha) both of them reveal similar economic indices even rather close emergy indices. The difference appears when we consider the size of the region affected. In an area of 20 000 ha, as used by CPM, the MIED project could take only a tenth for ethanol and electricity production and the rest of it, 18 000 ha, could be used with diverse agricultural projects, cattle, aquaculture, natural forest, forest plantations; those complementary projects would lead to better ecological and social indices (more jobs/hectare). As result, instead of “a sea of cane without people” we would observe a patched area with biodiversity. Nevertheless, for practical matters, in this study we compare only the industrial systems. In Figure 1 we show the energy flows diagram of MIED project and in Figure 2 the aggregated flows diagram.

A MIED system producing 20 000 liters/day of ethanol (90% concentration) for use in motor cars would have the following elements: (a) total area of 2 060 ha, 1 670 ha for raw materials (780 ha of sugarcane and 890 ha of sweet sorghum that will supply the distillery when cane is not available) and 390 ha for other uses, (b) a whole cane handling system, billet feeding system, juice extraction system with diffuser, distillery with fermentation tanks and distillation columns; (c) a 60-80 atm boiling house and turbo generator; (d) a bio-gas digester; (e) bagasse hydrolysis unit, cattle feeding lots and slaughterhouse; (f) industrial operation during 10 or 11 months/year; (g) preservation of, at least, 20% of the agricultural land as Legal Reserve (LR), and preservation of Permanent Protected Areas (PPA) to meet the Brazilian law.

The MIED outputs, besides 20 000 liters/day of ethanol, would be: (a) 26 200 MWh/y of electricity from the combustion of sugarcane and sorghum bagasse; (b) bio-gas from fermentation of distillery wastes and cattle manure to produce enough steam to run the distillery (3 500 m^3/day); (c) rich fertilizer effluent from the bio-gas digester, suitable for use on the complex's fields. The internal consumption of 24 tons per day of silage fodder will permit semi-confinement of cattle to supply meat for a population of 10 000 people; (d) 2 500 liters/day of milk; (e) 700 calves per annum; (f) a range of other crops or vegetables (0.5 t/ha) that can be grown on the sorghum land (grain productivity: 2 000 and 3 000 kg/ha) during the 8 months of the year between sorghum crops.

Some advantages of MIED are: (a) no burns; (b) production of food; (c) obeisance to laws concerning preservation of forested areas; (d) use of motors adapted to vaporized ethanol; (e) attraction of thousands of people without hope in the cities back to the countryside; (f) an alternative option to petroleum thermoelectric plants.

MIED innovates in operational procedures and use of modern technologies. It offers a new vision for the Sugar Industrial Complex: small and integrated systems distributed throughout the country.

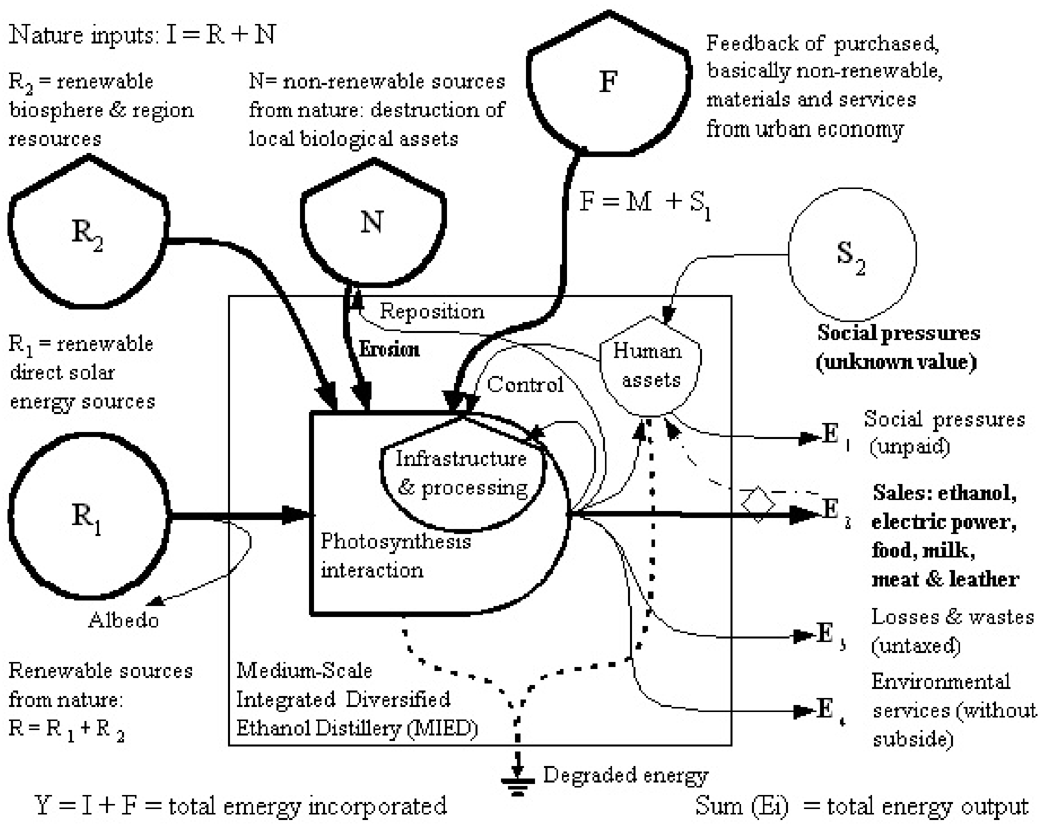

Figure 2. *Aggregated Diagram of Emergy Flows*

It is genuinely a revolution over the historically used conventional production models based on big plantations. The agricultural and technical issues are proved and well understood, and it is clear that the real challenge in implementing MIED project lies in setting up institutional arrangements and regulatory framework that would ensure successful making of rural projects. The MIED proposal could incorporate in the future organic and agro-ecological agricultural techniques. It is felt that its potential benefits would far outweigh the costs. Anyway, creative solutions in agriculture and renewable energy are much needed and recommended by Agenda 21.

Table 2. MIED x CPM indices

	MIED	CPM
Ethanol Capacity	20,000 L Ethanol/day	200,000 L Ethanol/day
Total Area (hectare)	2,060 ha	25,490 ha
Emergy flows		
R (sej/ha/year)	1.36E+15	1.36E+15
N (sej/ha/year)	3.32E+14	8.27E+14
I = R + N	1.69E+15	2.19E+15
M (sej/ha/year)	3.24E+14	7.95E+15
S (sej/ha/year)	5.34E+15	3.50E+15
F = M + S	5.66E+15	1.15E+16
Y = I + F	7.35E+15	1.36E+16
Emergy indices		
EYR =Y/F	1.30	1.19
EIR = F/I	3.34	5.24
ELR = (N+F)/R	4.41	9.03
%R = R/Y	18.50	9.97
Q total (J/ha/y)	1.95E+11	2.99E+11
Tr =Y/Q total	3.76E+04	4.57E+04
Tr =Y/Q sugar	-	96,036
Tr =Y/Q ethanol	86,486	214,421
Tr =Y/Q electricity	118,569	4,442,078
Products		
Ethanol (J/ha/y)	8.50E+10	6.36E+10
Electricity (J/ha/y)	6.20E+10	3.07E+09
Sugar (J/ha/y)	-	1.42E+11
Bagasse (J/ha/y)	-	9.00E+10
Vegetables (J/ha/y)	3.21E+09	-
Milk (J/ha/y)	3.20E+10	-
Meat (j/ha/y)	4.39E+09	-
Leather (J/ha/y)	8.68E+09	-
Yeast (J/ha/y)	6.31E+07	-
Qualified Work (sej/ha/y)	1.84E+15	2.62 E+15
Unqualified Work (sej/ha/y)	7.69E+13	2.36E+14
Profitability	1.05	1.12

Environmental and sustainable development benefits

This approach to ethanol production fulfils the requirements for financing of instruments such as the Clean Development Mechanism (UNO´s Kyoto Protocol). It is envisaged that MIED complexes could be constructed to provide the basis for decentralized rural development nodes in areas suitable for sugar cane production. The ethanol produced could be used for transportation purposes and production of ethanol-based gel-fuel suitable for domestic use. In addition, once fuel cells become available, it could be used for power generation at the individual household level.

The MIED project would provide good quality jobs and a technical solution to allow the possibility of sustainable development. There are further possibilities of productive activities derived from other outputs such as electricity, agricultural products and cattle. In the current global predicament of rising petroleum prices and climate change concerns, it offers a good and elegant solution to create rural jobs and access to affordable and convenient sources of energy.

Further investigation is required for better understanding of the behavior of the model, but it is felt that MIED system may give significant benefits in countries where climate and soil resources could make the adoption of this kind of agro-industrial system possible.

RESULTS AND DISCUSSION

Global Transformity: Tr = (R+N+M+S) / (Sum of energies produced)

As basis for comparison we used the transformity of the system and not of a specific product. We considered the total emergy captured and the sum of all the energies of sold products (ethanol, electricity, vegetables, milk, meat and leather). The transformity values are 45,660 sej/J (CPM) and 37,600 sej/J (MIED). They reveal that MIED project has better system efficiency.

Table 3. Human Labor

	First Method*		Second Method**		Third Method***	
Human Labor (sej/J)	Tr	Year	Tr	Year	Tr	Year
Brazil						
Unqualified Labor	7.66E+05	2001	3.57E+06	2001	-	-
Qualified Labor	7.66E+06	2001	-	-	-	-
USA						
Unqualified Labor	2.62E+06	2001	8.08E+06	2001	8.90E+06	1996
Qualified Labor	1.57E+07	2001	-	-	2.46E+07	1996

* The first method is based on emergy content of minimal salary in each country (sej/ year) divided by one worker metabolism (Joules/year).

** In the second method the values are obtained dividing the annual emergy of the country (sej/year) by the total population metabolism (J/ year).

*** The third method values are obtained multiplying the energy expended by a human being by the transformity of that person' considering education and experience (Odum, 1996).

Net Emergy Yield Ratio: EYR = Y/F

Net emergy yield ratio values obtained for the two systems are satisfactory when compared with other agro-industrial systems in Brazil. Both systems deliver free energy to the surrounding economy. The value for MIED (1.30) is slightly larger than that for CPM system (1.19), because it uses environmental services and takes advantage of its integration concept.

Emergy Investment Ratio: EIR = F/I

The emergy investment ratio of MIED project is smaller (3.34) than the EIR value for CPM (5.24), still this is a reasonable value when compared to EIR values of other industrial activities, which may vary between 0.8 and 40. The mean value for this ratio in USA is 8.0 (Odum, 1996).

Renewability: (R%) = 100 (R/Y)

The renewability of the MIED project is bigger (18.5%) than the value of CPM (10%); still these low values of renewability express that these options will not survive in social systems without petroleum subsidies. The MIED project makes more and better recycling and uses less chemicals inputs. MIED´s renewability index could be improved when we consider the same affected region (20 000 ha). As we mentioned before, the MIED project could be planned as a tenth part of a bigger, more diversified agro-ecological rural system with less use of non-renewable resources.

Environmental Loading Ratio: ELR = (N+F)/R

The ELR value of the MIED project is better (4.41) than the value for the CPM system (9.03). It is due to efficient treatment of effluents, better recycling with animal participation. If organic and agro-ecological procedures were incorporated as well as water treatment the ELR ratio of MIED would be improved.

Social and Economic Analysis

Profitability:

The MIED system has a slightly lower profitability (1.05) than the new model of CPM (1.12). MIED's profitability is affected by national and international policy concerning agricultural prices, taxes and subsidies. The discussion about public policy to promote more sustainable rural systems has already begun in Brazil. In order to implement more sustainable systems progressively at national level, research must be done about commercial trade and international prices in order to consider equitably producers and consumers. Regional planning should benefit this kind of ethanol system production due to its ecological and social advantages.

Labor:

Jobs in the conventional system (CPM) are based on manpower exploitation; with low salaries in manual harvest and offer of work for only a short period of time (seasonal jobs), hence the job quality is very low. Although the work is hard it involves women and sometimes children. Payment to workers is based on the amount of cane cut and collected. So, the laborers are forced to work very hard, receiving a small amount of money that sometimes allows only paying food. MIED project would offer better and stable jobs for a longer period of time or more work hours if this system would be adopted in a regional scale.

CONCLUSIONS

This is the first emergy analysis prepared for a medium-scale, diversified and integrated ethanol production system and may induce reflections on how to proceed in the future to establish self-sufficient rural systems that could also absorb people from cities. Its renewability needs to be improved with an appropriate mixture of agricultural and forest activities. This article has made a special effort to include the Forest inputs in the MIED system in order to value this important element within this system. The project also needs to be reformulated from the perspectives of regional planning, employment and agrarian reform. The MIED transformities for ethanol and electricity showed the systems good efficiency in comparison with other production systems producing electricity and ethanol. The CPM system showed to be efficient only to sugar production.

ACKNOWLEDGEMENT

We thank Anita Kacenelenbogen Guimarães for her kind and careful revision of our manuscript.

REFERENCES

CORSINI R. (1988). Mini Usinas Integradas. Exposição Comparativa. Anais SINERGE, vol. 1. Brasil. pp. 154-162.

CORSINI R. (1999). Viabilidade econômica de Mini Usina de álcool Integrada. Monografia. EESC, Brasil.

ELLIOT, E. T. e COLE, C.V. (1989). A perspective on agro-ecosystem

VIOLA, E. J.; LEIS, H.R; SCHERER-WARREN, I.; GUIVANT, J.S.; VIEIRA, P.F.; KRISCKE, P.J. Meio Ambiente, Desenvolvimento e Cidadania: desafios para as Ciências Sociais 2.ed. São Paulo, Cortez. Cap. 3, p.99-133.

OMETTO, A. R. (2000). Discussão sobre os fatores ambientais impactados pelo setor sucro-alcooleiro e a certificação sócio-ambiental. São Carlos. Dissertação (Mestrado) – Escola de Engenharia de São Carlos, Universidade de São Paulo.

RAMOS, P.A.R. e LOMBARDI G. (2001). Viabilidade econômica do projeto conceptual para execução do projeto dimensional. Relatório de pesquisa FAPESP. Escola Engenharia São Carlos, São Paulo, Brasil.

WORLD RESOURCES. World Resources 2000-2001 People and Ecosystems: The fraying Web of Life Hardbound. United Nations Environment Program, World Bank World Resource Institute. http://www.elsevier.com/homepage/sag/worldresources/agro.html (29/08/2000).

LANZOTTI, C.R.; ORTEGA, E. & GUERRA S.G.M, 2001. Emergy analysis and trends for ethanol production in Brazil. Emergy Synthesis. Proceedings of First Reunion on Emergy and Transformity. Center of Environmental Policy. University of Florida.

ORTEGA, E. & MILLER, M (08/29/2001). Avaliação ecossistêmica - emergética de processos agrícolas e agroindustriais. Estudo de caso: a produção de soja. http://www.unicamp.br/fea/ortega/curso/portoalegre/portoalegre.htm

ODUM, H.T. (1996). Environmental Accounting: Emergy and environmental decision-making. 370 pages, John Wiley & Sons, Inc., New York, USA.

STAB (2001). Revista da Sociedade Brasileira de Técnico do Açúcar e do Álcool. São Paulo.

CALCULATIONS

1) Natural Resources
1.1) Renewable (R)

R1 Rain on land:

Rain: 1 200 mm/m^2/y. Gibbs's free energy for water: 4 949 J/kg.

1.2m^3/ m^2/y * 10 000 m^2/ha * 1 000kg/ m^3 * 4 940 J/kg = 5.93 E+10 J/ha/y

R2 Nutrients from nature:

The biochemical and physical weathering of soil will supply 18 kg/ha of P to plant nutrition. The plant needs 425 kg/ha/year of essential elements: 119 kg of N (nitrogen), 51 kg of P (phosphorus) and 276 kg of K (potassium). Part of the nutrients will be restored by irrigation of bio-fertilizer produced by digestion of industrial wastes, corresponding to 426 kg/ha/year of essential elements: 50 kg N/ha/y, 33 kg P/ha/y and 281 kg K/ha/y plus the residues of livestock, which correspond to 62 kg/ha of N.

R3 Nitrogen (atmosphere):
Microorganisms inoculated will supply up to 7 kg/ha/year through biological fixation of nitrogen of the air.

R-4 Biological control - Forest
According to STAB (2001), without biological control there is a loss of 0.68 t /ha/y of sugar. Biological control services are provided by natural forest reserve and also supplied by a laboratory. The forest contributes with 25%. The calorific potential of organic matter is: 5400 kcal/kg * 4186 J/Kcal = 22.6 E+06 J/kg.

0.68 t/ha/y * 0.25 * 1 000 kg/t * 22.6 E+06 J/kg = 0.38 E+09 J/ha/y.

R-5 Groundwater - irrigation
Irrigated quantity: 0.5 m^3/ha/y. Gibbs's free energy for water: 4949 J/kg.

0.500 m^3/ha/y * 5 000 J/kg * 1 000 kg/m^3 = 2.50 E+06 J/ha/y.

R-6 Biodiversity gain
The growth of forest for this area was estimated to be close to values obtained from commercial forests of pines or eucalyptus, almost 2 tons by hectare by year.

2 tons * 1000kg/t * 5400 kcal/kg * 4186 J/kcal = 2.24 E+9 J/ha/y

1.2) Non-renewable (NR)

NR-1 Soil loss
The organic matter loss in soil with straw covering is around 182 kg/ha/y:

182 kg/ha/y * 4 186 J/kcal * 5 400 kcal/kg = 4.11 E+09 J/ha/y.

NR-2 People loss
To obey a new Brazilian law mechanical harvest will be adopted in sugar cane areas, resulting in a decrease in jobs. A machine picks 300 t/day while a laborer picks an average of 7.5 t/day. We will have less than two operators for the whole area (2 600 ha). The loss is of 0.018 persons/ha.

0.018 workers /ha * 3200 kcal /day (metabolic spends) * 4 186 J/kcal * 120 days/year =2.9 E+07 J/ha/y

2) Economic resources (F)

The calculations were split according to the activities accomplished in MIED: agriculture, livestock and industry.

2.1) Agriculture (sugar cane, sweet sorghum, grains and vegetables)

2.1.1) Materials (MA)

MA-1 Seedlings
144 kg of cane seedlings for 5 years, 10 kg of sweet sorghum seeds and 1.54 kg of seeds of grains and vegetables each year with a stock of 5 %: ((144/5 + 10 + 1.54) kg) * 1.05 = 4.1E+1kg/ha/y.

MA-2 Crop Protection
Average use of herbicides: 3.0 liters/ha/y. Herbicide density: 0.8 kg/L. Agricultural area: 1 705 ha; total area: 2 060 ha.

3.0 L/ha/y * (1 705 ha / 2 060 ha) * 0.8 kg/L = 1.99 kg/ha/y.

MA-3 Equipment
Total costs of agricultural equipment for crop production, harvest and transport: US$ 2 349226. Depreciation occurs in 30 years. Average price of steel in agricultural equipment: 3.86 US$/kg.

(2 349 226 US$ / 3.86 US$/kg) / (2 060 ha * 30 y) = 9.848 kg/ha/y

2.1.2) Services (SA)

SA-1 Unqualified labor
Thirteen workers (p) on the agricultural area of 2 060 ha. An unqualified worker spends 3200 kcal/day. 1 year = 315 work days:
((13 p/d)/ 2 060 ha) * 3 200 kcal/p/d * 4186 J/kcal * 315 d/y = 2.66 E+07 J/ha/y.
SA-2 Qualified labor
Two qualified workers in 2 060 ha. A qualified worker spends 2 500 kcal/d.
((2 p/d) / 2 060 ha) * 2 500 kcal/p/d * 4 186 J/kcal * 315 d/y = 3.20 E+06 J/ha/y
SA-3 Agricultural operations
Annual expenses on agricultural operations: 761 851.38 US$/y; the total area is 2 060 ha.
761 851.38 US$/y / 2 060 ha = 196.70 US$/ha/y.
SA-4 Maintenance
The maintenance of the agricultural machines is 6% of 219 469.48 US$/y.
(219 469.48 US$/y * 0.06) / 2 060 ha = 6.39 US$/ha/y
SA-5 Taxes and rates
The taxes of the agricultural area are calculated by adopting 2% of the agricultural sales, which is 76.72 US$/ha/y.
76.72 US$/ha/y * 0.02 = 1.53 US$/ha/y.

2.2) Livestock
2.2.1) Materials (ML)
ML-1 Livestock purchases
The number of cows is 3 438; a calf weighs 75 kg and, for reproduction, an annual replacement of 25 % is needed; the equivalent heat energy of cattle is 7 438 596 J/kg, the area is 2 060 ha; the period of depreciation is 30 years.
(3 438 * 75 kg) / (2 060 ha * 30 y) * 0.75 * 7 438 596 J/kg = 2.33 E+07 J/ha/y.
ML-2 Milk factory
The total cost of the system is 145 000 US$.
(145 000 US$ / 2 060 ha * 30 y) = 2.346 US$/ha/y.
ML-3 Corrals
The total cost of corrals is 87 587 US$.
87 587 US$ / (2 060 ha * 30 y) = 1.417 US$/ha/y.
ML-4 Slaughterhouse
The cost of slaughterhouse is 34 000 US$.
34 000 US$ / (2 060 ha * 30 y) = 0.55 US$/ha/y.
ML-5 Fermentation tanks
The fermentation tanks are destined to the production of animal feed. The total cost is US$ 40 000.
40 000 US$ / (2 060 ha * 30 y) = 0.65 US$/ha/y.
ML-6 Leather tanner center
The total cost is US$ 1 978.
1 978 US$ / (2 060 ha * 30 y) = 0.032 US$/ha/y.

2.2.2) Services (SL)
SL-1 Manual work labor
Use the same calculation as for simple labor, SA-1. Seven workers.
(7 p/d / 2 060 ha) * 3 200 kcal/p/d * 4 186 J/kcal * 315 d/y = 1.43 E+07 J/ha/y.
SL-2 Qualified labor
Use the same calculation as for qualified labor, SA-2. Two qualified workers.
(2 p/d / 2 060 ha) * 2 500 kcal/p/d * 4186 J/kcal * 315 d/y = 3.20 E+06 J/ha/y
SL-3 Animal husbandry
The total expenses for treating healthy cattle is 234 180.52 US$/y; the total area is 2 060 ha.
234 180.52 US$/y / 2 060 ha = 113.68 US$/ha/y.

SL-4 Maintenance
The annual expenses of maintenance is 9% of US$ 219 469.48
219 469.48 US$/y * 0.09 / 2 060 ha = 9.59 US$/ha/y.
SL-5 Taxes and rates
The taxes for livestock are calculated as 2% of the annual sales of its products, which is 944.31 US$/ha/y.
944,31 US$/ha/y * 0,02 = 18.89 US$/ha/y

2.3) Industry
2.3.1) Materials (MI)
MI-1 Chemical inputs
The volume of oil for the production of alcohol and electricity is 40.86 liters per hectare, for the whole area. The density is 0.80 kg/L.
40.86 L/ha * 0.80 kg/L = 32.7 kg/ha/y.
MI-2 Equipment and infrastructure
The total quantity of steel in industrial equipment and infrastructure (with 30 years of depreciation) is 7.16 kg/ha/y.
MI-3 Civil and industrial construction
The total expenditure for the civil and industrial construction is US$ 166 500, the total area is 2 060 ha; the period of depreciation is 30 years:
166 500 US$ / (30 y * 2 060 ha) = 2.69 US$/ha/y.

2.3.2) Services (SI)
SI-1 Unqualified labor
Use the same calculation as for simple labor, SA-1. Twenty-nine men working at the industrial complex.
(29 p/d / 2 060 ha) * 3 200 kcal/p/d * 4 186 J/kcal * 315 d/y = 5.94 E+07 J/ha/y.
SI-2 Qualified labor
Use the same calculation as for qualified labor, SA-2. Eleven qualified workers.
(11 p/d / 2 060 ha) * 2 500 kcal/p/d * 4 186 J/kcal * 315 d/y = 1.76 E+07 J/ha/y.
SI-3 Administration labor
Use the same calculation as for qualified labor, SA-2. Seven officers.
(7 p/d / 2 060 ha) * 2 500 kcal/p/d * 4 186 J/kcal * 315 d/y = 1.12 E+07 J/ha/y.
SI-4 Lab labor
Use the same calculation as for qualified labor, SA-2. Five technical workers on labs.
(5 p/d / 2 060 ha) * 2 500 kcal/p/d * 4 186 J/kcal * 315 d/y = 8.00 E+06 J/ha/y.
SI-5 Biological control - laboratory
Use the same calculation as for biological control by forest, R-4. Associate rate for labs is 75% of the total biological control:
0.68 t/ha/y * 0.75 * 100 000 kg/t * 8 807 344 J/kg = 4.49 E+09 J/ha/y.
SI-6 Manufacturing
Annual expenditure on manufacture are US$ 950 013.34, the total area is 2 060 ha.
950 013.34 US$/y / 2 060 ha = 461 US$/ha/y.
SI-7 Maintenance
Annual expenditure on maintenance are 85 % of US$ 219 469.48, the total area is 2 060 ha.
(219 469.48 US$ / 2 060 ha) * 0.85 = 90.56 US$/ha/y.
SI-8 Taxes and rates
The industrial taxes is 2% of the total sales of the industrial products, which is 1 610.56 US$/ha/y.