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INTRODUCTION

The need for renewable energy sources lead Brazil to establish the National Alcohol Program (PNA) in 1975. This program sought to increase ethanol production though appropriate economic policy actions involving the traditional technology already in widespread use in the country. First priority was clearly given to quick response and immediate application instead of technological improvements on existing techniques or alternate fuels.

Ethanol production in Brazil has in fact expanded rapidly in the last few years in response to the government policy of economic incentive. About 80-90% of the total funds invested in industrial alcohol plants was borrowed from the Bank of Brazil at interest rates lower than inflation rates.

Ethanol[1] and gasoline[2] production

year	ethanol 10^3 m^3 total	ethanol 10^3 m^3 fuel	gasoline 10^3 m^3	ethanol-gasoline mixture (%)
72	681	389	12004	3.24
73	666	306	13929	2.20
74	625	217	14322	1.52
75	556	233	14619	1.59
76	664	300	14724	2.04
77		1177	14103	8.35
78[3]		1589	14448	11.00
80[3]		2465	14501	17.00
84[3]		3184	15922	20.00

1-Source:Instituto do Açucar e do Alcool. Ministerio da Industria e do Comercio. Brasilia.
2-Balanço Energetico Nacional.Ministerio das Minas e Energia. 1978
3-Estimative.

Considering the high artificial price of gasoline for the consumer in Brazil (US$0.42/liter) the increase in ethanol production occurred without technological developments to improve efficiencies and lower production costs.

Within the contraints of the relatively small flexibility of PETROBRAS refineries in varying the relative production amount of petroleum derivative, it is only justifiable to

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increase substantially ethanol production for gasoline substitution if there is simultaneous reduction or substitution of the demand of others petroleum products.

In the particular case of Diesel oil, the substitution by ethanol presents some technical and economic difficulties, but it is expected to find some possible technical solution in the future.

Liquid fuels prices[1] per liter, in Brazil

fuels	production final price	consumer price
ethanol	0.29	0.42
gasoline	0.19	0.42
diesel oil	0.11	0.22
fuel oil	0.045	0.065

1-Conversion rate: Cr$22.00/dollar

These considerations and data on the economical aspects of the problem, show the need of a high production of petroleum substitutives. To reach a large ethanol production it is important to analyse the physical constraints imposed by the amount of available land and the particular conditions of soil quality and climate for raw material cultivation. Sugar cane is practically the only raw material exploited on a commercial basis for ethanol production and requires soils of good fertility and special climate conditions; these conditions are already a limiting factor for sugar cane expansion, since its cultivation competes already with other food crops in the utilization of good quality soils. So, it is more and more necessary to search other raw materials and fuels that could become part of a brazilian solution to its energy needs.

The objective of this paper is to present an energy comparison of different raw material- sugar cane, sweet sorghum, cassava, eucalyptus and pinus -, and to provide subsidies for the research and selection of crops for ethanol production.

AGRICULTURE AND ENERGY

Composition and Yield of Raw Materials

The composition and yield of sugar cane, sweet sorghum, cassava, eucalyptus and pinus, are presented in tables 1a, 1b and 2.

Table 1a- Composition % {1, 2, 3, 4, 5, 6}*

	sugar cane	sweet sorghum		cassava	
	stems	stems	grains	roots	"ramas"
moisture	72-76	68-72	11-15	68	76
fiber	9-13	14-17	2-3	1.4	23
sucrose	12-16	9-12	1-2	2.0	
glucose	0.2-1.5	1.0-4.0		1.2	
starch			55-65	25-35	
total sugar[1]	13.0-17.0	12.0-16.5	1.0-2.0		

1) fermentable sugars (glucose %):sucrose x 1.05 plus glucose

* { }- references

Table 1b- Composition % {3, 7, 8, 9, 10}

	eucalyptus	pinus	sugar cane fiber	sweet sorghum fiber
cellulose (alfa)	50.0	50.0	40.0	35.0
hemicellulose	20.0	15.0	27.0	27.0
hexosans	2.5	9.6	1.0	
manans	1.3	7.0		
galactans	1.2	2.6		
pentosans	17.5	5.4	26.0	
xylans	16.8	3.9	25.0	
arabans	0.7	1.5	1.0	
lignine	25.0	30.0	22.0	20.0

Table 2- Yields and dry matter production (t/ha) { 5, 11, 12, 13, 22, 23}

crops[1]	yield /year	yield /month	dry matter /year	dry matter /month
sugar cane	45-60	3.8-5.0	12.6-16.8	1.1-1.4
	52[3]	4.3	14.6	1.2
sweet sorghum				
stems	30-40	6.7-8.9	9.6-12.8	2.1-2.9
	35	7.8	11.2	2.5
grains	2-4	0.4-0.9	1.7-3.5	0.3-0.8
	3	0.7	2.6	0.6
cassava				
roots	10-15	1.1-1.7	3.2-4.8	0.3-0.5
	12.5	1.3	4.0	0.4
"ramas"[2]	7.5-10.0	0.7-1.1	1.8-2.4	0.1-0.3
	8.8	0.8	2.1	0.2
eucalyptus			11.8	1.0
pinus			14.6	1.2

1)plant cane has a 18 month cycle (land is required for 2 years) and 3-4 ratoons of 12 months;sweet sorghum: 4.5 months; cassava: 15-22 months (land is required for 2 years) eucalyptus: 7 years (2 ratoons of 7 years); pinus: 25 years (7 partial harvests in this period); 2)"ramas":aerial part of cassava plant; 3)average.

Except for sweet sorghum wich is not cultivated on commercial basis, these data are representative of plantations in the State of Sao Paulo.

Yields of Glucose and Ethanol

Table 3 and 4 shows the yields of glucose, residues and ethanol. In order to make possible a better comparison between raw materials we considered 2 systems, according to the cellulose utilization for ethanol production or not. System I is related to the processing of fermentable sugars and starch. System II involves also processing of cellulose.

Table 3- Yields (t/ha) of glucose[1] and residues (dry basis)*

	system I				system II			
	glucose		fiber		glucose		lignine	
	/year	/month	/year	/month	/year	/month	/year	/month
sugar cane	7.8	0.65	5.7	0.48	9.5	0.79	1.3	0.1
sweet sorghum	6.7	1.45	5.4	1.20	8.3	1.85	1.1	0.1
stems	5.0	1.11	5.4	1.20	6.6	1.47	1.1	0.1
grains	1.7	0.38	-	-	1.7	0.38	-	-
cassava	4.0	0.17	1.8	0.08	4.6	0.38	0.4	0.03
roots	4.0	0.17	-	-	4.0	0.33	-	-
"ramas"	-	-	1.8	0.08	0.6	0.05	0.4	0.03
eucalyptus	-	-	-	-	4.3	0.36	3.0	0.25
pinus	-	-	-	-	6.1	0.51	4.4	0.37

1)glucose conversion factors:sucrose x 1.05;starch x 0.95;cellulose x 0.70
* {5, 6, 7, 8, 9, 14, 15 }

Table 4- Yields (liters/ha) of ethanol[1] {6, 8, 14, 15}

	system I		system II	
	/year	/month	/year	/month
sugar cane	4541	378	5530	461
sweet sorghum	3900	867	4832	1074
stems	2911	647	3843	854
grains	989	220	989	220
cassava	2329	194	2678	223
roots	2329	194	2329	194
"ramas"	-	-	349	29
eucalyptus	-	-	2503	209
pinus	-	-	3551	296

1)ethanol conversion factor: 58.22 liters/100kg glucose (20ºC)

Agricultural Energy

In table 5 is listed, in a resumed form, the energy expended in the agricultural phase of the alcohol production. These figures were obtained according to a recent study carried in the State of Sao Paulo and the utilization of input-output brazilian matrix {17}; it represents a more realistic evaluation than previous studies {19}.

Table 5- Energy (Mcal/ha/year) expended in agricultural production

	sugar cane	%	s. sorghum[1]	%	cassava	%	eucalyptus	%	pinus	%
fuel	2475	61.3	987	53.2	561	55.2	381	71.6	316	74.1
fertilizer	997	24.7	1122	40.1	448	29.4	36	6.8	1	0.2
defensive	332	8.2	69	2.5	53	3.5	60	11.3	86	20.3
machinery	119	2.9	65	3.0	39	2.6	21	4.0	17	4.0
labor	116	2.9	12	0.4	73	4.8	34	6.4	-	-
other	-	-	23	0.8	51	3.3	-	-	6	1.4
total	4039		2798		1525		532		426	

Source: Internal Report, Instituto de Fisica, Sao Paulo

1) estimative

INDUSTRIAL ENERGY

The industrial energy considered was: a) the energy invested in the capital good,-expresses energy embodied in the equipment; b) operational energy-expresses energy of chemical products and other materials consumed in the processing of the final good; c) maintenance; d) combustible - expresses the energy for industrial processing of raw material.

Industrial energy figures for ethanol production from fermentable sugars are shown in table 7. They were calculated based on reference {21}, wich presents details for that evaluation. For ethanol production from cellulose, it was first evaluated the energy consumption based on reference {16}. Ethanol production from starch is estimated based on ethanol from cellulose. Table 6 presents the results of the calculations.

Industrial processing energy (combustible) is the major component, representing 90% of the total energy of industrialization This fact shows that from an energy point of view a program for utilization of fuels produced from biomass will only be successful if the combustible used for industrial processing is also from a renewable source.

Another aspect concerns the importance of energy conservation measures. In Brasil this is particularly important in sugar cane distilleries if one considers that: a) present energy spent on industrial processing is the same as 30 years ago, and b) bagasse drying is not used. The surplus energy from bagasse could be used in electric power generation {24}.

Table 6- Industrial energy of ethanol production (Kcal/liter)

	fermentable sugars[1]	cellulose[2]
capital goods (20 years lifetime)	168.9	91.6
operation	131.1	452.6
maintenance	168.9	91.6
processing (combustible)	4932.8	6000.0

1) Source: reference 21; sugar cane and sweet sorghum stalks

2) Wood

Table 7 - Industrial energy (Mcal/ha/year)

	cap. goods		operation		maintenance		sub total		combustible		total	
	I[1]	II[2]	I[1]	II[2]	I[1]	II[2]	I[1]	II[2]	I[1]	II[2]	I[1]	II[2]
sugar cane	767	858	595	1043	767	858	2129	2759	19252	25351	21381	28110
sugars	767	767	595	595	767	767	2129	2129	19252	19252	21381	21381
cellulose	-	91	-	448	-	91	-	630	-	6099	-	6729
sweet sorghum	583	668	830	1252	583	668	1996	2588	17297	23044	19293	25632
sugars	492	492	382	382	492	492	1366	1366	12342	12342	13708	13708
starch	91	91	448	448	91	91	630	630	4955	4955	5585	5585
cellulose	-	85	-	422	-	85	-	592	-	5747	-	6339
cassava	213	245	1054	1212	213	245	1480	1702	11669	13821	13149	15523
starch	213	213	1054	1054	213	213	1480	1480	11669	11669	13149	13149
cellulose	-	32	-	158	-	32	-	222	-	2152	-	2374
eucalyptus	-	229	-	1133	-	229	-	1591	-	15435	-	17026
pinus	-	325	-	1607	-	325	-	2257	-	21898	-	24155

1) system I as shown in table 3 and 4

2) system II as shown in table 3 and 4

ENERGY BALANCE

Considering the results shown in table 7 and other available information {19,21}, a concept of a "self sufficient hectare" was introduced to compare the energy balance for different crops: it consists of the partial utilization of one ha by an eucalyptus plantation (or any other wood) occupying an area which is sufficient to provide the industrial processing energy (fuel) required by the crop cultivated on the rest of the hectare. For example, for cassava industrialization (system I) in one hectare, 0.91 ha would be cultivated with cassava leaving 0.09 ha to be used for eucalyptus plantation; this wood would supply all the necessary energy for the industrialization of cassava.

Based on figures of tables 8 and 9, it is possible to make de following observations:

a) All raw materials have a low overall efficiency (Et/A+I) and there is a wide difference between them (0.63-0.90) at the present state of the technique. When combustible for industrial processing is not taken into account - Et/A+I-IP - (being considered part of system), then efficiencies increase but still present a large difference (3.41-5.96);

b) The efficiency of agricultural energy - Et/A - presents the widest variation (5.7-36.8). Considering the efficiency for agricultural combustible energy - Et/Ac - , the general trends are similar (9.2-49.8). Wood is 2 to 7 times more efficient than other raw material in relation to agriculural energy; the other raw material have, in a general sense, similar efficiencies between then.

c) The efficiency of the industrial phase (Et/I), as contrasted to the agricultural phase energy, shows much lower values for wood and other cellulosic material. Considering the efficiency rate, it is remarkable that the industrial energy, and not agricultural energy, is responsible for lower efficiencies.

Observing other industrial energetic efficiencies (Et/Ip and Et/I-Ip) it is seen that industrial processing energy has a dramatic effect upon the energy balance.

In distillation process it is well accepted that it is possible to reach better energetic efficiencies. But concerning sugar cane the necessity of high pressure steam to drive the mills is a limiting factor over low pressure steam economy.

Also, those efficiencies always show lower values for cellulose industrialization. This fact suggests the need to achieve better efficiencies for cellulose hydrolisis which is considered very low {25}; research is under way showing the possibility to obtain efficiencies 100% higher {25}.

The Et/I-Ip coefficient is based on the use of renewable energy for industrial processing, furnished by an eucalyptus plantation, which allows the achievement of higher efficiencies (6.4-10.8).

Analysis of Et/I-Ip coefficient show that cellulose problem is more related, once again, with acid hydrolisis efficiency; the industrial operation energy plays a less important role, since it is much lower.

Table 8- Energy balance (Mcal/ha/year) for a "self sufficient hectare"[1]

	area[1]	ethanol	agriculture[2]			industry[3]		residues[4]		balance
	%		a	b	total	c	d	e	f	
sugar cane										
system I	100.0	22878	4039	-	4039	2129	19252	21090	+ 1838	18548
system II	70.7	19690	2854	156	3010	1951	17915	3400	-14515	14729
sweet sorghum										
system I	100.0	19648	2798	-	2798	1996	17296	19980	+ 2684	17538
system II	72.3	17603	2023	147	2170	1871	16667	2943	-13724	13562
stems										
system I	100.0	14666	2798	-	2798	1366	12341	19980	+ 7639	18141
system II	78.0	15092	2181	117	2298	1527	14100	3173	-10927	11267
cassava										
system I	90.8	10657	1385	49	1434	1480	10598	6049	- 4549	7743
system II	80.1	10802	1221	106	1327	1702	11065	1185	- 9880	7773
eucalyptus	91.2	11596	489	43	532	1591	14194	10208	- 3986	9473
pinus	89.8	16069	383	54	437	2257	19669	14623	- 5046	13375

1) see text; area % occupied by the crop (the other part is occupied by an eucalyptus plantation to provide energy); 2) agricultural energy: a) energy expended by the crop; b) energy expended by the eucalyptus plantation; 3) industrial energy: c) energy expended with capital goods, operation and maintenance; d) energy expended with combustible for industrial processing; 4) residues (fiber and lignine): e) energy produced by residues; f) energy balance of residues energy and energy necessary for industrial processing.

Table 9- Energy efficiency coefficients

	$\frac{Et}{A}$	$\frac{Et}{Ac}$	$\frac{Et}{I}$	$\frac{Et}{I-Ip}$	$\frac{Et}{Ip}$	$\frac{Et}{A+I-Ip}$	$\frac{Et}{A+I}$
sugar cane							
system I	5.66	9.24	1.07	10.75	1.19	3.71	0.90
system II	6.54	10.57	0.70	7.14	1.10	3.41	0.63
sweet sorghum							
system I	7.02	13.21	1.02	9.84	1.14	4.10	0.89
system II	8.11	16.28	0.69	6.80	1.06	3.70	0.63
stems							
system I	5.24	9.86	1.07	10.74	1.19	3.52	0.89
system II	6.57	12.13	0.75	7.71	1.07	3.55	0.68
cassava							
system I	7.43	13.34	0.81	7.20	1.01	3.66	0.73
system II	8.14	14.40	0.70	6.35	0.98	3.57	0.64
eucaliptus	21.80	30.44	0.68	7.29	0.82	5.46	0.66
pinus	36.77	49.75	0.67	7.12	0.82	5.96	0.65

Et - Ethanol energy; A - Agricultural energy; Ac - Agricultural combustible energy; I - Industrial energy; Ip - Industrial processing (combustible) energy

CONCLUSIONS

The agricultural energy balance shows clearly the high energetic efficiency of forest crops. The tropical conifer forest has showed better results than eucalyptus, due not only to higher crop yields but also to its composition.

This favorable aspect of forest crops associated to the existence of a successful 12-year program of reforestation in Brazil, would allow a rapid response to higher biomass needs at low costs, also allowing any farmer (even with low purchasing power) to participate in the energy production program.

The energy balance analysis is not conclusive. It is necessary to consider particular aspects of the country and its different regions, such as technological development, social aspects, climate and land availability and quality. In spite of the good results shown by the sugar cane energy balance, the expansion of this crop is limited by two factors: a) availability of high fertility soils and an adequate topography for mechanization and, b) high investments for cultivation (energy intensive crop),which are only possible for a more limited part of rural properties.

In particular for cellulosic material, the high energetic gain in the agricultural stage becomes seriously absorbed by the industrial efficiency due to: a) low acid hydrolysis efficiency with a consequentely low ethanol yield, and b) high energy consumption for industrial processing, requiring 6170 kcal/liter which is superior to the calorific value of ethanol (5038 kcal/ liter), and leading to energetic deficit.

Besides the wood crop agricultural energetic aspect which recomends it for the biomass production program, other factors, peculiar to Brazil, must be added to the previous one making it acceptable when a national energetic program is aimed; they are: a) wood crops adjustment to utilization of large areas having low soil fertility, low water availability and low populational density; b) adoption, by brazilian government, of policies to concentrate efforts on ethanol production; c) necessity to produce liquid combustible in large scale and using national technology.

In so considering, it is suggested the intensification of research on cellulose hydrolisis, specially on enzimatic hydrolitic process development, for being the latter much more efficient than the acid process which probabily will make cellulose industrialization more efficient.

Energy conservation is showed as another important technological improvement to be reviewed specially regarding to distillation process and combustible residues (bagasse, e. g.) drying.

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