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ABSTRACT

A comparison is made of the energy costs in the production of ethanol in Brazil and in the United States. Ethanol is produced mainly from sugarcane in Brazil and the energy balance is clearly greater than 1, even if no credit is given to the cane bagasse than can supply all the heating needs of the process. In contrast to that the production of ethanol from corn in the United States has an energy balance smaller than 1. Improvements in technology could change this situation somewhat; in the meantime other reasons rather than energy economy such as by products credits have to be invoked to justify the use of corn as a raw material for fuel production.

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Brazil has embarked in a large program of production of ethanol from sugarcane that is supplying approximately 60,000 barrels per day (bpd) presently and should reach 200,000 bpd in 1985[1]. Most of this ethanol is mixed to gasoline in the amount of 20% yielding gasohol which is used by practically all automobiles in the country (approximately 8 million of vehicles in 1979). This 1:5 ethanol to gasoline mixture does not need special adaptations of the motors. Starting in 1980 an increasing number of cars will be either converted or manufactured to use pure ethanol and their number should reach 2 or 3 million vehicles in 1985.

In contrast to that there is a very heated debate going on in the United States on the validity of a gasohol program[2,3]; unlike Brazil, ethanol in the US is produced from crops surplus (mainly corn) except in the southern states such as Louisiana which are sugarcane producers[3].

A number of questions have been raised in the US against gasohol such as automobile performance, air pollution, land deplection, economics and above all the question of whether production of ethanol will increase rather than decrease fossil-fuel consumption[2]; in other words, that the energy balance of ethanol production (as defined by the ratio of the energy content in the ethanol to the fossil-fuel energy inputs) is actually smaller than one.

The striking differences in policy of the US and Brazil regarding the use of ethanol clearly calls for some explanation. We will discuss here the basis for these differences.

ETHANOL FROM SUGAR CANE

Sugarcane is practically the only commercial source of ethanol in use in Brazil; this is due to the fact that it is easy to obtain ethanol from fermentation of sugarcane juice.

The fermentation of sugars proceeds through the following reactions:

Hexoses $C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$

(glucose + frutose) 180g 92g (ethanol)

Sucrose $C_{12}H_{22}O_{11} + H_2O \longrightarrow C_6H_{12}O_6 + C_6H_{12}O_6 \longrightarrow$

342g 180g (glucose) 180g (frutose)

$\longrightarrow 4C_2H_5OH + 4CO_2$

184g (ethanol)

Typical composition of sugarcane in the southeastern region of Brazil is given in Table I.

TABLE I

Composition of Sugarcane (southeast of Brazil)

	% by weight	average
Sugars	13 - 17	15
Sucrose	12 - 16	14
Hexoses (glucose and frutose)	0.2 - 1.5	1
Fiber (bagasse)	9 - 13	12
Humidity	70 - 73	73

Source: Reference 4

The efficiency for the extraction of the sugars from sugarcane is 95% and the efficiency of fermentation is also 95%;

then in practice the yield of ethanol per ton of sugarcane should be approximately 91 liters. Large scale inefficiencies characteristic of present commercial processing plants bring this figure to a much lower value, around 66ℓ. With the productivities listed in Table II one can obtain 3500 liters of ethanol/ha/year from a typical plantation in Brazil.

TABLE II

Productivities of Sugarcane Plantations in Brazil

Cycle (years)	Nr. of harvests	Total productivity (per cycle) (ton/ha)	Yearly productivity (ton/ha/year)
4	3	180 - 240 210 (ave.)	45 - 63 52 (ave.)

Source: Reference 4

The energy consummed in the preparation of ethanol is due in part to the agricultural phase (growing and harvesting of sugarcane) and in part by the industrial phase (extraction of the juice, fermentation and destillation). Direct and indirect energy expenses are computed[5,6].

In the agricultural phase approximately 85% of the energy is spent in liquid fuels for motorized field equipment (48%), in the manufacturing of the machines themselves (15%) and in nitrogen for fertilizer (22%).

In the industrial phase over 90% of all energy is fuel most of which is used to produce steam; agricultural residues (bagasse) can therefore be used to supply part or all the heat needed for such purpose.

Table III shows a breakdown of the energy expenses for ethanol production from sugarcane in Brazil and in the US .

TABLE III

Energy Inputs in Ethanol Production from Sugarcane
(kcal/liter)

	Agricultural phase	Industrial phase	Total
Brazil*	1,150	3,050	4,200
US**	2,430	3,100	5,530

*Source: Reference 5
**Source: Reference 2

As one can see the agricultural phase in Brazil consumes three times less energy than the industrial phase which reflects the fact that agriculture is less energy intensive than in the US where the energy spent in the two phases is approximately equal. Surprisingly enough, the yield of sugarcane is not higher in the US than in Brazil (72 tons/ha).

The energy needed for the industrial phase can in principle be entirely supplied by the bagasse[5]; each ton of sugarcane produces 250 kg of bagasse (with 50% humidity, with calorific content of 2150 kcal/kg); 1 kg of bagasse produces 2,44 kg of steam where one takes into account the efficiencies involved (1 kg of steam = 540 kcal). Therefore per liter of ethanol one has 4 kg of bagasse or 8.6 kg of steam. Only 5.5 kg of steam (3,050 kcal) are needed per liter of ethanol; there is an excess of 3.1 kg of steam for each liter of ethanol.

If it was not for this bagasse the energy balance for ethanol production would be smaller than one in the US as shown in table IV (1 liter of ethanol has a calorific content of 5.040 kcal).

We are assuming that only the calorific content of the ethanol counts when it is used as a substitute for gasoline ; in reality ethanol is a better fuel than gasoline; as a final result the consumption of ethanol is only 22% greater than the consumption of gasoline for the same mileage, as demonstrated extensively by more than 2000 cars, fueled with pure ethanol (95^{o} G.L.), used in tests in the last 2 years in Brazil.[7]

TABLE IV

Energy Balance for Ethanol Production from Sugarcane

	Energy in 1 liter of Ethanol (A) (kcal/liter)	Energy needed without credit of bagasse (B) (kcal/liter)	A/B	Energy needed in agricultural phase (C) (kcal/liter)	A/C
Brazil	5,040	4,200	1.2	1,150	4.4
US	5,040	5,530	0.91	2,430	2.1

ETHANOL FROM CORN

The typical composition of corn is given in Table V.

TABLE V

Composition of Corn

	%
Starch	72.2
Protein	8.9
Humidity	13.8
Others	5.1

Source: Reference 8

Starch has to be converted into sugars before fermentation; this is done by enzimatic hydrolysis. Two enzimes are generally used: alfa-amilase which converts the starch in oligosaccharide and amilo-glucosidase which converts them in glucose.

$$\underset{100g}{\text{Starch}} \xrightarrow[\text{Enzimatic Conversion}]{} \underset{130.7g}{\text{Glucose}} \xrightarrow[\text{Fermentation}]{} \underset{66.4g}{\text{Ethanol}}$$

In practice only 85% of the starch is converted into sugars; so the overall conversion of starch in ethanol is approximately 75%,when accounting for fermentation efficiency (95%) and convertion of starch to non-fermentable sugars (5%) is considered.

The average yield of corn in the US is 6.01 t/ha and in Brazil only 2.78 t/ha (with 15% moisture) from which 2325 and 1075 ℓ/ha of ethanol, respectively, can be produced.

The energy balance for ethanol production from corn can be calculated using the numbers of Table VI.

TABLE VI

Energy Inputs in Ethanol Production from Corn
(kcal-liter of ethanol)

	Agricultural phase	Industrial phase	Total
US*	2,833	9,300	12,133
Brazil**	1,815	9,300	11,115

*Source: Reference 8
**Source: Reference 9

Corn does not produce bagasse and therefore one does not have a significant amount of energy to use from agricultural wastes in this case except from burning 20% of the cobs and stalks (the acceptable fraction of waste removal without damaging the soil)[10]; this could supply at the very best approximately 1/3 of the process energy needed; this is an upper limit,since stalks is not a direct by-product of the grain, as the bagasse is from sugarcane - some extra energy has to be used if we want to collect and transport them to the industrial plant.

The energy balance for ethanol production from corn can be calculated from the numbers of Table VII.

TABLE VII

Energy balance for Ethanol production from Corn

Energy in 1 liter of Ethanol (A)	B Total Energy needed without any credits (B)	A/B	Total Energy needed with credits due to burning wastes (C)	A/C
5,040	US 12,133	0.415	8,633	0.584
	Brazil 11,115	0.453	7,615	0.662

An energy balance superior to 1 cannot be obtained, unless credits for by-products (such as animal feed), for the higher value of the kcal of ethanol as compared with gasoline when used in I.C. engines and for the octane booster property of the ethanol when blended to gasoline are claimed. Even in these circumstances ethanol is barely a net energy producer[11], so it is evident that less nobel fuel has to be used in the processing, to displace oil consumption.

It is therefore rather clear that ethanol production from sugarcane in Brazil as compared to ethanol production from sugarcane or corn in the US and Brazil is clearly more favourable for the following reasons:

1. the agricultural phase of sugarcane production is less intensive than similar cultures in the US by a factor of 2. Almost the same figure is seen when one compares corn in Brazil and US. This can be a natural trend of agriculture, in developing and developed countries.

2. sugarcane produces enough by-products (bagasse) to supply all the process energy needed; this is not the case of corn in which the burning of cobs and stalks supplies at most 1/3 of the process energy needed.

Improvements in technology could reduce the energy needed for ethanol production from crops and push the energy balance above 1; these improvements are much more imperative when corn is being used than for sugarcane.

In addition to that there might be other reasons (besides energy economy) to convert grain supplies (which is a solid) in a liquid fuel; this is also the case for liquefaction of coal to produce synfuel, or wood hydrolysis for the production of ethanol.

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