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ENERGY BALANCE FOR THE PRODUCTION OF ETHYL AND METHYL ALCOHOL

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ABSTRACT

Energy requirements to produce ethyl and methyl alcohol from five different crops (sugar cane, cassava, sweet sorghum, eucalyptus and pinus) were calculated considering different processing systems: a) transformation of fermentable and/or non fermentable sugars into ethanol and b) transformation of cellulosic materials into methanol. Whenever it was possible the calculation used energy coefficients evaluated from Brazilian input-output matrix. Figures are presented for all the energy consumption in the agricultural phase and for the energy consumed as combustible for the industrial phase. In two particular cases, ethanol produced from sugar cane juice and methanol produced by hydro-carbonization, all the energy embodied in the industrial processes were measured. Capital and maintenance energies became very important when considering crops that requires small amount of agricultural energy. Wood is the less energy intensive crop for ethanol production and, at least for the two examples examined in detail, methanol requires less energy than ethanol to be produced.

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I) INTRODUCTION

The search for alternative renewable sources of energy has been recently the subject of many investigations in developed and less developed countries. The large strategic risks resulting from a dependence on imported oil, the high prices of petroleum and the cummulative pollution of CO_2 in the atmosphere are the main reasons for the attention being given to this area of research.

Brazil assumed a leading position in the utilization of renewable energy sources with the National Alcohol Program (PNA) in 1975. This program established an increasing utilization of ethyl alcohol for automotive propulsion. In 1978 the total production of ethanol amounted to 2.5×10^6 m^3, which corresponds to an average blend of 14% to gasoline (1). New distileries are under construction and probably by the end of 1979 the total production will be 4×10^6 m^3, which is enough to reach the technical limit of 20% blend to gasoline* (2) .

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* Any further increase in the blend will require engine modifications if an efficient utilization of the fuel is intended.

The increase in ethanol blending, together with other conservation measures, explains partially the almost constant annual consumption of gasoline in the country since 1973*, in spite of the increasing fleet of automobiles in the last few years (the substitution of gasoline motor trucks by Diesel operated trucks is another part of the explanation). Figure I shows the total number of cars and the annual gasoline consumption in recent years. The consumption of Diesel and combustible oil increased at an average rate of 8% per year, which accounts for the crescent need of crude oil, despite the stabilization of the gasoline consumption.

The choice of ethanol as a gasoline additive was very convenient since it was possible:

1) to utilize the full installed capacity of the existing alcohol factories,
2) to redirect raw material used in the sugar production to an economically more profitable sector because sugar is presently quoted at very low prices in the international market,
3) to develop an industrial activity which uses only existing local "know-how".

The selling price of alcohol by the producers to the large companies responsible for the blend to gasoline (and subsequent resale) is quite high. The only reason it can compete with gasoline prices is because Brazil, along with several other countries, has artificially raised the prices of the oil derived products. Table I lists the current price of ethanol and some of the petroleum derived fuels in Brazil.

The country is now debating the future of the PNA. As we conclude from these preliminary considerations, one possibility is to start the production of cars with new engines designed to operate with pure alcohol; another choice would be to blend alcohol and Diesel oil in order to get a real reduction in the

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* Actually only after 76 the alcohol content in gasoline increased significantly.

physical amount of imported oil. There are many technological difficulties for the utilization of an ethyl alcohol - Diesel oil blend; however, there is widespread agreement that these problems can be solved through the utilization of additives (3,4) which enhance the self-ignition of the blend in current Diesel engines (15 to 16 atm of pressure). Nevertheless, as can be seen from Table I, the price of ethyl alcohol is not competitive with Diesel oil.

The only way to overcome this economical problem is by an increasing technological effort to reduce the production costs of the ethanol, along with the search for other options compatible with the liquid fuel distribution system already used for gasoline. Presently, methanol produced from biomass (wood in particular) is under strong consideration, since it's price appears to be more competitive with Diesel oil than ethanol.

Several aspects must be investigated before a choice between methanol and ethanol as a substitute for gasoline may be made. The brazilian experience with the utilization of ethanol as a fuel is enormous, in contrast, little is known about problems related to the use of methanol for this purpose. Pollution and corrosion characteristics are often presented against the use of methanol (5). It is also well known that methanol-gasoline blends are much more sensitive to water than ethanol-gasoline blends (5).

In this paper it is compared the energy balance for producing the two fuels. The energy balance is one fundamental measure of the suitability of the fuel as an energy carrier.

II) METHODOLOGY OF ANALYSIS

II.a) Production Sources

Presently, commercial ethanol is being produced in Brazil only through the utilization of directly fermentable sugar from sugar cane juice. Nevertheless, other methods and crops are available and are being considered on the laboratory scale. We include in this comparison all the following alternatives:

1) processing of directly fermentable sugar
2) processing of starch
3) processing of cellulose

from the following crops

a) sugar cane
b) cassava
c) sweet sorghum
d) wood (eucalyptus and pinus)

From sugar cane (a) is possible to prepare ethanol from the juice fermentation (1a), from the hydrolysis of cellulose and from both (1a + 3a). The same is true if we select sweet sorghum, but in this case we can add the hydrolysis of starch (2c) as another way of producing alcohol. Cassava can be a source of ethanol through hydrolysis of starch (2b), hydrolysis of cellulose from stem (3b) and from both (2b+3b). Starting with wood we can arrive to the final product by hydrolysis of cellulose (3d).

Methanol can be produced from biomass; in particular Eucalyptus and Pinus wood have been studied more closely, because they grow in soils which are not qualified for food production and they require a very small quantity of energy for their cultivation.

Several processes are listed in the literature as potential routes for the large scale commercial production of methanol. However, at the present state-of-art, hydro-carbonization seems the more appropriate process (7). For this reason, in our analysis we did energy balance calculations for the hydrocarbonization process for Eucalyptus and Pinus crops.

Methanol is produced by the catalytic reaction of hydrogen and carbon monoxide at moderate temperature ($\approx 300^{o}C$) and high pressure (100-350atm). The required hydrogen/carbon monoxide mixture commonly known as synthesis gas or syngas is obtained from steam gasification of carbon at temperatures around $650-700^{o}C$ (8). Usually the output gas from the reactor must be cleaned from other gases before compression to high pressure for methanol production.

II.b) Methodology of analysis

In order to obtain the energy balance one must examine in detail the various options for ethanol and methanol production, listing all the energy costs involved in the agricultural and industrial phases of their preparation. The energy expended in distribution and resale is not taken into consideration. To disregard these costs in a comparative study of these two alcohols introduces negligible error since both products are liquid fuels with almost the same heat value per liter (5).

The measurement of the total "built in" energy in the products is analysed with the help of well known techniques such as Process Analysis and or Input-Output Analysis (I-O Matrix). Whenever possible we used the Brazilian I-O Matrix compilled with data from the 1970 Census (9). Since this matrix is only concerned with the industrial sectors, all energies figures derived from it must be a lower limit to the real energy cost. The matrix also does not include charcoal and wood as inputs since their production does not involve industrial activity. This omission can introduce a considerable error into the energy coefficients derived from the I-O matrix, especially in a country where the sources of energy present a distribution as shown in figure II.

To reduces this last error we added, to the energy expenditures derived from the I-O Matrix, the energy cost of charcoal used in iron and steel production. This evaluation was made with figures of the average consumption of charcoal in iron and steel industries (10) which are responsible for over 90% of the industrial use of charcoal in Brazil (9). Thus it was possible to arrive at an energy coefficient of 13000 kcal/US$ (1970) expended in the purchase of iron and steel, which reflects the energy content of the charcoal not taken into consideration by the I-O Matrix.

In several cases it was impossible to extract the energy coefficient from the Brazilian I-O Matrix, as it is the case of the fertilizers, since they were not produced in the country in 1970. In all these situations we used energy data from the I-O Matrix of the US economy (11). Price deflators for the Brazilian and American currency were extracted from Ref.12 and 13, respectively.

III) THE PRODUCTION ENERGY COSTS - ETHANOL

III.a) Agricultural phase

This investigation was reported by Silva et al (17) for sugar cane, sweet sorghum and cassava. Other authors (14,15,16) reported this investigation only for sugar cane. For a developing country like Brazil, the data from Silva et al (17) seems more appropriate; it is also more convenient to use because it quotes results for all the three crops which are of interest here. In their paper, da Silva et al classified all the energy costs in ten sectors. We used these same sectors, neglecting however the energy cost of man-power* and reevaluating the other costs. Table II lists all the energy requirements in the agricultural phase evaluated in this paper and in Ref. 17.

Eucalyptus and Pinus energy expenditures were evaluated from available data (20). The energy conversion was made following the prescription used for the previous crops. Table III presents a comparison of our results and those from Ref. 20.

III.b) Industrial phase

The evaluation of the total energy "built-in" the capital investment, consumed in operation and maintenance of an ethanol plant was carried out using as a model a typical brazilian autonomous distillery of 120,000 l/day and 150 days of operation

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* Some authors believe it is more appropriate to not include man-power as an energy cost. The man consumes a certain amount of energy to survive even if he is not working, thus, this energy is not directly linked with the alcohol producing system. In any case, man-power is a small fraction of the total energy consumption (17).

per year (this is the most frequently sold unit in the country, in recent years). Figure III shows a detailled lay-out of all the plant modules: crushing, fermentation, distillation, process steam and electric energy units, water treatment and civil constructions. Table IV lists the economic and energetic costs of the main components of the distillery.

Table V presents a comparison between our results and the ones obtained from Ref. 21. Since large quantities of process steam together with a moderate amount of electric energy are required to operate the plant, it is a common practice in Brazil to built a thermo-electric unit inside the alcohol plant. This is not the case considered in Ref. 21, where electric energy and process steam are bought from external suppliers , which increases the operational cost and decreases the fuel consumption, when compared with the brazilian distillery.

The evaluation of the total energy invested in the thermo-electric unit was carried using the energy coefficients extracted from the brazilian I-O Matrix (9). From the available data of Ref.22 it is also possible to quote this energy. In the Appendix we present in detail a comparison between the results derived from Ref. 9 and Ref. 22.

To determine the combustible expended in the operation of the distillery we assume, as suggested by Ref.9, that bagasse is enough to supply all the energy requirements for the machine operation. The operational costs have a small energetic content as compared with combustible and amount to 3.89% of the capital energy costs (21). It is also necessary to add the maintenance costs which are arbitrarily chosen as 5% of the capital costs (it is compatible with an average life of 20 years for the alcohol plant).

IV) THE ENERGY COSTS OF METHANOL PRODUCTION

IV.a) Process Description

Various authors (23,24,25) describe the process for methanol production from biomass. A short description of the principal steps will now be given.

Wood is harvested, stored, dried and cut to feed a gasifier. Part of the wood is combusted to CO_2, supplying the necessary heat to keep the device at a high temperature (650-700°C). At this temperature steam is injected and reacts with carbon through the reaction

$$C + H_2O \rightarrow CO + H_2$$

Figure IV presents a block diagram of a typical methanol plant with a processing capacity of 570,000 liters/day. We can see its several components including a unit for oxygen production used in the partial oxidation of carbon. If oxygen is replaced by air it is then necessary to include a cryogenic unit to remove the large amount of nitrogen which is present in the exhaust of the gasifier, to avoid large operational energy expenses in the high pressure compressors and high capital energy costs in the construction of the synthesis unit.

Carbon monoxide, hydrogen and several other gases are produced and their percentage composition is strongly dependent on the kind of gasifier and its operational temperature, as can be seen from Table VI. The undesirable gases are removed by scrubbers; heavy hydrocarbons and char are recovered and used to supply part of the energy requirements of the factory.

A shift unit is also included in the plant to produce more hydrogen through the reaction

$$CO + H_2O \rightarrow CO_2 + H_2$$

which is required to reach a H_2/CO ratio of two, thereby optimizing the synthesis efficiency.

The gas is then ready to be converted in CH_3OH in the synthesizer. There are three main classes of synthesizer, according to the gas pressure

1) High pressure $\simeq$300 atm

2) Medium pressure $\simeq$150 atm

3) Low pressure $\simeq$80 atm

In the synthesis unit, CO and H_2 undergo the catalytic reaction

$$CO + 2H_2 \rightarrow CH_3OH$$

IV.b) Energy costs - Agricultural and Industrial Phases

The agricultural costs are already evaluated in section III.a for wood.

The industrial costs can be computed from several projects (23,24,25). Table VII presents the most relevant data. Since the cost estimate of Hokanson et al (23) is the most detailed one and more suitable for an energy analysis we chose it as our prototype for a methanol plant. Table VIII lists all the components, their classification by economic sector and their total "built-in" energy (evaluated when possible from Ref.9).

The operational costs were estimated under the following assumptions:

a) The total installed electric power (42180 kw_e) is generated by thermo-electric units which consume 147550 kg/h of steam at an input pressure of 60atm and output of 2atm (23).

b) The total consumption of low pressure process steam (93980 kg/h (23)) is a by-product from electric generators and must be excluded as an operational cost.

A fraction of the combustible used in the boiler (56%)

are heavy hydrocarbons produced during the gaseification process and the balance (44%) is wood at a rate of 15.8 ODT/h. The heavy hydrocarbons do not contribute to the energy cost, and the heat content of wood is taken as 4500 kcal/kg (oven dried). The total annual combustible consumption for 330 days of continuous operation amounts to 5.63 x 10^{11} kcal.

Plant maintenance is arbitrarily set as 5% of the total capital energy costs, that is 26.2 x 10^{9} kcal/year.

Table IX lists all the industrial costs for methanol processing.

V) DISCUSSION

The embodied energy in the capital goods of methanol and ethanol factories is very low compared with the energy content of the fuel for the factory operation. It is possible therefore to estimate as a first approximation the total energy costs for all crops (and different industrialization process) neglecting the embodied energy in the capital goods. Table X presents the energy costs for ethanol and methanol production, using different crops and industrial processes, neglecting for the industrial phase the embodied energy in the capital goods and maintenance. Table XI lists the energy embodied in the final products at the output of the factory. Table XII shows the energy balance for several crops and industrial processes with the approximation stated above and also considering that all energy needed for industrial processing was derived from burning wood (Eucalyptus) which is produced as a complement of the crop raw material. In order to use the same criteria for different crops we based our calculations in the concept of a "self-sufficient" hectare. The self-sufficient hectare consists on the partial utilization of 1 ha for Eucalyptus crop sufficiently large to cover the energy deficit of the industrial processing of the raw material grown in the rest of the hectare. For example, for the sugar cane crop (system 2) since all bagasse is used as raw material (including the cellulose), there is an industrial energy deficit which is covered by wood cultivated in 0.25 ha, for each 0.75 ha of raw material harvested. The last two columns of table XII can be interpreted as follow:

1) The utilization of wood as raw material is 3 to 5 times more efficient than the other crops considered;
2) Wood is 50% more efficient if the final product is methanol. Each kcal expended yields 33.4 and 45.2 kcal of energy as a liquid fuel if we use Eucalyptus and Pinus, respectively.

Nevertheless the efficiencies quoted in Table XII are correct only as a first approximation. Two aspects must be examined in more detail:

a) The capital energy invested in the plant installation, maintenance and operation was neglected as stated above. This introduces a significant error, mainly in the methanol evaluation, because the total external energy involved is very low. Capital and maintenance energies, as can be seen from Table IX, amount to 4.14×10^{10} kcal/year for the production of 1.893×10^{8} ℓ of methanol, that is, 218.7 kcal/l must be added to the energy costs, increasing the total external energy to 1458 and 1804 Mcal/ha/year for Eucalyptus and Pinus, respectively. For ethanol produced from sugar cane (system 1), as seen from Table V we have to consider an energy cost of 8.44×10^{9} kcal for the production of 18×10^{6} l/year, that is, 496 kcal/l, increasing the total energy expenses from 3796 to 5467 Mcal/ha/year.

b) Electrical energy is generated in ethanol plants at a rate of 1 kw_e for each 9 kg of input steam and in the methanol plant at a rate of 1 kw_e for each 3.5 kg of steam, since higher pressure is used in the latter project. As already proposed by Moreira et al (26) the utilization of high pressure turbine reduces the total amount of bagasse consumed in ethanol processing. Bagasse could be dried to 10% moisture with minor expenses, since at the factory there are enough heat derived from exhausted water at temperatures between 50 and 70°C, increasing its heat content to 4000 kcal/kg (27). With the utilization of this superior combustible it should be possible to produce 4.2 kg of steam at 30 atm and 300°C burning 1 kg of bagasse in a boiler operating with 80% efficiency. A fully electrified alcohol plant requires for operation an excess of 1245 kw_e over the 681 kw_e already used in the present conditions (item IIIb), that is, 1926 kw_e. With the utilization of high pressure steam all this energy could be produced from the burning of 3.50/4.20 x 1926 = 1605 kg of bagasse/h; since the total amount of bagasse available (with 10% moisture) is 10400 kg/h the excess of 8810 kg/h would be able to generate 10570 kw_e to be sold to external consumers.

Table XIII lists the corrected efficiencies when a more realistic calculation, modified as suggested in the above considerations (a) and b)), is performed. A comparison of these results with the previous ones (Table XII) shows the importance of an accurate evaluation of the capital and maintenance energy for a correct efficiency figure. It is also clear that 1 kcal of methanol can be produced with less energy than 1 kcal of ethanol. Many more calculations must be conducted for a knowledge of the total industrial energy for other crops and processes. Even for ethanol from sugar cane juice and methanol from pyrolysis more precise determination of the efficiency is highly desirable.

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APPENDIX

Estimate of Total Energy Embodied in the Electricity Generation Unit

The capital and installation energy invested in a thermoelectric unit is quoted in literature as $3.53\text{x}10^6$kcal per kw_e of installed power (22). From this energy coefficient it is possible to evaluate the total energy requirement for any thermoelectric generation unit, in particular the one used in the 120,000 l/day distillery refered in this paper, if scale factor corrections are neglected.

Assuming that alcohol processed from sugar cane juice requires:

1) Low pressure steam (1.5atm) at a rate of 5.5kg of steam/liter of alcohol (17) for heating and distillation purpose;

2) High pressure steam (15atm) to drive the motor of the crushing unit; it is necessary 14 hp.h/t of sugar cane and the motor consumes 14 kg of steam/hp.h (28);

3) High pressure steam (15atm) to drive a set of knives used to chip sugar cane before crushing; it is necessary 6 hp.h/t of sugar cane and the motor consumes 14 kg of steam/hp.h (28);

4) High pressure steam (21atm) to drive a thermogenerator to produce electricity at a rate of 9 kwh/t of cane with a consumption of 8.9kg of steam/kwh produced (28);

it is possible to evaluate the minimum installed power required and the total steam used for the operation of the 120,000 l/day alcohol plant. The figures are 681 kw_e and 660×10^3 kg of steam/day at 21atm.

Using the energy coefficient obtained from Ref.22 and assuming an installed electric power unit of 1000 kw_e, the total capital and service energy involved is 3.53×10^9 kcal. Since the electric generator uses only 22% of the total steam produced, if we add this fraction of. item 4, item 5 and item 6 from Table IV, all together, we evaluate the total energy embodied in the thermoelectric unit as 6.01 x 10^9 kcal. The difference between this result and the previous one is not large and could be attributed to the small size of the thermoelectric unit.

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TABLE I

Liquid combustibles prices in Brazil**

	Refinery's Price 1978 dollar's/l	Consumer's price 1978 dollar's/l
Ethanol (99.6^{O}GL)	.29	.42
Ethanol (95^{O}GL)	.24	n.a*
Gasoline	.19	.42
Diesel Oil	.11	.22
Combustible Oil	.045	.065

* Not available to the consumer.

** From Ref. 2 .

TABLE II

Average expended energy in the agricultural phase of energy production from sugar cane, cassava and sweet sorghum. On an average, plant cane requires 2 years to grow, ratoon cane requires 1 year. Cassava requires 2 years to grow. From sweet sorghum one can obtain two crops per years, one being a ratoon crop.

	Sugar cane (Mcal/ha/year)		Cassava (Mcal/ha/year)		Sweet sorghum (Mcal/ha/year)	
	This paper	Ref.17	This paper	Ref.17	This paper	Ref.17
Labor	-	118	-	136.5	-	105
Machines	402 1)	638	279 1)	200	787 1)	1250
Combustibles	2239 2)	1976	1491 2)	1327	4217 2)	3722
Nitrogen	687 3)	903	347 3)	555	1665 3)	2222
Phosphorus	89 3)	59	45 3)	73	200 3)	176
Potassium	96	144	53 3)	58	133 3)	230
Lime 4)	37	37	50	50	50	50
Seeds 5)	188	205	118	125	23	25
Insecticides 4)	3	3	24	24	145	145
Herbicides 4)	55	55	24	24	96	96
TOTAL	3796	4138	2431	2572	7316	8021

1) Tractor, truck and agricultural implements - In this paper it is assumed an average life of 10 years for the tractor and implements; 5 years for the truck. Data taken from Ref.17 and transformed in energy according to figures extracted from Ref.9; to evaluate the maintenance energy it is used data from Refs.18 and 11.

2) This combustible energy estimate differs from Ref.17 by the inclusion of the processing energy costs of petroleum derivatives as quoted in Ref. 19.

3) Data from Ref.17 transformed in energy according to the U.S. I-O Matrix, Ref.11. The brazilian fertilizer's production in 1970 was very small.

4) Energy data from Ref.17.

5) In this paper these energies have been evaluated under the hypothesis of Ref. 17, that is, sugar cane and sweet sorghum seeds consumes 30% more energy than the commercial production. It is necessary to use 8.0 ton/ha of sugar cane seeds and 10 kg/ha of sweet sorghum seeds.

TABLE III

Average Energy costs in the agricultural phase for ethanol or methanol production from wood. (Eucalyptus and Pinus).

	Eucalyptus (Mcal/ha/year)		Pinus (Mcal/ha/year)	
	This work	Ref. 20	This work	Ref. 20
Machines	28 1)	21	23(1)	17
Combustibles	428 2)	381	355(2)	315
Fertilizers(3)	36	36	1	1
Defensives	59	59	86	86
Barker(3)	-	-	6	6
Total	551	497	471	425

1) Evaluated from Refs. 9 and 20; maintenance costs obtained from Ref. 11.

2) The figure already includes the energy spent in the processing of petroleum derivatives, according to Ref. 19.

3) Energy data from Ref. 20.

TABLE IV

Economic and energetic investment costs of ethanol plant components. Capacity - 120,000 l/day, operating period - 150 days/year

Description	Price(1) (10^3 Dollar(1978))	Energy (10^9 kcal)
1 - Sugar cane unloading and conveying	510	4.851
2 - Sugar cane preparation and milling	1230	9.150
3 - Juice treatment	210	2.162
4 - Boilers	715	6.780
5 - Thermogenerators	155	.797
6 - Electric power distribution system	715	3.718
7 - Water treatment	75	.728
8 - Laboratory	50	.485
9 - Machine shop and hardware	120	1.265
10- Distillery	1280	12.127
11- Alcohol storage	330	3.104
12- Stillage treatment	285	2.781
13- Metallic structures	340	3.201
14- Other	110	1.067
15- Transportation	185	1.424(2)
16- Buildings	1360	7.13(2)
TOTAL	7670	60.77

1) Data form Cooperativa Central dos Produtores de Açúcar e Álcool do Estado de São Paulo, COPERSUCAR.

2) Calculated from the U.S. I-O Matrix, Ref. 11.

TABLE V

Annual energy costs of an ethanol plant. Raw material - sugar cane. Ethanol produced only from directly fermentable sugar.

COSTS	Brazilian typical distillery Energy (10^9kcal)	Ref. 21 Energy (10^9kcal)
Capital goods (lifetime 20 years)	3.04 1)	40.30 2)
Operation	2.36	2141.2
Combustible	88.79	-
Maintenance	3.04	40.30
TOTAL	97.23	2221.8
Annual capacity ($x10^6$ 1)	18	259
$\frac{\text{Energy consumption in the industrial phase}}{\text{liter}}$	$5.40\times10^3 \frac{\text{kcal}}{\ell}$	$8.58\times10^3 \frac{\text{kcal}}{\ell}$

1) See Table IV

2) Obtained from Ref.21 and transformed in energy according to Ref. 11.

TABLE VI

Typical outcoming gas composition from some reactors*

Reactor type	Lurgi	Winkler	Kopper-Totzek
Combustion's type	Fixed	Fluidized	Entrained
Pressure (atm)	26.5	1-3	1
Temperature (^{o}C)	815	1090	1480
Raw material	Coal	Coal	Coal
Size (cm)	.95 → 5.10	.64	70% → 200Mesh.
Coal type	Non-caking	Non-caking	All
Oxidizing agent	O_2	O_2**	O_2
Crude gas -	volume percentage		
H_2	40.7	43.3	33.2
CO	18.6	35.4	55.6
CO_2	29.8	16.8	9.9
CH_4	9.6	3.2	.4
HC	1.0	0	0
N_2	.0	1.0	.7
H_2S	.3	.3	.3

* Ref. 23

** Air can also be used as oxidizing agent

TABLE VII

Estimated total costs of a methanol plant using wood as raw material

REFERENCE	23	24	25
Methanol production (m^3/day)	570	1370	765
Total cost (10^6 dollars)	52 1)	103 2)	63.9 2)
Working period (days/year)	330	330	330
Annual investment cost (dollars/t)	91.2 1)	75.2 2)	83.5 2)
Raw material consumed (ODT/day)	1120	2700	1559
Energy acquired for operation	380 3)	600 kW_e 4)	--

1) In 1975 dollars

2) In 1976 dollars

3) ODT/day of wood

4) Installed power

T A B L E   V I I I

Description, economic and energetic costs of the ethanol plant using wood as raw material. Capacity 1.89 x 10^8 l/year.

DESCRIPTION REF. 23		Cost (1) (x10^3dollar(1975))	MATRIX SECTOR	Energy/price (1) ($\frac{\text{kcal}}{\text{US\\$ (75)}}$)	Energy (10^9kcal)
Wood storage and reclaim		1650	Industrial machinery	10100	16.7
Gasifier		4000	Iron and steel forgeds	14700	58.8
Cooling, scrubbing and recovery		975	Stainless steel products	6960 (2)	6.8
First stage compressors	ENGINES	250	Electric engines	7200	1.8
	MACHINES	962	Industrial machinery	10100	9.7 11.5
CO_2 removal system, Hot Carbonate & MEA		1704	Stainless steel products	6960 (2)	11.9
Second stage compressors	ENGINES	50	Electric engines	7200	0.4
	MACHINES	1000	Industrial machinery	10100	10.1 10.5
Gas preparation (shift converter)		75	Industrial machinery	10100	0.8
Second CO_2 removal system		364	Stainless steel products	6960 (2)	2.5
Methanol synthesis	ENGINES	75	Electric engines	7200	0.5
	MACHINES	1455	Industrial machinery	10100	14.7 15.2
Methanol separation		621	Stainless steel products	6960 (2)	4.3
Converter-Reactor		530	Iron and steel forgeds	14700	7.8
Cryogenic system		4231	Industrial machinery	10100	43
Installation		6164	-	-	0.
Buildings		1370	Non-residential buildings	8740 (3)	12.0
Electric energy generation		12756	Estimated from Ref.22	3.53×10^6 (4)	148.9

(cont.)

TABLE VIII

Description, economic and energetic costs of the ethanol plant using wood as raw material. Capacity 1.89 x 10^8 l/year.

DESCRIPTION REF. 23	Cost (1) (x10^3 dollar (1975))	MATRIX SECTOR	Energy/price ($\frac{\text{kcal}}{\text{US\\$ (75)}}$)	Energy (10^9 kcal)
Water and process steam distribution system	2192	Pipe-line transportation	17900 (3)	39.2
Site preparation				4.2
parking - free-way	276	High-way construction	15300 (3)	2.3
other	231	average	10000 (5)	6.7
Purifier	639	Iron and steel forgeds	14700	9.4
Electric energy distribution system	875	Energy transmission hardware	10240 (3)	9.0
TOTAL	42450			414.5

Notes:

1) Coefficients obtained from I-O Brazilian Matrix, except when marked.

2) From Ref. 22.

3) Calculated with data from Ref. 11.

4) Value in kcal/kw_e; obtained from Ref.22.

5) Estimated value.

TABLE IX

Annual energy costs of a methanol plant using wood as raw material.

Capacity 1.89 × 10^8 l/year.

COSTS	ENERGY (10^{10}kcal)
Capital goods (lifetime 20 years)	2.07
Operation	-
Combustibles	56.30
Maintenance	2.07
TOTAL	60.44
$\frac{\text{Energy consumption in the industrial phase}}{\text{liter}}$ $\left(\frac{10^3\text{kcal}}{\ell}\right)$	3.193

TABLE X

Energy costs for ethanol and methanol production, using different crops and industrial processes. Agricultural and industrial phase

CROP	Alcohol Production (l/ha/year)	Residual Lignine Production (t/ha/year)	excess bagasse production with 50% moisture (t/ha/year)	Energy consumption (Mcal/ha/year)		TOTAL
				Agricultural phase	Industrial phase	
Sugar cane						
system 1*	3564[1]	-	4.71[1]	3796	14704[2]	18497
system 1+2*	4894[3]	1.50[3]	-	3796	23483[4]	27279
Cassava						
System 1*	2523[1]	-	-	2431	12301[5]	14732
System 1+2*	2963[3]	.50[3]	-	2431	15205	17636
Sweet sorghum						
System 1*	5165[1]	-	2.15[1]	7316	22585[6]	29901
System 1+2*	7123[7]	2.17[7]	-	7316	35509	42825
Eucalyptus						
System 2*	2800[3]	3.00[3]	-	551	18482[4]	19033
Methanol	6668[8]	-	-	551	18480[9]	20431
Pinus						
System 2*	3840[3]	4.40	-	471	25347[4]	25818
Methanol	8249	-	-	471	24594	25065

* System 1 - Fermentation of sugar from sugar cane or cassava roots or stems and grains from sweet sorghum. System 2 - Hydrolysis of cellulose from sugar cane from cassava stems, from sweet sorghum stems and from wood.

1) Ref. 17
2) To produce 1 liter of alcohol 5.5 kg of steam is required; 1 kg of bagasse (50% moisture) produces 2.4 kg of steam. Heat content of bagasse = 1800 kcal/kg .
3) Ref. 20
4) 1 liter of alcohol from cellulose requires 8.0 kg of steam - Ref. 20.
5) 1 liter of alcohol from hydrolysis of starch requires 6.5 kg of steam.
6) 1 liter of alcohol obtained from sweet sorghum stems requires 5.5 kg of steam and 1 liter of alcohol from grain requires 6.5 kg of steam.
7) Fermentation efficiencies according to Refs. 17 and 20.

TABLE X (cont.)

8) According to Ref. 23, 1 ton of methanol is produced from 2.24 ODT of wood; from Ref. 20 is known that 11.8 ton/ha/year and 14.6 ton/ha/year of oven dried eucalyptus and pinus wood are obtained, respectively.

9) Datum obtained using the combustible cost listed on table IX; wood with a heat content of 4500 Mcal/ODT is used as combustible.

TABLE XI

Total energy content in the alcohol and in the excedent residues (excluding the cellulose needed for alcohol processing)

CROP	Alcohol Production (l/ha/year)	Residual lignine excess production (t/ha/year)	50% moisture excess bagasse production (t/ha/year)	Produced energy (Mcal/ha/year) ALCOHOL[1]	RESIDUES[2]	TOTAL
Sugar cane						
System 1*	3564	-	4.71	18020	8478	26498
System 1+2*	4893	1.50	-	24744	5400	30144
Cassava						
System 1*	2523	-	-	12756	-	12756
System 1+2*	2963	.50	-	14981	1800	16781
Sweet sorghum						
System 1*	5165	-	2.15	26114	3870	29984
System 1+2*	7123	2.17		36014	7812	43826
Eucalyptus						
System 2*	2800	3.00	-	14157	10800	24957
Methanol*	6668	-	-	25285	-	25285
Pinus						
System 2*	3840	4.40	-	19415	15840	35255
Methanol	8249	-	-	31276	-	31276

* See table X footnote.

1) Ethanol heat content - 5056 kcal/l; methanol heat content 3792 kcal/l, Ref.5.

2) Bagasse heat content (50% moisture) 1800 kcal/kg; Lignine heat content 3600 kcal/kg, Ref.20.

T A B L E X I I

Energy balance. All the energies in Mcal/ha/year

CROP	Fraction of occupied area (%) 1)	Alcohol energy	Industrial Energy Produced 2)	Industrial Energy Consumed	Industrial Energy Balance	Agricultural Energy A 3)	Agricultural Energy B 4)	Agricultural Energy A+B	Alcohol energy 5) / external energy	Total energy 6) / external energy
Sugar cane										
System 1	100	18020	23182	14704	+8478	3796	0	3796	4.75	6.98
System 1+2	75	18558	4050	17612	-13562	2847	138	2985	6.22	6.22
Cassava										
System 1	81	10332	0	9964	-9964	1969	105	2074	4.98	4.98
System 1+2	79.8	11985	1440	12164	-10724	2976	110	3086	3.88	3.88
Sweet sorghum										
System 1	100	26114	26455	22585	+3870	7316	0	7316	3.57	4.10
System 1+2	65.7	23769	5155	23436	-18280	4829	187	5016	4.74	4.74
Eucalyptus										
System 2	87.4	12373	9439	16153	-6714	481	70	551	22.46	22.46
Methanol	72.8	18407	0	14773	-14774	401	150	551	33.41	33.41
Pinus										
System 2	84.8	16464	13432	21494	-8062	400	84	484	34.02	34.02
Methanol	68.3	21362	0	16798	-16798	322	175	497	42.98	42.98

1) Fraction of total area occupied by the crop. The remaining part is occupied by the Eucalyptus culture, with the purpose of supplying the energy deficit of the industrial phase.

2) Total energy extracted from available residues (bagasse or lignine).

3) Energy consumed in the agricultural phase for raw material production.

TABLE XII (cont.)

4) Energy consumed in the agricultural phase for Eucalyptus production which is used as combustible in order to cover the industrial energy deficit.

5) Only energy expended in agriculture must be computed as external energy. Industrial energy is supplied by wood and/or residues.

6) Total energy = alcohol energy plus the remaining residues energy.

TABLE XIII

Energy efficiency

CROP	A Produced energy (Mcal/ha/year) ALCOHOL	 ELECTRICITY	B External consumed energy (Mcal/ha/year)	EFFICIENCY A/B
Sugar cane System 1	18020	3245[1)]	5801[2)]	3.66
Eucalyptus Methanol	18407	-	1613	11.4
Pinus Methanol	21362	-	1729	12.4

1) Electric energy sold during 150 days/year with a 50% load factor

2) It was assumed that energy embodied in capital goods and industrial maintenance energy are increased by 20% on account of the high pressure steam and the increase in electric power generation capacity.

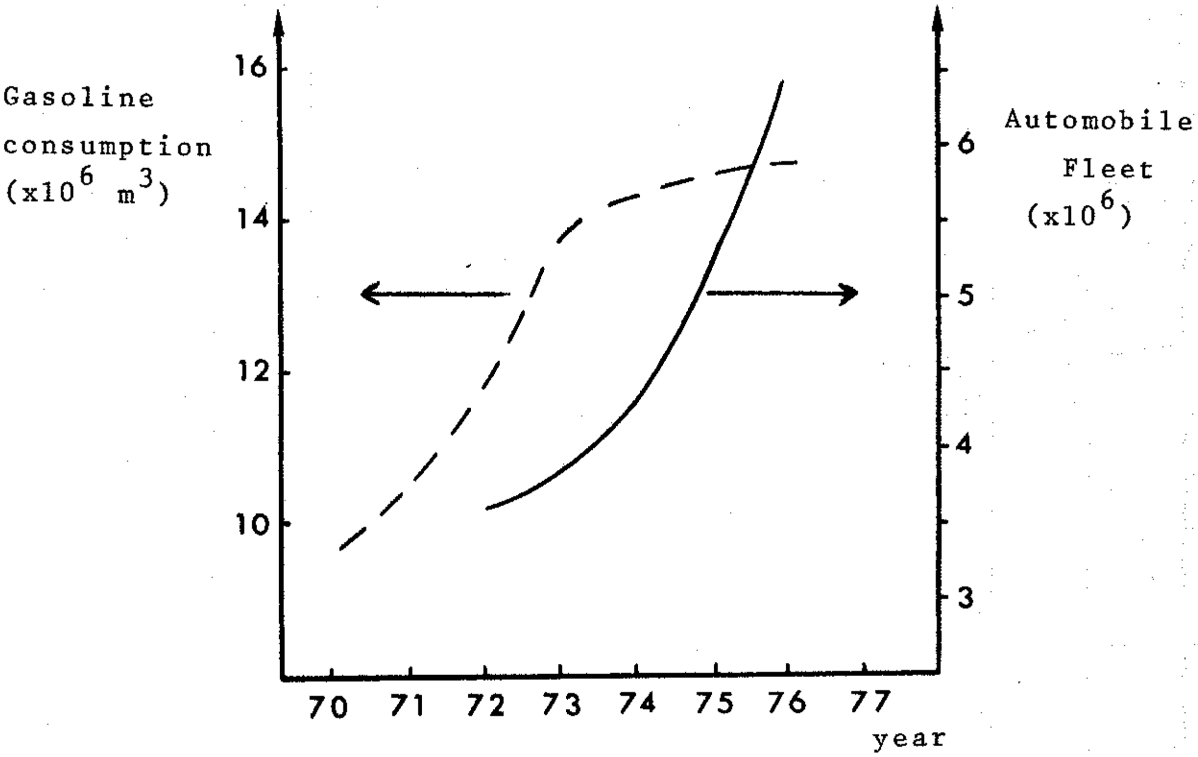

Fig.I Brazilian automobile fleet and gasoline consumption in the last year

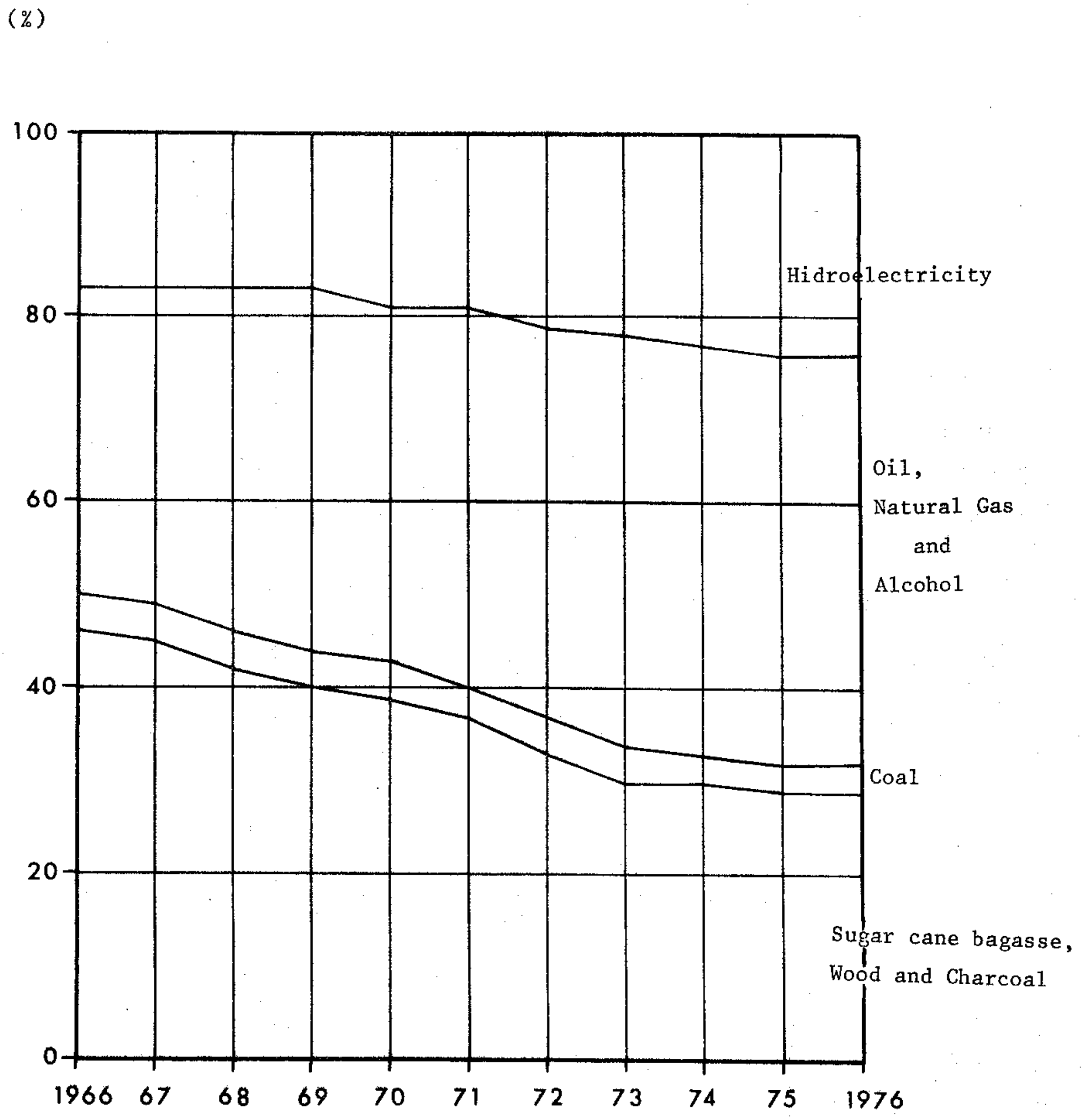

Fig. II Relative participation of all primary energy sources in Brazil, in the last decade

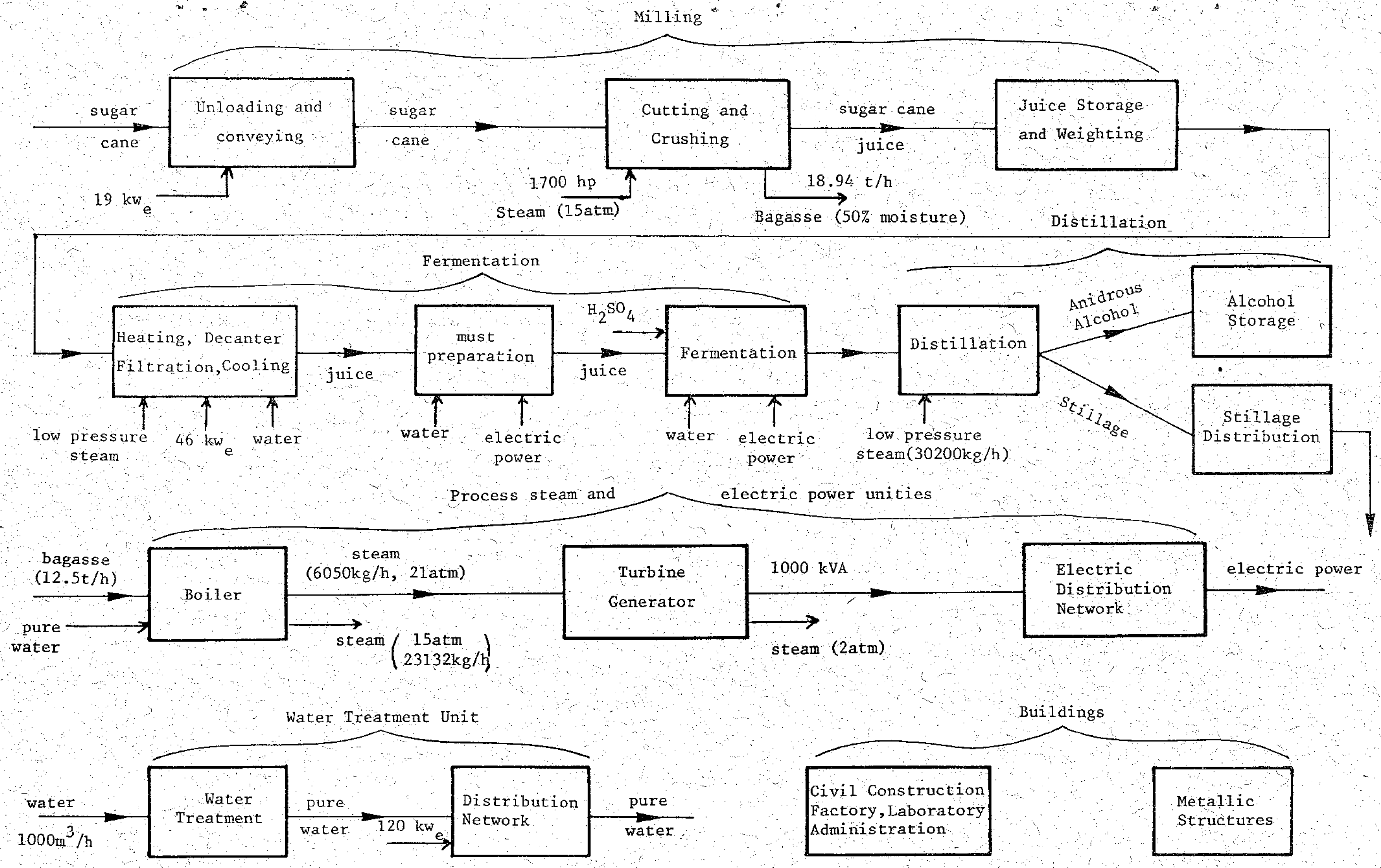

Fig. III Block diagram of an ethanol plant. Raw material - sugar cane; ethanol obtained from directly fermentable sugars

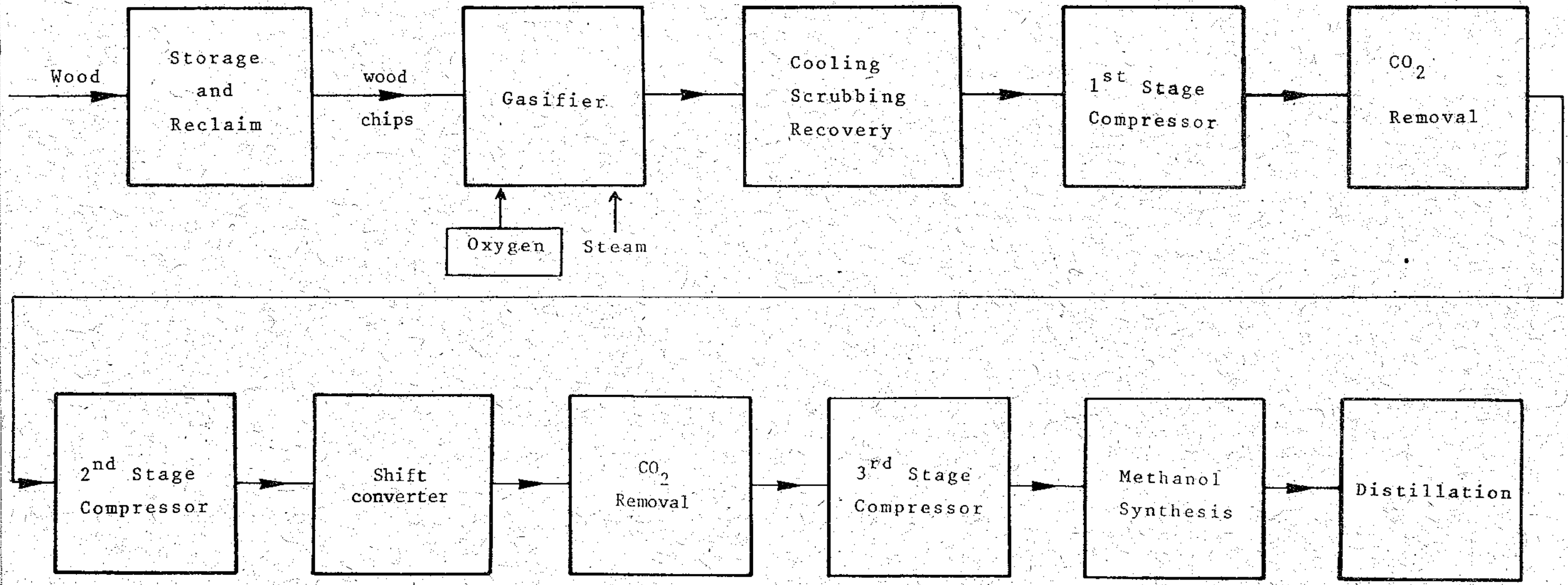

Fig. IV Block diagram of a methanol plant. Raw material-wood
From Ref. 23.