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IMPACT ON NATURAL AND HUMAN RESOURCES OF ETHANOL PRODUCTION FROM BIOMASS

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PREFACE

The Resources Group at IIASA is concentrating an increasing amount of effort on the WELMM analysis and/or comparison of natural and synthetic liquid fuels, conventional oil, shale oil and syncrude from tar sands, liquid fuels from coal, etc. All these are of fossil origin. But a completely different class of synthetic liquid fuel also deserves attention--one which is derived from so-called biomass. In this class of primary importance are alcohol and methanol (from wood). Methanol is of particular interest since it can also be produced from coal, and a promising process has been developed (by the Mobil Oil Corporation) to convert methanol to much needed high grade gasoline.

Economic comparisons are relatively difficult since the stages of development of these various liquid fuels are very different--some are still in the laboratory stage or at the pilot stage, others are very near commercial application or even already commercialized (tar sands). Also, impact on natural resources differs greatly from one type of fuel to another and from one process to another. We therefore decided to use the WELMM method to achieve a better understanding of some of the systems aspects of these liquid fuels.

Various reports and working papers have already been devoted to the topic as far as fossil fuels are concerned.

This paper opens up a new field: biomass liquid fuels. It is based on various studies--with a different initial objective--carried out by Bruno Lapillonne and colleagues at the IEJE. I thought it would be interesting to reshape some of the results, or reflections, according to the WELMM format. This paper shows the result of this effort, and although still preliminary is very interesting.

It is a double pleasure for me to introduce the paper, since a few years ago Bruno Lapillonne helped me to pioneer the "WELMM approach".

Finally, the paper is a good and encouraging example of continuation of close cooperation between IIASA scientists--even long after they have returned to their home institutions.

Michel Grenon.

IMPACT ON NATURAL AND HUMAN RESOURCES OF ETHANOL PRODUCTION FROM BIOMASS

The oil crisis of 1973-74 has acted as a revelator of the oil dependence of industrialized countries and of the exhaustibility of this resource. Since then countries' energy policies have focused on the development of substitutes to oil, either by immediate investment or by stimulating research and development for new energy sources and technologies. In that respect, Brazil assumed a leading position in the utilization of renewable energy sources with the implementation in 1975 of the National Alcohol Program (PNA). This program aimed at substituting gasoline with ethanol, produced from sugar cane, by producing in 1980 a motor fuel blend of 20% alcohol and 80% gasoline. In 1978, the total alcohol production amounted to 2.5 $10^6 m^3$, which corresponded to an average blend of 14%. This production was expected to be about $4.10^6 m^3$ in 1979.[*] The 20% blend is usually considered as the technical limit; any further substitution of gasoline with alcohol can only be done by the utilization of 100% alcohol cars.

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[*] Equivalent to approximately 2.10^6 tons of oil.

Since the Brazilian decision to develop alcohol as a source of energy has been publicized, many countries, especially those among the sugar cane producers, have been looking towards Brazil, considering that a similar strategy could help them in alleviating their energy supply difficulties (foreign dependence, balance of payments). Apart from the energy aspects, the sugar exporting countries consider alcohol production as a means to diversify their sugar cane production to a more economical and profitable sector since sugar is presently quoted at a low price on the international market. Various studies carried out in some of these countries make us think that the Brazilian experience may induce too rapidly, by an imitation effect, the development of similar programs in other countries without a careful investigation of their particular economic, energy, and agricultural conditions. As a consequence, premature decisions may be taken in favour of alcohol with negative impacts on their future economic development and food supply. The pitfall of most of these alcohol feasibility studies is to mainly concentrate on the energy aspects (e.g. energy supply versus energy demand, cost comparison of alcohol and gasoline). The purpose of this paper is to look at some impacts of the development of large-scale alcohol production in a country. It concentrates mainly on the impacts on natural and human resources and tries to identify difficulties, constraints on bottlenecks that alcohol production may have to overcome to be considered viable. The idea behind this analysis is that society does not consume energy alone, but a complex set of natural and human resources.*

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*We refer here to the WELMM approach developed at IIASA by M. Grenon [1],[2]: WELMM (Water, Energy, Land, Manpower and Materials).

In this investigation we are perfectly aware of not having covered all the systems aspects of alcohol production: for instance we did not look at its social and institutional implications, or at its interference with the food supply systems [3].

TECHNOLOGY

The technology of ethanol production from biomass involves two major stages: an agricultural phase during which a crop is cultivated and harvested and an industrial phase for the conversion of the crop into ethanol. There are two basic methods of processing crops into ethanol. The first method, and the one most frequently used, calls for a fermentation of the directly fermentable sugar contained in the crops. The second method is based on the hydrolysis of the cellulose and/or starch and, as it has only been developed on a small-scale, it will not be discussed in this study. The fermentation method can use a wide range of raw materials such as sugar cane juice, cassava, and fruits (e.g. bananas, etc.). In this paper we will only concentrate on sugar cane and cassava since they represent the most promising raw materials for large-scale production of alcohol on a global level. Figure 1 is a flow diagram of an ethanol plant using sugar cane as a raw material. The first operation--the milling--consists of the unloading, cutting, and crushing of the sugar cane. The cane juice, once extracted, is heated and filtered to obtain must which is then fermented. Ethanol is finally obtained by distillation. Although each one of these industrial operations is well known, technical improvements are still possible. For instance new milling processes are being developed which can increase the juice yield con-

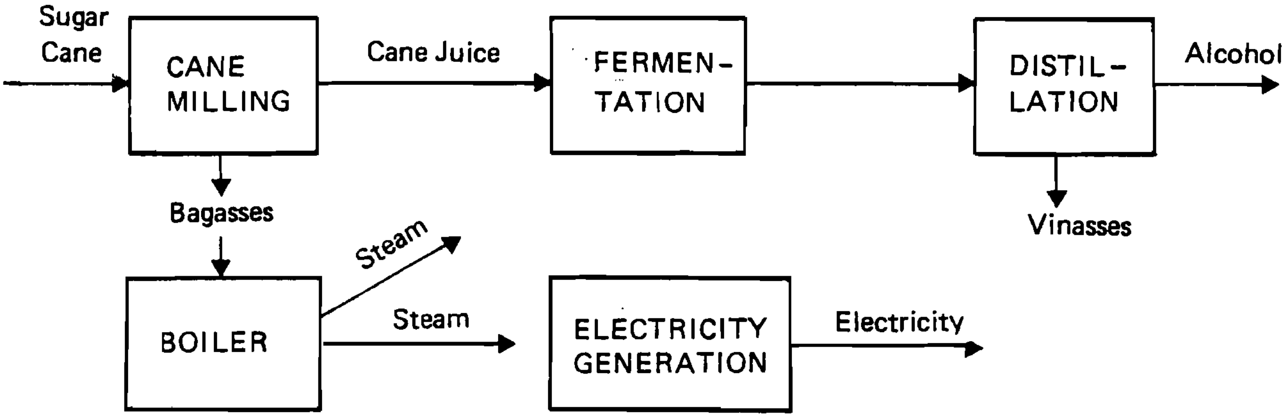

Figure 1. Flow Diagram of an Ethanol Plant

siderably. For the fermentation stage, new varieties of microbiological activators are being studied which are more resistant to alcohol concentration and therefore may lead to higher yields.

Alcohol production from cassava is not currently being carried out on an industrial scale and technical problems still exist e.g. direct fermentation, as with sugar cane, is not possible and enzymatic action is required. Since less accurate information is available for cassava than for sugar cane, we shall devote most of the analysis to sugar cane--making some comments on its advantages and disadvantages when compared to cassava.

WATER

The influence of alcohol production on water resources appears at the agricultural and industrial levels. Water is needed at the agricultural phase for the irrigation of the sugar cane plantation. The quantities required may vary significantly from one region to another depending on the climatic conditions. The availability of water is a necessity for a region which would want to develop sugar cane plantations. Irrigation facilities may have to be built in dry areas, with probable positive impacts on other crops, since these facilities could supply water to other crops.

As is the case for most industrial processes, sugar cane transformation into alcohol requires large amounts of water. Water is mainly used to wash the cane; water is also needed for steam production but the condensed water is recycled. We did not find reliable information on the quantities of water required: it is probably of the order of several tons of water per ton of sugar cane (one source of information indicates 5 tons [3] and another 17 tons/t [5]). The water is not consumed in the process and has therefore to be discharged into the environment. The typical size for an alcohol plant is presently 100-120 m^3 alcohol production per day. Such a factory will have to reject large amounts of waste water which may significantly increase the pollution of the water sources. In Brazil this problem is considered as very serious since most of the distilleries are located near rivers. Regulations forbidding direct discharge into the rivers are expected to be put into force. According to reference [4], an alcohol distillery of 100 m^3/day capacity would produce the same pollution as the sewage of a city of about 70000 inhabitants.

The cane juice fermentation leaves a liquid residue called vinasse: about 12 m^3 of vinasses are produced for each m^3 of alcohol. The disposal of the vinasses is by far the most acute environmental issue related to large-scale alcohol production. A distillery of 100 m^3/day capacity produces about 1200 m^3/day of vinasses which represents a polluting power equivalent to that of a city of 400000 inhabitants. The 1978 Brazilian alcohol production was about 30 million m^3 of vinasses, which gives an order of magnitude of the dimension of the problem. Any further development of the Brazilian Alcohol Program will be confronted with this issue. No satisfactory solution has yet been found but any solution will mean an increase in the alcohol production costs. Several disposal alternatives are presently under consideration.

-- direct application on the soil as a fertilizer (problem of transportation, and of chemical content of the vinasses);

-- incineration and use of the ashes, rich in potassium, as a fertilizer;

-- anaerobic fermentation to produce biogas (problem of finding a use for the gas)

-- fermentation to recover proteins and prepare animal food.

ENERGY

Alcohol production from sugar cane represents a conversion of biomass into energy. Biomass can be considered as the primary energy source and alcohol as the energy form under which it can be used by the consumers. The harvesting, upgrading and transportation of the primary energy sources requires additional consumptions of energy. It is therefore interesting to look at the energy balance of the overall operation i.e. to evaluate how much and what type of energy has to be mobilized during the different stages of the alcohol production and to compare it with the energy content of the outputs (alcohol, and possibly byproducts).

Agricultural Phase

The energy required at the agricultural stage (i.e. sugar cane production) is mainly used for the cane harvesting in the form of motor fuels (collecting trucks, truck loading machines). The amount of energy used may vary significantly from one plantation to the other, depending on the level of mechanization of the harvesting and the average distance between the sugar cane fields and the ethanol plants. In most countries, the sugar cane production is semi-mechanized i.e. the cane is cut manually and is collected and loaded into trucks with a machine. The distance of transportation field/factory depends on the size of the plant, the size of the fields and the dispersion of the fields around the plant. The distilleries are usually installed in the middle of the sugar cane fields in order to reduce transportation costs. Because of the above-mentioned factors a large dispersion in the energy requirements in sugar cane plantation exists. As a typical average for Brazil, Silva [5] and Moreira [6] indicate a direct consumption of about 9GJ/ha.* Apart from these direct energy requirements, energy has, in addition, to be consumed indirectly for the fabrication of agricultural machinery and trucks, nitrogen fertilizers and various miscellaneous input materials (herbicides, insecticides). If we add up the direct and indirect requirements, we get a total of about 17 GJ/ha, roughly distributed as follows [6]:

Direct (motor fuels) ≃ 55% (9 GJ/ha)
Indirect ≃ 45% (8 GJ/ha)
    (machines) ≃ (15%)
    (nitrogen fertilizers) ≃ (20%)
    (miscellaneous materials) ≃ (10%)

Cassava (manioc), usually considered as an alternative raw material for ethanol production, requires 40% less energy, (i.e. 10 GJ/ha, of which 6 GJ/ha is for direct fuel consumption); the distribution between direct and indirect components is almost the same as with sugar cane [6].

Industrial Phase

An alcohol plant requires for its operation large quantities of process steam together with a moderate amount of electricity. In most cases, the electricity and steam are co-generated on site, using bagasses as a fuel. Bagasses are waste organic materials with an average moisture content of 50% and a calorific value of about 7.5 GJ/t (≃ 1800 kcal/kg)

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*Because of the uncertainties in the energy consumption figures, we have rounded all of them in this section; the idea being to provide an order of magnitude and not exact figures.

left over after the extraction of the cane juice. Apart from their utilization as an energy source they can also be used as a construction material and as a raw material in paper fabrication. Two energy supply schemes can be envisaged for the co-generation of steam and electricity:

i. the production of low pressure steam and the generation of electricity at a rate of 1kWe for each 9kg of input steam; in this case the design is such that the plant is self sufficient in electricity and almost all the bagasse is used.

ii. the generation of electricity through the production of high pressure steam (30 atm); this leads to an excess of electricity which can be sold outside.

The first scheme is presently the only one to be developed since the companies have so far not had enough incentive to increase their investments (high pressure boilers) to sell electricity to external consumers (case of the second scheme).

The indirect energy requirements (e.g. energy invested in the facility or in the input materials) is small compared to the direct energy consumption. According to [5] and [6], the indirect requirements represent less than 10% of the total requirements.

Table 1 indicates the energy requirements of ethanol production from sugar cane and cassava. The net energy efficiency is about 2 in the case of sugar cane and about 1 with cassava. The recovery of cassava stems represents

TABLE 1: ENERGY BALANCE OF ETHANOL PRODUCTION (MJ/l alcohol)

		Net energy production			External energy requirements	Ratio energy produced/ energy required
		Wastes	electricity	Alcohol		
Sugar Cane	No co-generation	10 to 21[a]	-	21	18	1,7 to 2,3
	Traditional co-generation scheme	?	-	21	12	1,8
	Production of electricity surplus	?	4	21	12	2,1
Cassava	No recovery of organic wastes	-	-	21	19 - 25	0,9 to 1,2
	50% recovery of organic waste	8	-	21	20	1,5
	100% recovery of organic waste	15	-	21	21	1,7

Sources: from references [4],[5] and [6]

Definition
Net energy production = energy available for external consumers
External energy requirements = energy to be purchased outside

[a] The theoretical heat content of the recovered bagasses correspond approximately to 21 GJ/l ethanol; but in practice it is considered that only half of this calorific value is useful.

a possible way of improving the cassava/alcohol energy balance but technical problems still exist. From this table one can see that the cassava route is much less interesting since we have to consume almost as much energy as is recovered in the alcohol; nevertheless low quality fuel may be used in the distilleries. Even in the most optimistic case (full recovery of the cassava wastes),the energy balance is less favorable than with sugar cane. All these figures have to be considered carefully since they depend greatly on:

-- the agricultural yield (here average yields were taken: 54t/ha for sugar cane and 14,5t/ha for cassava);

-- the energy quality of the residues and their mode of utilization.

LAND

The concept of energy production from biomass implies the mobilization of land to grow the raw materials (e.g. wood, sugar cane). The definition of the land potential that can be devoted to such production calls upon two criteria: on the one hand, a criterion of suitability of the land to the selected crops (soil types, climate, topography), on the other hand a criterion of land availability (e.g. land without culture).

Not all land types are suited to sugar cane cultivation. Sugar cane needs good soil qualities and rather flat land. It also requires water but not too much (rainy areas give low alcohol yields) and good sun conditions. Sugar cane cultures are restricted to tropical areas. Compared to the alternative crops usually considered to produce energy (e.g. wood, cassava), sugar cane is probably the most demanding in terms of climatic conditions and land quality; this causes a serious limitation on the available agricultural land and land potential for sugar cane.

The concept of available land is more difficult to grasp. One usually considers as available the land presently unused. Good quality land which is not used is probably limited, except in a few countries (like Brazil for instance). Areas presently occupied by subsistence crops or low productivity (and rentability) plantations may also be considered as available. But one should be aware of the consequences of shifting from the existing crops to energy crops like sugar cane: replacement of polycultures by a monoculture which increases the soil exhaustability, effect on the food supply of the local population if subsistence crops are replaced by sugar cane, reduction of local agricultural production and risk of dependence on inputs. In any case the decision to devote large areas of land to energy crops should not be left to the experts and industrialists alone, but should be controlled by the government and be part of its overall development policy, especially in its energy and agricultural aspects. In any feasibility study on large-scale sugar cane/alcohol development, one should evaluate the potential available land only after having considered, on the one hand the long-term land requirements for an adequate food supply of the population, accounting for both the population evolution and improvement in the nutrition and on the other hand the requirements for substituting imports of basic agricultural products with domestic production. After deciding what land should be reserved to fulfill these priorities, policy decisions should be made to decide the allocation of the remaining land potential between sugar cane (or other energy crops) and other cultures which may be more interesting for the country. Such decisions should not only look at economic aspects (rentability, effect on balance of payments) but also at social, institutional and environmental impacts.

The amount of land that has to be committed to reach a given alcohol production depends on the one hand on the agricultural yield of the raw material (e.g. the productivity in tons/ha), and on the other hand on the conversion efficiency of the crop into an energy form (ethanol or methanol for instance).

Table 2 indicates the average sugar cane yield observed in various South American countries. These yields vary quite a lot from one country to another, (range between 50 and 150t/ha), mainly because of differences in ecological conditions (land quality, climate) and in the sugar cane varieties. Similar differences can be observed within each country. In Ecuador for instance the average yield of the big plantations belonging to the sugar mills is 90t/ha compared to 66t/ha for the independent cane growers. In Brazil, although the average yield is low compared to the other countries (46t/ha), the productivity exceeds 60t/ha in the Sao Paolo State, the main region where the alcohol production is presently being developed.

The fermentation and distillation of sugar cane juice usually yields between 63 and 70 litres of alcohol (ethanol) per ton of cane; in the rest of the report we will use an average yield of 67 l/t. Therefore we can evaluate now the average quantity of alcohol that can be produced from the cultivation of 1ha of

Table 2: Sugar cane yield in Latin America

	1967	1976	Trend
Brazil (average)	46 t/ha	47 t/ha	approximately constant since 1967
Sao Paulo State (Brazil)	56 t/ha	64 t/ha	1%/year 1947-1976
Venezuela		80 t/ha	
Colombia		120 t/ha	180 t/ha for 18 months
Ecuador (average)	41 t/ha	67 t/ha	6%/year 1967-1976
Central America		70-84 t/ha (depending on the country)	
Peru		150 t/ha	220 t/ha for 18 months

Source: Reference [3]

sugar cane for various countries. It varies between 3000 and 10000 l/ha; measured in energy units [1] this means an energy yield of between 60 and 210 GJ/ha. In this study we will consider as typical for South America an alcohol yield of 4500 l/ha i.e. about 95 GJ/ha - the equivalent of 2 tons of oil.

The likely alcohol production from sugar cane in Brazil in 1986 is expected to be about $5.10^6 m^3$; taking an average productivity of 60t/ha. This means that about 1,2 million ha will be devoted at that time to sugar cane. A realistic evaluation of the agricultural potential of Brazil indicates a maximum of 308,5 million ha, of which only 68% (209.10^6ha) are suited to permanent short cycle crops (e.g. sugar cane) [4]. Therefore, the land use for sugar cane in 1986 is almost insignificant compared to this potential (less than 1%). However, one should be careful when dealing with this global concept of land potential:

-- sugar cane, as explained above, requires good quality land, good sunny conditions and water resources, therefore the effective sugar cane potential is probably much lower than the agricultural potential.

-- too large a distance between sugar cane plantations and consumer markets may increase alcohol cost and make unsuitable large but remote areas which would otherwise have been suitable for the production of sugar cane.

-- the potential development and land requirement of other crops should be taken into account.

If Brazil has no land constraints, other countries such as Ecuador and Colombia may well have constraints (see reference [3] for example).

Cassava fermentation is often considered as a possible alternative route to ethanol, since it can grow on low quality and dry land. Cassava therefore reduces the risk of competition of energy plantations with other crops and extends the land potential for alcohol production. In addition the quantity of alcohol that can be extracted from cassava is much higher than with sugar cane (170 l/t compared to 67 l/t). At present the cassava cultivation is mainly practiced in small plantations to provide food for the local population: it is a non-technical culture and the yield is rather low (10-15t/ha). As a result, with the present agricultural practices, cassava plantations could yield about 2500 litres of alcohol/ha, that is to say almost half as much as with sugar cane. One can argue, and experiments have shown the practicability, that productivity improvements could be obtained with more intensive cultivation but this is rather speculative and would need changes in its cultivation practices.

Table 3 compares the land commitments for various energy crops. When looking at Table 3 one should bear in mind that the data may differ quite a lot from one country to another, because of differences in agricultural productivity of each crop. Of the four crops considered in this table the sugar cane/ethanol route appears to be the less land-intensive process.

Table 3: Energy productivity per hectare for various energy crops

	Alcohol production[b]			References and comments
	l/ha/year	GJ/ha/year		
		Gross[c]	net[d]	
Sugar cane/ethanol	4500[a]	95	40	Traditional co-generation scheme (see Table 1)
Cassava (manioc)/ethanol	2500	55	0	Normal process without recovery of the wastes (see Table 1)
Eucalyptus/methanol	6700	105	20	(6)
Pines/methanol	8300	130	25	(6)

[a] A reasonable range to be considered around this value is 3500-5500 l/ha/year.

[b] Rounded figures.

[c] Calorific value of the alcohol produced.

[d] Net energy balance: difference between energy produced and energy used. One should carefully consider the concept of net energy since we have put a high quality fuel (ethanol) on the same level as the fuels consumed in the industrial process (85% to 90% of the total energy required) which can be a low grade fuel (lignite, wood, peat).

MATERIALS

Contrary to some new energy sources like oil shales or tar sands, ethanol from sugar cane does not involve significant material problems, either as input material or as waste material. At the agricultural phase, the main materials required are fertilizers; the amount needed may vary significantly from one region to the other depending on the soil characteristics. In order to provide some order of magnitude, we indicate the fertilizer requirements estimated for the Brazilian Alcohol Program in Table 4. It appears that on average 665 kg of fertilizer has to be used per ha which means approximately a consumption of 150-170 kg per m^3 alcohol (based on an alcohol yield of 4000-4500 l/ha). Other materials are required to grow sugar cane but in smaller quantities. According to Brazil Acucareiro (private communication), a sugar cane plantation consumes on average 0.50 kg/ha of fermicide and 3,30 kg/ha of herbicide (no insecticide is required). With all these figures a production of $5.10^6 m^3$ alcohol in 1986 in Brazil would lead to the following direct material requirements: between 750000 and 850000 tons of fertilizers, and about 5000 tons of herbicide and fermicides. At the industrial phase no significant quantities of materials are consumed.

Apart from the direct requirements, structural materials (mainly steel) are required for the agricultural machinery and for the construction of the alcohol plant. We do not have any quantitative information on these requirements.

In the case of cassava the fertilizer requirements are of the same order of magnitude. As mentioned above the fermentation is not direct and enzymes have to be used (about $5kg/m^3$

Table 4: Nutrient and fertilizer requirements in sugar cane plantations in Brazil.[a] (in kg/ha)

		North	Center/South	Average[b]
nutrients	nitrogen (N)	100	45	60
	phosphorus (P)	140	95	110
	potassium (K)	120	65	80
	total	360	205	250
fertilizers	sulfate of ammonium (20.5% N)	490	220	290
	triple superphosphate (46% P)	305	205	240
	potassium chloride (60% K)	200	110	135
	total	995	535	665

[a] Rounded figures; source: private communication.

[b] Weighted according to the distribution of the sugar cane production between the two regions (about 70% in the center and south).

alcohol). Although the volume of enzymes involved is not important, it may be a source of foreign dependence since they may not be produced locally (which is presently the case in Brazil).

The production of ethanol induces the generation of residues (bagasses, liquid wastes called vinasses with sugar cane; cassava stems and fermentation wastes with cassava). We have already discussed the problems raised by their disposal therefore we will not comment on them here.

MANPOWER

Compared to the traditional energy production routes, alcohol production is more labour intensive. Most of the labour is needed in the agricultural phase, mainly to harvest the sugar cane. As already mentioned most of the sugar cane production is presently semi-mechanized (manual cutting, collection with machines). The development of full mechanization is presently not economical because of the low salary level prevailing in most developing countries. Even if these conditions were to change,such an evolution would probably not be desirable as there is high unemployment in these countries; in any case it could not be spread to all plantations since the mechanization of sugar cane cutting requires very flat land. The present employment of agricultural personnel is one man for 2.8 ha in Brazil, one man for 3 ha in Ecuador. In Colombia the manpower productivity is higher, one man for 4 ha. These figures include only workers engaged in the harvesting labours, which actually represent the great majority of the labour. No technical qualification is required for the personnel in charge of the harvesting. Sugar cane production is a seasonal activity since the harvest lasts on average 180 days/year (usual range is between 130 and 200 days/year). This means that most of the labour is seasonal which causes certain sociological problems. In Brazil, according to a 1970 census ('Censo Agropecuario 1970') about 608000 persons were working in the sugar cane culture (3.5% of the total occupied population), distributed as follows: 40% independent workers (field owners), 30% permanent employees and 30% temporary employees. The same census indicates that the production structure is totally different for cassava since more than 90% of the people involved in the cassava culture are independent workers: all the cassava is grown in small farming units as opposed to sugar cane for which large plantations prevail. From an employment standpoint, cassava presents two major advantages for a developing country: on the one hand, the people are occupied all the year round, on the other hand its culture is totally manual and more labour intensive (0,7 ha per worker for cassava against 2,8 ha for sugar cane). Whether based on cassava or sugar cane, an alcohol program will undoubtedly create a large number of agricultural jobs and therefore permits a reduction of rural migration, which is a serious issue in most developing countries.

An alcohol program will also create employment in the alcohol plants, a typical distillery of $100m^3$/day capacity employs between 50 and 100 workers, most of them being skilled workers.* The direct employment requirement, to support an alcohol plant with a capacity of $100m^3$/day ($18000m^3$/year)** can be

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*estimated from references [7],[8] and [9]

**Since the sugar cane has to be processed when it is harvested the distillery usually only operates during the harvesting season (average 180 days).

estimated at 1400* persons (more than 90% being employed in plantations; reasonable range 1100-1700). A production of 5 million m^3 in 1986 in Brazil will therefore concern directly about 400000 persons.

To have an overall picture of the impact of alcohol production on employment, one should include the people employed in the manufacturing of agricultural machinery, the fabrication of the distillery components and finally the construction of the distilleries. In the frame of this study we have not tried to evaluate these indirect employment effects; this could be done using a disaggregation of the investment costs according to its major components and an input/output matrix (see Tables 5 and 6).

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*Based on 3 ha per worker and 4500 litres/ha

Table 5: Distribution of the cost of an ethanol plant by main components (capacity: 120m^3/day, operating period: 150 days/year).

Description	Cost[a] (10^3 Dollar (1978))
1. Sugar cane unloading and conveying	510
2. Sugar cane preparation and milling	1230
3. Juice treatment	210
4. Boilers	715
5. Thermogenerators	155
6. Electric power distribution system	715
7. Water treatment	75
8. Laboratory	50
9. Machine shop and hardware	120
10. Distillery	1280
11. Alcohol storage	330
12. Stillage treatment	285
13. Metallic structures	340
14. Other	110
15. Transportation	185
16. Buildings	1360
TOTAL	7670

Data for Brazil from COPERSUCAR, Ref [6].

Table 6: Investment cost for sugar cane plantation

	Cost (Dollar 1979/ha)
Preparation of the plantation (levelling of the ground, plowing, irrigation).	≃ 1000[a]
Transportation equipment, agricultural machines (trailers, trucks, filling equipment)	≃ 400[b]
TOTAL	1400

Note: The real investment cost is higher since the cost of land, which varies according to the region, should be added to the costs given above.

[a] Typical cost for Colombia [9] and Ecuador [3], excluding the cost of the land.

[b] Cost pertaining to a big plantation of 14000 ha which could supply about 3 distilleries of 120 m^3/day (see Table 5) [3].

CONCLUSIONS

The main resource constraint on large-scale production of alcohol from biomass is clearly the land. In countries with limited available land areas, an alcohol program may conflict with other land utilization (mainly other agricultural products). The opportunity of producing alcohol in any country or region, should result first from a careful investigation of the amount of land which could be reasonably mobilized for large-scale sugar cane cultivation, accounting on the one hand for its positive and negative side effects, and on the other hand for alternative utilization of the land.

In countries where a significant land potential for biomass plantations exists, one will have to make a choice between the various possible primary resources (e.g. sugar cane, cassava, wood). In this report we have only touched on some aspects of this problem. It is difficult to give a general answer as to which resource is the most appropriate: this should be assessed in each individual case, accounting for the particular ecological and economical situation of each region. Nevertheless, sugar cane appears to be the most attractive raw material for countries with land suitable for sugar cane:[*]

- -- the technology of both sugar cane cultivation and ethanol production is well known, and has many years of industrial experience;
- -- this technology offers developing countries the possibility of developing alcohol production with a limited dependence on industrialized countries and therefore to set up an autonomous agro-industrial base;
- -- sugar cane is the least land-intensive raw-material for alcohol production;
- -- sugar cane is the most efficient raw material from an energy standpoint since the wastes (bagasses) can be recovered to supply energy in the distilleries: a net energy gain (ratio of about 2 between the net energy output and the energy required in the process) combined with a substitution of a low grade energy source (bagasse) with a high quality fuel (ethanol);
- -- ethanol from sugar cane provides a means for sugar producing countries to control the sugar market and stabilize the sugar price.

Alcohol production from biomass is labour-intensive in its agricultural phase, some raw materials being more intensive than others (cassava compared to sugar cane for instance). This aspect is a positive factor in favour of alcohol produc-

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[*] This concerns about 90 developing countries, equally distributed between America, Asia and Africa.

tion in developing countries since, on the one hand, such a production creates a large number of jobs (compared to any other energy chain) in countries where unemployment is usually high and, on the other hand, the people are employed in rural areas which could improve the living conditions of the rural population and reduce rural migration. Most of the agricultural jobs do not require any qualifications which is an advantage for most developing countries where there is usually a shortage of skilled manpower. It may have negative long-term consequences on peoples' education by maintaining, for instance, a large number of cane cutters. Jobs will also be created in the industrial sectors producing transportation equipment, agricultural machinery and distillery components as well as in the upstream sectors producing basic materials (e.g. steel, fertilizers). In the distilleries there is a need for qualified people (e.g. chemical engineers, microbiologists and technicians); in some countries too rapid a development of an alcohol program may be constrained by a scarcity in some of these qualifications.

Alcohol distilleries use a large amount of water; the water is not consumed and therefore has to be discharged. Because of the expected large size of distilleries (100m^3/day of capacity is at present considered to be the typical capacity) a direct discharge of their liquid effluents will significantly increase water pollution and water treatment will be necessary. The most acute issue in that respect concerns the disposal of the vinasses: several solutions are currently under consideration but none has been implemented on a large-scale so far.

In this report we have mainly dealt with present technologies. Since large-scale alcohol production may only become significant in the long-term--apart from some countries, such as

Brazil, which have very favorable conditions--it would be interesting to complement this investigation by looking at the possible technological improvements and their consequences on resource use:

- -- in the energy balance of distilleries (wastes, recovery, better optimization of co-generation, use of low grade fuel ...);
- -- in agricultural techniques (benefits and negative effects of full mechanization on energy consumption and employment, yield improvement, optimal use of fertilizers ...);
- -- in liquid waste disposal (use as an energy source, fertilizer or animal feedstock).

Further analysis is also necessary to make a better evaluation of the needs in skilled manpower, specially in the distilleries, as well as the overall impacts on equipment production and material production (steel); this would allow a better idea of the impacts of biomass development on economic growth.

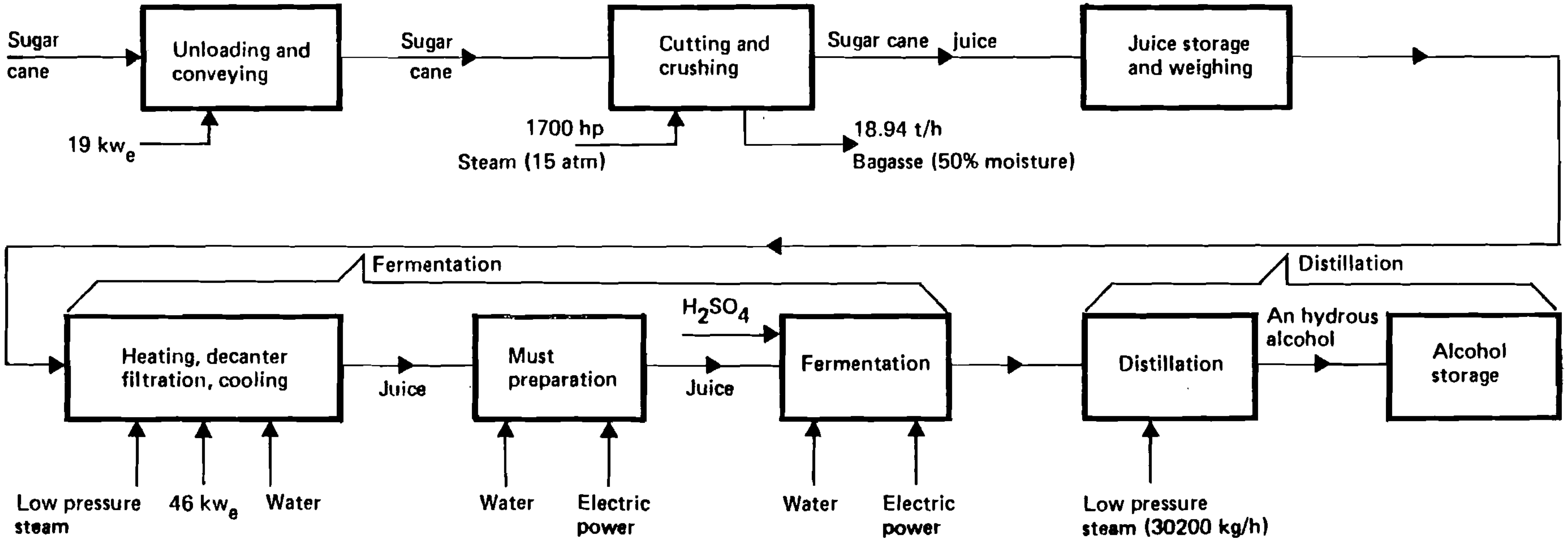

Figure 2. Block diagram of an ethanol plant
Source: Ref 6.

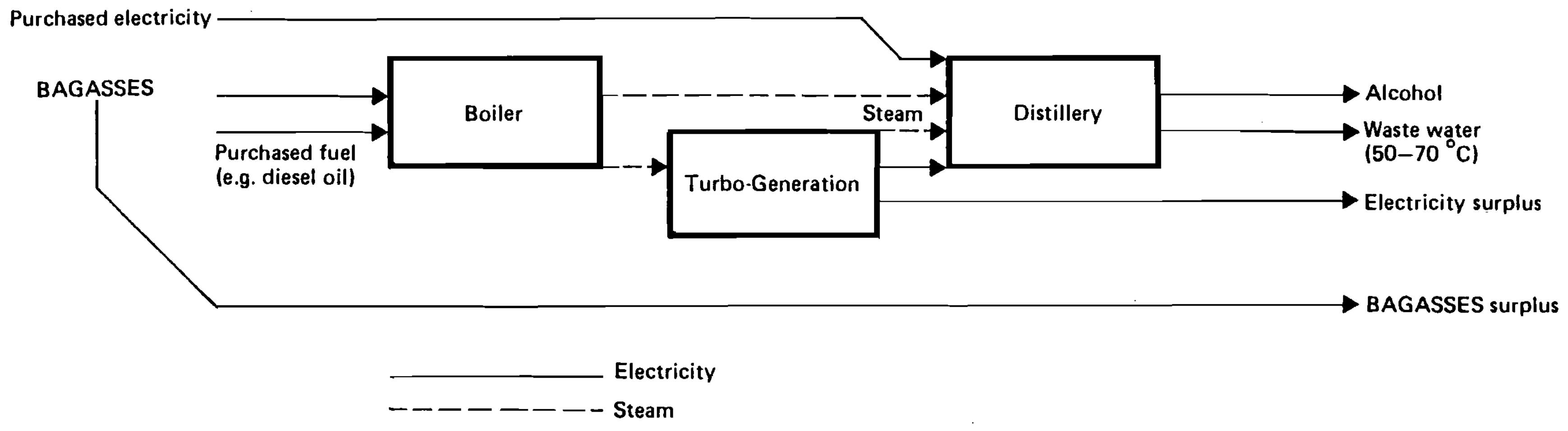

Figure 3. Energy scheme of alcohol production from sugar cane

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