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Workshop on Fermentation Alcohol for Use as Fuel and Chemical Feedstock in Developing Countries

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REVIEW OF PAPERS*

by

UNIDO Secretariat

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Owing to the late submission or non-submission of many papers, it has not been possible to distribute in advance a complete set of papers to each participant as originally planned. To remedy the situation, this review, which is an informal paper, has been prepared by the UNIDO Secretariat to help participants in assimilating the papers and to guide the discussions during the Workshop. We apologise for any omissions or misinterpretations.

1. Assessment of alternative raw materials for fermentation alcohol

1.1 Developing countries' policies for energy and the environment

1.1.1 Need for self-reliance and self-sufficiency

a) General views on industrial development

All authors assume that there is a need to promote industrialization of developing countries. At the same time, they stress the importance of choosing the right type of industries. Fritz emphasizes that there is the danger of developing countries becoming more dependent on the industrially advanced countries than they were at the time of colonialism if adequate attention is not given to the choice of industries, to the social implications and to the question of how these countries may develop further on the basis of a nucleus of industries. There is room for blackmail if developing countries are dependent on foreign countries for their basic needs. Developing countries should get rid of the enormous economic and therefore political pressure put on them by the industrialized countries.

Several authors (e.g. Fritz, Moreira, Sunico, Ali, Mariotte) stress that, in the energy sector, the increasing bills for oil imports required to maintain the economic progress in developing countries, steer them into uncomfortable situations, and in order to avoid this strategic risk, they should develop their own resources.

At the same time it is emphasized (Aguso, Karan, Sunico, Vicharangsan) that the economics of developing and utilizating their own resources must be right.

This doesn't seem to contradict Fritz's statement that GNP should not be considered the most appropriate measure to assess development.

b) Acquisition and development of appropriate technology, not necessarily modern

Fritz mentions as example that despite its enormous output, American-type agriculture would not be appropriate to developing countries. The acquisition of the most modern technology, which is not necessarily the most appropriate, bears the danger of too strong economic dependence on rich countries.

Can this Workshop provide an answer to the question of whether fermentation alcohol can be considered an appropriate technology and whether it can serve as a basis for further general development of the developing countries?

Further, can a developing country, after having decided to embark on fermentation alcohol production and utilization afford not to buy the most modern distillery? Presumably, no general answer can be given to this question.

Many authors (e.g. Moreira, Bejraputra, Vicharangsan, Sunico, Mariotte, Fritz, Brown) consider that fermentation alcohol technology requiring not too sophisticated know-how, provides a good basis for industrialization. It is generally believed that the use of this technology has considerable beneficial effects on the improvement of agriculture by increasing the added value of agricultural products, increasing employment opportunities (and thereby reducing social problems), and solving the problem of surpluses of sugar, cassava and other crops.

In many countries there would be good opportunities to establish agro-based industries but, as Brown puts it, it is difficult to evaluate how and where to start, in view of the deficiency of adequately trained personnel and infrastructure for industry.

c) The problem of shortage of technological and scientific manpower and the brain drain

Ali mentions that, while there is a need to create positive mechanisms to develop rural areas, agriculture must be seen to be progressive and that there is a necessity to prevent migration of population to urban areas; the shortages of skilled manpower and the brain drain prevent this kind of rural and agricultural development.

Fritz indicates that out of 10 000 people, there are in African countries 6 scientists, engineers or technicians; in Asia there are 22; whereas in the developed world there are 112. Ali specifically indicates that in many countries engaged in fermentation alcohol production, there are too few microbiologists, chemical engineers, mechanical engineers and biochemists and that there are no research and development activities of their own.

Fritz mentions that apart from buying technology (the means of production) it is necessary also to buy the means for research and development work. Agreements on buying plants should include laboratories and training facilities.

d) The need for technical and technological co-operation among developing countries

Fritz: Developing countries should share experience among themselves.

Note: Additional opinion and comments are invited on this topic.

1.1.2 Need for studies on the energy sector

- Studies by region, country and continent;
- Studies on different types of energy and the availability of skilled labour for energy production;
- Status of industry with respect to energy production and consumption;
- Location of industry and population distribution and their influence on choice of energy type and size of energy plant;
- Potential of energy production from agriculture;
- Energy reserves including liquid and solid fuels, wind, hydropower, etc;
- Utilities required for energy generating industries.

While the need for these studies is generally considered as essential, it must be realized that there is often lack of adequately trained personnel to carry them out (Fritz). Many countries are not in a position to acquire relevant and reliable data concerning their own resources in energy, minerals or even agriculture.

1.1.3 Social and economic impact of fermentation alcohol production and energy plantation

It is universally recognized that if fermentation alcohol is to take a major position in the provision of liquid fuel and chemical feedstock, high-yielding crops such as sugar cane and cassava will have to be grown on a much larger scale than hitherto. There will be a need for land development with consequent creation of employment opportunities. Authors like Sunico, Brown, Vicharangsan, Moreira, Ali, Mariotte, among many others do not consider negatively the promotion of agriculture, i.e. expanding, rationalizing and intensifying. It is thought to be one of the better and immediate means to combat social problems, to improve living conditions and to prevent the migration of population to urban areas.

While the extension and intensification of cultivation of crops like sugar cane, cassava, etc. provide opportunities for improving agricultural standards, there is also a need for further training in agricultural production and processing.

Ali shows that developing countries may have the potential for additional production of fermentation alcohol in terms of available land; that there is also a need for further improving the yield per hectare (e.g. sugar cane), and that there is often lack of finances to develop adequate infrastructure.

The demand being enormous for liquid fuels and suitable chemical feedstocks, it is concluded that the increased cultivation of sugar and starch crops would not worsen the present precarious position of world sugar price; on the contrary, a major market outlet like ethanol would have the effect of raising world sugar prices.

The authors agree that industrialization in developing countries is best based on agriculture, the latter being the activity of longest tradition and one which could be improved most easily.

The required degree of technological development to produce fermentation alcohol is considered to be achievable, provided adequate training is given.

The question may be raised regarding the pros and cons of intensive use of agricultural machinery, particularly in energy plantations. It is known that many developing countries despite an apparent vast surplus of labour use very expensive harvesters, ploughing machines, bulldozers, etc. which have to be imported and are usually poorly serviced. Ali indicates that in Central American countries there is room for development of mechanized agriculture, considering the shortage of manpower.

1.1.4 Environmental impact of fermentation alcohol production and energy plantation

a) Necessity of effluent treatment

Most authors assume that fermentation alcohol production for use as fuel or chemical feedstock will have to be done in very large units. The effluent problems, well known to the present distilleries, will be considerably increased. Hence, treatment is required. Considering also that by far the largest proportion of nutrients removed from the soil by the crops is contained in the slops, Kelly, Prince, Schreier and Karan envisage an efficient recycling process. This recycling to the soil may be direct or indirect, i.e. by previous use as animal feed additive (Lewicki) or after additional microbial transformation (SCP or methane) (Prince, Megrath). Technical and feasibility aspects of these processes are discussed under 2.7.

b) Prevention of deforestation and desertification

Some authors (Moundlic, Vicharangsan) have shown that the population explosion has already led to devastating effects on the forests. Inefficient use of firewood, even for cooking only, creates an exorbitant demand on wood reserves.

Moundlic proposes an efficient alcohol burner which uses only a fraction of the energy normally required by wood burning. In Upper Volta, wood consumption per family averages 4.8 metric tons p.a. This demand could be replaced by 144 kg of ethanol in final use, the efficiency of the wood hearth being about 5% or less, that of ethanol to be produced from molasses could replace two-thirds of the wood required. Similar proposals are made by Vicharangsan (Thailand): use of alcohol-fuelled stoves instead of wood and alcohol lamps instead of kerosene.

c) Prevention of atmospheric pollution by lead from motor car exhausts

The anti knocking effect (high octane rating) of ethanol-blended gasoline in internal combustion engines is well known. Lead compounds which produce the same effect can be replaced by about 15% anhydrous ethanol in gasoline. The poisonous effects of lead from motor car exhausts in large cities may be difficult to quantify from the point of view of public health, but this Workshop may try to assess the degree of priority to be attributed to this aspect. Moreira et al., Bejraputra and Sunico seem to consider the health problem to be of no inconsiderable magnitude.

1.1.5 Assessment of ethanol as a major liquid fuel

Mariotte has shown that the gasoline demand in developing countries located 30° North and South of the Equator (excluding Brazil) is about 80 million kl (80 000 million litres) per annum.

Ethanol could already be considered to be a major liquid fuel for developing countries if it could replace 15% of this amount.

It is uncertain if and when petroleum supplies for use as liquid fuel will run out; what is more likely is that oil price inflation will continue to stay higher than the inflation of other commodity prices.

Mariotte has calculated that the production of 12 million kl of fermentation ethanol, representing the above 15% replacement of gasoline, would require an area of 3 million ha of sugar cane when cane juice only is used for alcohol production. With an investment cost of 10 billion US$, including effluent treatment, Mariotte estimates that the annual savings in foreign currency could be 1 billion US$, representing the cost of 5 nuclear power stations and equalling 69 million tons of petroleum.

Mariotte furthermore shows that of 92 developing countries suitable for sugar cane production, 37 are in Africa, 22 in Asia, 27 in America and 6 in the South-Sea Islands. In addition there are some countries outside the equatorial region where a potential for the production of fermentation alcohol exists, e.g. USA (using corn) and Sweden (using wood).

Ingram reckons that a replacement of gasoline by 15% with fermentation ethanol in Guatemala would necessitate an increase of the present cane sugar plantations by 20-25% if the present export molasses is utilized for this purpose as well.

An increase in arable land area of this order is possible (about 39,000 ha).

Schreier considers that the potential biomass for energy conversion is equivalent to 5×10^{20} J p. a., a small proportion of the total biomass produced annually.

Kelly, as a result of an intensive study in Queensland (Australia), has shown under which conditions an industrialized country, dependent upon large imports of mineral oil, can become a major producer of fermentation alcohol. **Kelly** like other authors, considers that the production costs should be such as to make this price of fermentation alcohol competitive or near-competitive to the price of gasoline. A competitive price could be obtained under the following conditions:

Increasing the sugar cane yield through breeding and cultivation practices to 160 tons per ha;

Rationalising to its utmost the use of labour and agricultural machinery. This is considered possible in organized plantations of at least 1,600 ha, and preferably 50,000 ha, operated in shifts as in a major industrial plant;

Processing the sugar cane in distilleries sufficiently large to process the yield from 50,000 ha. With a yield of 19.7 kl alcohol per ha, which can then, presumably, be obtained from whole cane, including cellulose hydrolysis, a major factor in economizing the process would be reached. The present world average of alcohol from sugar cane juice is approximately 4 kl per ha;

Additional rationalizations have been assumed in the distillery (see 2.1 and 2.6).

1.1.6 Fermentation alcohol versus food production

a) Competition for land between fermentation raw material and food crops

Mariotte considers that a 15% replacement of gasoline by fermentation alcohol, for which in all developing countries 3 million ha of sugar cane, for example, will be required, would not interfere in any way with the required food production. In Australia, a developed country, the required fermentation alcohol can be produced by additional land development (Kelly). In Australia, the present demand of 14 Gl p.a. of liquid fuel could be met by utilizing an area of 3,250 km^2, seven times the extent of the present Queensland sugar industry.

The Brazilian example is well known, there is (Moreira et al.) sufficient land reserve to develop their fermentation alcohol project. Bejraputra and Vicharangsan indicate that there is at present excess production of carbohydrate crops in Thailand. Similarly, Sunico emphasizes the difficulties for sugar on the export market and expects relief in this respect if the Philippines are able to make use of their excess sugar locally.

Schreier considers that of the total biomass of the globe, the proportion used for food is very small and that the presently available biomass will be sufficient to cover world-wide energy needs. Several authors (e.g. Brown) indicate that, because of a lack of infrastructure, molasses are not made use of in many developing countries.

Note: Participants from developing countries are invited to comment on this point.

b) Competition for agro-industry by-products between production of fermentation alcohol and alternative uses, e.g. animal feed

The major agro-industrial by-product is molasses. The biggest proportion is used for compounding animal feeds, followed by use in the fermentation industries (ethanol, baker's yeast, citric acid, monosodium glutamate, feed yeast, butanol). As already shown above, some countries have so far not been able to make use of, or export, their molasses to any significant extent.

Ingram shows that in Guatemala the present export molasses would supply about 30% of the fermentation alcohol required to replace 15% of the present demand of gasoline.

Note: The recent OECD publication: "Molasses and Industrial Alcohol", published by the Development Centre of OECD, Paris 1978, should be considered.

Karan estimates that about 50% of the gasoline demand in Fiji could be met by available surplus molasses.

1.2 Potential world capacity for fermentation alcohol production

1.2.1 Present productivities per unit area of arable land

There is general agreement that the crops suitable for fermentation alcohol production are those producing sugar and starch reserves. They can produce high yields per ha and are the most convenient for further processing to alcohol. Sugar cane is considered the crop with the highest potential, followed by cassava. In some regions, other agricultural products, such as surplus bananas, dates, figs, carob, sugar beet, fodder beet and cereals, may play a role.
Yield figures quoted by authors of this Workshop are shown in Table 1.2.1.

Table 1.2.1 Productivities per unit of arable land

A. Sugar cane

Yield t/ha	Alcohol per crop l/t	Alcohol per unit area kl/ha	Author	Remarks
54.4	66	3.6	Saito	
33.5-45.9			Vicharangsan	Thailand, present average
50.4	70	3.6	Bejraputra	Thailand, higher yield figures
70-84			Ingram	Central America
70	60	4.2	Mariotte	World average
90	97	8.8	Kelly	Whole stalk (incl. tips)
160	123	19.7	Kelly	Extrapolated to the mid 1980s in Queensland, whole cane processing

Table 1.2.1 (continued)

B. Cassava

Yield	Alcohol per crop	Alcohol per unit area	Author	Remarks
t/ha	l/t	kl/ha		
12.2-14.25			Vicharangsan	Thailand
13.3	262		Bejraputra	Thailand
	160		Mariotte	World average
9.0		1.4	Saito	
50			Prince	Australia
		3.5	Kelly	Australia
		7.0	Kelly	New varieties and agricultural improvements

C. Maize

Yield	Alcohol per crop	Alcohol per unit area	Author	Remarks
t/ha	l/t	kl/ha		
2.8		1.1	Saito	
2.08	236		Bejraputra	Thailand

D. Molasses

Kg molasses per t of sugar produced	Kg molasses per to of cane	l alcohol per t cane	Author	Remarks
216	28,7	8.8	Kelly	Australia

Note: In other countries, molasses per ton of cane may be two to three times higher (higher proportion of hexoses).

E. Various Crops (Mariotte)

	litre alcohol/t
Potatoes	130
Bananas	250
Dates	200
Figs	100
Carob	100

1.2.2 Possible future productivities per unit area of arable land

Kelly made a significant statement about the true future potential of productivities of sugar cane: "The best country yields are about twice the world average, those of the best area of the best country are about twice the country average and those of the best farm in the best area are about twice the area average."

Thus, according to Kelly, there exists a potential for increasing the world average by a factor of eight without having to resort to new varieties. Queensland, with very high productivities, achieves about 34% of the known potential. Many countries operate at not more than 20% of achievable yield and some are as low as 10%. Kelly determined sugar cane to be the crop with the highest achievable photosynthetic efficiency. When grown as an economic crop, an efficiency of 8% can be reached.

According to Ingram, the yield of cane per ha in Central America could be increased considerably.

1.2.3 Potential world capacity to produce fermentation alcohol

For a detailed investigation of the present and future potential surplus of cane sugar and starchy roots in developing countries, tables 3, 4, 8, 9 and 10 listed by Hepner and those of Mariotte should be consulted. According to Hepner's forecast, all American developing countries by 1985 could produce a total of 3,340,000 tons of alcohol, Asian countries 2,380,000 tons, African countries 1,010,000 tons, with a world total of 6,730,000 tons, equivalent to 8,076,000 kl of alcohol, if all surplus sugar, starch and molasses from the developing countries are converted into alcohol.

Mariotte has estimated that the present demand for alcohol for a 15% replacement of gasoline in the developing countries would be about 12 million kl.

Whether Hepner's extrapolated yield figures can be considerably increased by additional land development if there exists another major outlet for these crops should be discussed, as should whether and when Kelly's super-high yield figures per unit of arable land can be reached in developing countries, and what the conditions would be (e.g. economic means to develop infrastructure, to develop agricultural land, to import or produce fertilizer, the needs for mechanization in agriculture, for irrigation, for insecticides, pesticides, the methods of financing agricultural and industrial development).

1.2.4 Case studies of the potential capacity of selected countries

Participants are invited to comment on the potential of fermentation alcohol production, taking into account the results of previous discussions.

1.3 Particular characteristics of various raw materials for the production of fermentation alcohol

1.3.1 Agricultural properties of various crops

a) Sugar Cane

Sugar cane, probably the crop with the highest potential, is spread over the whole world; the technique of milling and juice extraction is well known; there is surplus sugar; there exists a large additional potential in terms of available land; and there is a tremendous possibility of increasing the yield per ha (Mariotte).

As many authors put it, sugar cane can be grown anywhere there is plenty of sunshine and water; there is no particular requirement as to the type of soil (see, for example Kelly); there seems to be no indication of soil exhaustion but fertilizer has to be applied for high yields.

The cultivation and harvesting can be fully mechanized.

The average growth cycle is nine months, maximum two years.

The disadvantage of sugar cane as a crop is its seasonal harvesting (restricted to the dry season). However, as Kelly shows, the harvesting season can be considerably extended if cane is used for alcohol production and not for crystal sugar. There is no need to wait for maximum sucrose content, rather the time of harvesting will be dictated by optimal total (fermentable) sugar content.

Sugar cane is vulnerable to many diseases, but there seems to be adequate means to combat them, albeit at some cost.

Kelly has investigated the effects of fallow crops, i.e. cassava; there was some small additional total return.

b) Cassava (synonyms are manioc, mandioc, juca, tapioca)

Cassava is a crop suitable for semi-arid soils, which could be processed during off season of alcohol production from cane (Prince, Vicharangsan). The cultivation is easy and has no particular requirement as to the soil (Mariotte). Harvesting is difficult to mechanize (Kelly) but the requirement of fertilizer is low and poor soils can be used for its cultivation, hence the effect that the soil may become exhausted if no fertilizer is applied (Kelly).

c) Corn (maize)

Basically this is a tropical plant. The lower yield figures of alcohol per ha are partly compensated for by the fact that the processing of corn is possible throughout the year.

d) Molasses

Molasses have a comparatively low price and the possibility of processing through the year. Kelly finds that the use of molasses for large-scale alcohol production is feasible only if one or more of the following conditions prevail: the sugar factory is very large (15,000 tons of cane per day); the relative production of molasses is high owing to low quality cane or some other reason; transport costs for centralized collection are favourable; and the fuel costs for processing are favourable.

1.3.2 Feasibility of energy plantations

Kelly points out that, at least under Australian conditions, energy plantations which are separate from those for sugar production will be necessary for fermentation alcohol production, considering the necessity for very large units, for agricultural shift work combined with full mechanization etc. This divorce may be necessary also in many developing countries (Rudolph et al., Moreira, Schreier), although the degree of mechanization may not have to be to the same extent.

In a narrow sense, energy plantations refer to strongly mechanized plantations. The crop particularly suitable for mechanization is sugar cane. However, already there exist large projects for energy plantations in Brazil, using cassava as a crop (Moreira et al.). In the cultivation of cassava, efforts are made to obtain uniform sized roots that do not spread too far from the stalk. This helps in agricultural mechanisation and in processing.

Fully mechanized energy plantations, according to Kelly's model, provide the means of continuous use of equipment in agricultural operations (including irrigation, ploughing and planting), a high standard of mechanical maintenance of agricultural equipment, and the use of as large a proportion of available time as possible.

Kelly considers that the present standard of maintenance of agricultural equipment is about one tenth that of the factory standard and is even less in developing countries. The present use of chopper-type harvesters in the existing sugar industry in Australia is about 13% of the potential capacity. All in all, Kelly considers that even in developed countries there exists a potential for the reduction of the capital cost component by a factor of 5-7.

In terms of land development, Kelly points out that heavy investment will pay in the long run; this involves adequate irrigation supplies, drainage and flood prevention.

Kelly's system would involve 1,600 ha plantation units, operated (under Australian conditions) for 39 weeks, 7 days per week, 3-shift employment. Plantation units as large as 350 km^2 might provide some additional advantages.

Reference is made to 300 km^2 plantations in Argentina and Mexico that supply factories with 1,800 tons of cane per day.

According to Mariotte, one man is required in agricultural operation per 1/70 ha, and one cutting machine or harvester, for 170 ha (some do up to 400 ha) per campaign.

Heavy industrial mechanization with adequate maintenance involves skilled labour. The Workshop ought to discuss corresponding social implications (possible large differences in remuneration, few new jobs created etc.).

1.3.3 Properties for processing to ethanol

Total yield of easily available carbohydrates and sugar concentration in the final extract are the important criteria of crops for fermentation alcohol production. Sugar cane again ranks very high in this respect and, in addition, energy is available from the residues, or bagasse, after sugar extraction. However, the process of extraction, be it by a milling or a diffusing process, is costly, particularly in terms of investment (Saito).

Once the economic problem of cellulose saccharification is solved, sugar cane will obviously be the highest alcohol yielding crop (see yield figures); also, the total energy yield per ha and per annum is the highest.

Cassava is a suitable alternative for the drier regions, although the processing costs up to the stage of sweet mash are indicated to be higher than those for sugar cane (Saito).

Sugar beet is well known for its suitability for direct sugar juice fermentation, but it is hardly grown in developing countries. Prince indicates that the total sugar yield per ha is higher for fodder beet than for sugar beet; it is questionable, however, whether the lower sugar concentration in the extract will not prevent an economic handicap in the recovery of ethanol.

The production of sugar from sugar cane and the production of starch or sweet juice from cassava are well-known processes and according to experience, the processing reliability is good in developing as well as developed countries.

Similarly, the preparation of the mash does not present undue difficulties. Depending upon the region, there may be additional treatments required to prevent scaling in the mash columns for distilling the alcohol. This happens with some varieties of molasses (Madi).

1.4 Agricultural costs in fermentation alcohol production

Kelly has worked out for Australian conditions the agricultural production costs, extrapolated to 1985 using reasonable maximum productivity of sugar cane, whole cane harvesting with applications of space-age technology, in 35,000 ha estates at 160 t cane/ha (total alcohol production including cellulose hydrolysis = 690,000kl).

	US$/kl
Property development	8.3
Cultivation costs	0.8
Fertilizer and chemicals	1.1
Irrigation application	2.7
Harvesting	0.6
Total management	0.8
	14.3
Total agricultural cost (excluding transport of cane)	14.3
Transport of cane	4.4

Mariotte considers that for sugar cane at a yield of 60 t/ha investment costs in agricultural machinery are about US$ 1,000/ha.

Bejraputra indicates the following cost figures:

	Yield t/ha	Total agricultural cost US$/kl
Sugar cane (juice only is processed to ethanol)	50	21.5
Cassava	13.3	8.8
Maize	2.08	35.4
Molasses (cost of raw material)		15.5

2. Application of fermentation alcohol technology in developing countries

2.1 Processing costs and total production costs

Table 2.1

Investment costs for processing agricultural crops to ethanol

Sugar Cane

Operation period	Daily production	Yearly production	Total investment	Specific investment	Author
d.p.a.	kl p.d.	kl p.a.	million US$	US$ per 1 daily production	
150	60	9 000	14-16	250	Saito
273	2527	689 871	100	40	Kelly
150	330	50 000	25	75	Mariotte
250	200	50 000	15	75	Prince

Molasses

Operation period	Daily production	Yearly production	Total investment	Specific investment	Author
d.p.a.	kl p.d.	kl p.a.	million US$	US$ per 1 daily production	
300	60	18 000	5-6	100	Saito
300	50	15 000	6	120	Karan
300	30	9 000	5.7	185	OECD
300	30	9 000		370	OECD*

* independent from sugar factory

Cassava

Operation period	Daily production	Yearly production	Total investment	Specific investment	Author
d.p.a.	kl p.d.	kl p.a.	million US$	US$ per 1 daily production	
300	60	18 000	6-7	110	Saito
250	200	50 000		75	Prince

Dual process (sugar juice plus molasses fermentation from other sugar factories)

157	275	44 000		62.5	Kelly

According to Brown the investment costs in the fermentation and distillation operation are small in comparison to those of agricultural land development and other agricultural costs, the latter being about 10 times higher than the former. Mariotte points out that the required investment costs for fermentation alcohol are much smaller than the research activities for other alternative sources of energy.

Table 2.2. Manufacturing costs of fermentation alcohol

Sugar Cane (juice only)

including raw material (agricultural costs)	excluding raw material	Operations period	daily production	Author
US$/kl	US$/kl	d.p.a.	Kl p.d.	
450	320	150	60	Saito
340	162			Ingram
210-339		273		Prince
160		196		Kelly*
315				Kelly*

* 39 week agricultural operation, 7 d.p. week, 3-shift operation p.d.

Molasses

including raw material (agricultural costs)	excluding raw material	operations period	Daily production	Author
US$/kl	US$/kl	d.p.a.	kl p.d.	
210	140	300	60	Saito
255				Kelly
480	480		50	Karan
230	125	300	30	OECD

Cassava

300	142	300	60	Saito
126-215		250	200	Prince

Sugar Beet

164-279				Prince

Kelly has made forecasts for 1985 under various conditions of agricultural operation.

Table 2.3. Estimates of production costs by 1985 (Australian Conditions) according to Kelly for a distillery of 690 000 kl p.a.

Total Production Costs	Plantation Unit	Conditions
US$/kl	ha	
84	35 000	160 t cane p.ha, high productivity form, 7-day week, 39 wk.p.a., 3-shift p.d. whole cane processing
120	35 000	present form productivity whole cane
160	35 000	present form productivity cane juice only
90	1 600	high form productivity, whole cane
125	1 600	present form productivity, whole cane
175	1 600	present form productivity, juice only
125	50	high form productivity, whole cane

175	50	present form productivity, whole cane
270	50	present form productivity, juice only
315	50	present form productivity, juice only; 5-day wk, 28 p.a., 3-shift operation

In table 2.4 more detailed production cost figures are shown.

Table 2.4 Processing costs of whole sugar cane (including cellulose hydrolysis) to ethanol, (690 000 kl.p.a.)(Kelly)

	US$/kl
Transportation of cane	4.4
Capital assessment of factory	29.8
Maintenance	7.2
Labour and chemicals	1.1
Cost of cool	16.7
Local management	0.6
Total processing costs	59.8
Proportion of control centre costs	
Capital assessment	8.1
Management and operation	1.6
Cost of space-age technology	9.7
Total costs of ethanol ex distillery	83.8

2.2 Minimal and optimal plant size

From Kelly's compilation (Table 2.4) it is obvious that in terms of processing costs the capital assessment of the factory accounts for the largest proportion of processing costs (if coal is utilised as an external source of energy). The cost proportion of transportation of cane is about 1/7 that of capital assessment. It is well known that investment costs for a plant cannot be scaled down in proportion to plant size. In addition the cost of labour and the requirement for trained personnel will increase considerably with decrease in plant size. Hence there seems little likelihood of a larger number of smaller plants being more advantageous than a single huge plant. This is also the opinion of Schreier, Moreira et al., Brown.

There seems to be room for discussion, nevertheless, considering that very long transport routes tend to result in spoilage of cane to a small extent and reduction of the yield by the respiratory activities of the cane itself.

Additional consideration may also be given to those cases where molasses can be used as raw material.

2.3 Energy balance in fermentation plant and total energy balance including agricultural production

Kelly has examined several processes of which the data are shown in Table 2.3.1.

Table 2.3.1

Processing costs of sugar cane to ethanol (Kelly)

A. Dual production of raw crystal sugar and ethanol

Steam required*		N.Th.V. Potential	Net gain	Overall net thermal gain
kl/l alc.	MJ/l	MJ/l	%	%
6.44	14.5	21.3	32	20

B. Ethanol only (cane juice processing, no cellulose hydrolysis)

7.3	16.4	21.3	23.0	9.4

Bagasse surplus

C. Whole cane processing to ethanol; external energy by coal

6.7	15.08	21.3	29.17	16.7

* **incl. milling (4% of N.Th.V.), slops evap. (39-25 KJ/kg slop solids), distillation (2.5 kg steam/l), power generation (0.7-0.24 kg steam/l); excl. cane transport (1% N.Th.V.).**
Potential bagasse surplus 31.7%.

The requirements of process energy, using molasses as raw material has also been examined by Eder (see Table 2.3.3).

Table 2.3.3 Energy consumption in the production of anhydrous alcohol from molasses (Eder)

	Steam		Electrical energy
	kg/l	% total	kWh/l
1. Mash preparation			
molasses dilution, molasses clarification, sludge treatment	0.2	4.8	0.02
2. Fermentation			
pumps			0.005
yeast separator			0.01
3. Distillation, rectification			
dehydration	2.5	59.9	0.035
4. Slops recovery			
concentration to 65% D.M.	1.47	35.3	0.02
5. Energy for mechanical			
vapour compression (energy recovery)	—	—	0.18
6. Total	4.17	100.0	0.270
Alternative:			
Combined distillation, dehydration, slops evaporation	3.50		0.035
Total	3.70		0.025

According to Kelly, the requirements of energy for cane processing is divided up as shown in Table 2.3.4.

Table 2.3.4 Relative energy requirement in the production of anhydrous alcohol from sugar cane (Kelly)

Total steam usage	100.00%
Power	5.63
Sterilisation	14.78
Distillation, Dehydration	35.23
Slops evaporation	30.28
Miscellaneous	14.08

Schreier has drawn up the overall balance sheet shown in

Table 2.3.5 Energy balance sheet of cane juice processing to ethanol (Schreier)

A. Energy content of products (% cane)	
technical alcohol	0.73
power alcohol	34.73
conc. slops and filter cake	6.48
surplus bagasse (used to produce steam and electricity)	10.1
B. Process energy	
juice preparation	5.10
fermentation	0.29
distillation, dehydration	13.17
slops evaporation	3.66
C. Surplus energy	
heat	8.28
electricity	0.98
D. Losses (waste heat)	
preparation, fermentation, distillation	3.07
distribution of energy	0.10
steam power generation	21.90
internal consumption	1.01
Total	99.36

Moreira et al. have made detailed energy analyses for various systems and combinations, taking into account also agricultural energy, energy investment for various crops (cane, cassava, sorghum), using various procedures (with and without cellulose hydrolysis) and extending energy supply by wood. In addition, comparisons were made between ethanol production from wood by gasification. (Tables II, III, IV, V, VII, IX and X Moreira et al.) should be consulted for detailed reference.

The final aim was to establish the energy balance of the self sufficient ha (table XII, Moreira et al.). A summary of the results by Moreira et al. is shown in table 2.3.6.

Table 2.3.6 Energy balance of the self-sufficient ha (Moreira et al.) Mcal/ha

System	Alcohol energy	Residue energy	Agricultural energy	Alcohol external	Energy energy	Total minus agric. energy	Alcohol minus agric. energy
Cane							
Syst. 1	18 020	8 478	3 796	4.75		22 702	14 224
Syst. 1+2	18 558	-	2 985	6.22		15 573	15 573
Cassava							
Syst. 1	10 332	-	2 074	4 98		8 258	8 258
Syst. 1+2	11 985	-	3 086	3.88		8 899	8 899
Sweet sorghum							
Syst. 1	26 114	3 870	7 310	3.57		22 668	18 798
Syst. 1+2	23 769	-	5 016	4.74		18 753	18 753
Eucalyptus							
Syst. 2	12 373	-	551	22.46		11 822	11 822
Methanol	18 407	-	551	33.41		17 856	17 856
Pinus							
Syst. 2	16 464	-	484	34.02		15 980	15 980
Methanol	-	-	-	42.98		-	-

Syst. 1. Fermentation of sugar from sugar cane juice or cassava roots and stems or grains from sweet sorghum.

Syst. 2. Hydrolysis of cellulose from sugar cane, cassava stems, sweet sorghum stems or wood.

2.4 Methods of accounting to construct total balance of costs

a) Period of depreciation

Kelly proposes the following:

Total land development costs	75 years
Processing plant	20 years
Agricultural machinery	5 years (continuous usage, high maintenance standard)

b) Rate of interest

Kelly's index system in principle means to keep the ratio of periodic repayments to sale price of product constant. This method is considered suitable if repayment periods of 50 to 75 years are applicable: there is only a marginal (but significant) difference to conventional methods for repayments of 20 years, and no significant difference for repayment periods over 5 years.

For example: $100 invested at 5% interest, 75 years.
Conventional repayment: $5.13 per annum
Using an indexation increment of 3% per annum, repayments of $1.55 per annum would be made during the first 5 years, whereas the repayment in the 75th year would amount to $12.96.

c) Energy accounting and cost accounting

Greenfield and Nicklin point out the interactions between energy accounting and cost accounting in the sense that it is important to examine the joules as well as the dollars. Furthermore, it is very important to define the system boundary and take due account of energy recycle. In the production of fermentation alcohol from crops the net energy gain is small. Furthermore, recycle energy has to be considered at production costs, not at the current market price; capacity reduction through recycle energy has to be considered. The result is that energy prices rise at an unexpentedly high rate if both the production costs are high and the recycle proportion is high.

In terms of recycle energy the following have to be considered:

Land development

Field work

Harvest and transport

All plant operations

Slops utilization (evaporation, transport to the field, irrigation

Personnel dislocation and its regular transport

Moreira et al in their article argued that in their input-output analysis it would be unjustified to take into account the agricultural labour energy.

d) Methods of accounting in power alcohol use

Bejraputra and Ingram calculate the final value of 15% alcohol-blended gasoline, which is then to be rated as premium grade gasoline as follows:

Price of regular gasoline x (1 - 0.15) + 0.15 X = price of premium grade gasoline

X = blending price of ethanol

2.5 Requirement of utilities and labour

a) Water

According to Saito the following amounts of water (26°C) are required per litre of alcohol produced:

Cane juice	250
Molasses	250
Cassava	350

Note: Consideration should be given to the warm climate in the tropical regions and its effect on water and/or energy requirements. This aspect has hardly been dealt with by any author.

b) Nutrients

Nitrogen and phosphorous salts are normally added in order to achieve rapid fermentation. The amounts required are comparatively small. They do not represent a major part of the costs. Furthermore, added nutrients can be recovered in the form of yeast, which can be used as high-protein and vitamin component.

Attention may be drawn to Madi's observation that the amount of nitrogen salts added to the mash exceeded considerably the calculated amount of yeast production.

c) Labour

Kelly indicates that the normal requirement of one man-hour per 400 l of alcohol can probably be halved upon rationalization of the process.

2.6 Need for and possibilities of process optimization

Kelly has examined the possibilities of rationalization in agricultural production (see 1.4). Additional economizing can be done on the processing side.

The major plant cost components in fermentation alcohol production are investment costs (depreciation and interest) and energy requirement (above all for distillation and dehydration). If cellulose hydrolysis, e.g. of bagasse, is envisaged, there is an additional considerable cost component involved in terms of investment, maintenance and energy.

If storable raw material, such as molasses and grains, are processed, it is generally considered preferable to operate the distillery throughout the year reducing thereby capital cost on the fermentation and distillation plant as well as labour costs. The additional cost of storage capacity is small in comparison to other outlays.

In large plants appropriate economizing can be done in the processing sections.

a) Fermentation plant

At present, most potable alcohol is produced by batch operations. Fermentation plants are characterized by low productivities (low output per unit fermenter volume), high demand in labour costs and considerable energy requirement for mash sterilization. Normally it is required prepare fresh, (pure), cultures at regular, often very short, intervals, e.g. daily (Madi). Some companies do not require this when a continuous or quasi-continuous operation is maintained, which normally involves the use of centrifugal separators to re-use and "clean up" the yeast (Eder). Higher productivities can then be attained as there is a reduction of fermenter down-time (cleaning, fermentation lag phase) and of labour. Intensification of the process involves additional investment and energy in terms of separator operation.

Prince, Dellweg and Engelbart propose a tower-type continuous fermentation for which shorter residence time of the mash is claimed.

This results in smaller fermenter volume required for the same output. No centrifuges are involved.

In Meyrath's fully continuous system, very short residence periods (as little as 1 hour for 7% alcohol) are required. No centrifuges are involved and there is no need for mash sterilization. A two-stage operation is required if high mash density (above 8.5 Vol%) is used. Alcohol concentrations up to 13 Vol% can be obtained in total residence times of 12-13 hours. It is reckoned that a reduction in investment costs of the fermentation plant from 1/8 to 1/10 can be obtained as compared to a good batch process or a process involving centrifugal separators. Steam costs reduction is in the order of 0.8 to 1 kg. of steam per litre of alcohol produced as no mash sterilization or fermenter is required. Labour cost reduction is considerable as all operations are simplified. Surplus yeast recovery, a valuable by-product, is done without centrifugal separators in the form of a 20% (dry matter) slurry.

Vacuum fermentation processes have been examined also. They are characterized by high productivities. Eder shows that these types of fermentation processes are energetically unfavourable. Also it is questionable whether these processes can be run satisfactorily in practice as the very low residual alcohol concentrations result in a proneness to contamination.

b) Distillation plant

The major cost factor in the distilling and dehydrating operation is steam. The present trend is to achieve as high concentrations of alcohol in the mash as possible in order to reduce steam requirement. No concrete figures have been presented in this Workshop but this would be helpful as adequate optimization calculations could then be done. Higher alcohol concentrations in the mash (usually above 7 Vol %) involve disproportionately longer fermentation times. Hence, while saving on steam, which is certainly becoming more and more valuable, additional capital cost in terms of fermenter volume is involved.

c) Preparation of cane juice and mash treatment

In order to minimize capital and operating expenditure at the milling stage, Kelly proposes the following system for cane juice extraction: A 3-roller crusher followed by a shredder and a single 3-roller mill with appropriate pressure-feeder device and two preliminary sets of knives. The fibre, then containing about 25% of the residual juice, goes to a separate stream of a Ritter-type extractor, which is the "heap" technique, and from there to a pressure feeder of two sets of 3-roller mills. Both fluid streams are combined.

Rudolph et al. propose not to clarify the cane juice prior to fermentation. They also claim that a direct fermentation of disintegrated cane is possible. Hammermills are proposed instead of shredders. Temperatures of 100°C. to 110°C. are used for extraction. In hammermill-disintegrated cane a faster fermentation is obtained than in conventional extraction processes.

For the preparation of cassava mash, attention is drawn to the papers of Caransa and Bos.

Molasses, particularly from sugar cane, are normally clarified in order to prevent scaling in the mash column. Whereas centrifugal separators used to be employed for this, the trend is towards the cheaper method of sedimentation by gravity. In a continuous high-productive fermentation, Meyrath showed that there is no need for sterilization of either molasses or dilution water.

d) Hydrolysis of cellulosic materials

Kelly considers that thermal hydrolysis of bagasse is a low-cost route for converting coal into ethanol. More than double the yield per ha is obtained if whole cane is processed as compared to can price fermentation. Processing costs are increased from $145/kl to $156/kl. Total production costs, however, are decreased.

2.7 Effluent treatment and by-products

a) Slops treatment

Beet molasses slops, vinasse, can be evaporated to approximately 60% dry matter and sold as animal-feed ingredients or as fertilizer (Lewicki, Saito). It is claimed that molasses slops contain about 65% of the feed value of molasses; up to 10% can be used in feeds (2% - 3% for pigs); the digestibility is 50-60%; the digestibility of the protein about 90% (Lewicki). In Europe about 760,000 tons per annum of vinasse is marketed as animal feeds. In France, vinasse is applied as fertilizer at a rate of 2.5 to 3 tons per ha. In Japan, Kyowa Hakko produce about 140,000 tons per annum to be used as fertilizer. In Europe, the price of vinasse ex-factory varies between $17.50 and $62.50 per ton. The price is strongly influenced by that of soy bean meal. Lewicki considers that the feasible marketing radius is about 50 km from the evaporation plant.

Kelly, Schreier and Eder also consider that the most appropriate means of disposing of slops from molasses, cane processing or cassava, is by evaporation for use as fertilizer. Kelly's opinion is that the direct use together with the irrigation water in sugar cane plantations will be at least as expensive and probably less convenient than evaporation followed by use as fertilizer.

According to Prince, the anaerobic digestion of cassava slops would yield sufficient methane to cover all process heat and electricity generation.

The energy content of molasses slops, 2.5 Kg steam per litre of alcohol is high enough to cover the requirement for distillation/dehydration. However, feasibility to attempt complete digestion to methane is doubtful considering the very long retention time and, therefore, heavy investment.

According to Meyrath, it would seem more appropriate to recover about 70% of the slops' energy content by a short digestion period of about 16 hours and concentrate the residues for use as fertilizer.

It is doubtful whether it is appropriate in huge distilleries to use evaporated slops as animal feed. There is a large disparity in the quantities produced as compared to the demand.

b) By-products

The question of quantity disproportion may also be significant in the case of by-products such as surplus bagasse or CO_2 from fermentation. Bagasse has been used successfully in particle board manufacture CO_2 for soft drinks, fire extinguishers etc., but the amount of these products will probably be in vast excess of the demand.

The case may be different for single-cell protein. Feed yeast, or torula, could be produced from slops. Particularly the slops from hydrolysed bagasse are expected to be rich in utilizable pentoses. Torula yeast produced could be combined with saccharomyces yeast from the alcoholic fermentation and used as high-protein and vitamin feeds. While the amounts of yeast to be produced are large, possibly too large to be used in the country of production, there is an international market for the product if available in sufficient quantity.

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