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

Vienna, Austria, 26 - 30 March 1979

FUEL ALCOHOL FROM CROPS BY CONTINUOUS FERMENTATION*

by

R.G.H. Prince and D.J. McCann**

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R.G.H. Prince and D.J. McCann **

Sources of agricultural material for power alcohol are reviewed: wastes, trees, and various crops. Wastes have high costs and limited potential: cellulose-based plants such as trees are expensive to process: crops of choice for Australia are cassava and sugar and fodder beet.

The process under development at Sydney University for cassava to alcohol is described. The basis is a closely integrated agro-industrial complex, in which all wastes are processed: to generate methanol for internal fuel and/or external consumption: to allow recycling of fertilizer components and to convert other residuals to high protein animal feed.

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For both alcohol fermentation and waste digestion continuous tower fermenters are being developed. These are at the laboratory stage (12 Litres) for ethanol and pilot plant stage (6500 Litres) for methane. We expect a size reduction of an order of magnitude and hence a corresponding cost reduction in such equipment compared to conventional batch plant. Hydrolysis of starch and alcohol separation are also being investigated.

Product cost ex-factory, of $0.19 - $0.28 per liter is expected for such a process for a 50,000 kl/a plant, from cassava and sugar and fodder beet, less if any by-product credits are obtained. These costs differ by little more than the present tax from current petrol costs.

Sufficient suitable land appears to be definitely available in Australia to produce the alcohol required for 10-20 percent blends with petrol, and it is very likely that there will be sufficient available for complete replacement of petrol by alcohol if and when that is needed.

Crop based ethanol is discussed in relation to alternative "synthetic" fuels: methanol from natural gas and oil from coal: and a national development policy is outlined.

INTRODUCTION

In Australia as in other countries, different forms of energy are available to us to different extents and with very different certainties of availability in the future. Electricity appears to be secure for very many generations ahead, based on plentiful supplies of black and brown coal, extended when necessary by other means, such as nuclear processes based on also plentiful supplies of uranium. Natural gas is also abundant. However, in the case of liquid fuels, which at this time are essential for most of our transport needs, we only produce a proportion of our needs, a proportion which is starting to decline. We then need to examine the production of "synthetic" liquid fuels (i.e., produced from sources other than crude oil) in this country in some detail, and carry research and development of likely processes through at least to a stage where the feasibility, technology, and economics of these processes can be assessed with confidence.

One source of liquid fuels is plant material - in which energy from the sun has been trapped by photosynthesis. As this represents, at least potentially, a completely and infinitely renewable source of energy, it will become increasingly important, as we deplete other, finite forms of stored energy.

Suitable crop materials would be fermented to ethanol, which may be used as a fuel as such in internal combustion engines, or it may be mixed with petrol, to extend petrol supplies, and reduce imports of crude oil. It is by now well known that blends of up to 15 or 20% of ethanol with petrol require little or no modification of engines, and only simple adjustments for good performance.

RAW MATERIALS

Suitable raw materials for Australian fuel ethanol production have been considered and evaluated in some detail (McCann & Saddler, 1975; Saddler, McCann & Pitman, 1976).

One group of materials is represented by organic wastes. The most important in Australia would be cereal straw, sawmill wood waste, and perhaps urban organic wastes. Such materials appear at first sight attractive, because they are thought to be "free", and we usually wish to get rid of them. However, in reality the cost of gathering and moving the material to a central processing unit may be quite high, perhaps even equal to the value of the final product. Wastes, by their nature, tend to have a variable composition, not particularly well suited to the purpose in hand, and the quantity available may also be highly variable. Further the potential energy products from waste would amount to only a small proportion of our needs: cereal straw is in our case the most abundant, and even if extensively exploited would not supply a tenth of our liquid fuel needs in, say, 1985. A detailed study (McCann & Saddler, 1976) of cereal straw has confirmed these points. Expected costs and productivities for straw, as well as crops discussed below, have been summarised by McCann, Saddler and Prince (1976).

We then turn to crops grown specifically for the purpose: "energy crops".

One group are the cellulose-based crops: elephant grass, kenaf, and eucalyptus trees have been evaluated for Australian conditions (Saddler et. al., 1976) and eucalyptus to alcohol has been studied in detail (Morse & Siemon, 1976). Although such crops are high yielding and offer low costs as harvested in situ the final cost of the alcohol produced is high, perhaps twice as much as that produced from the second group of crops we shall consider. This is principally due to the difficult, and therefore relatively expensive hydrolysis required to convert the cellulose to fermentable sugars.

The second group are the starch and sugar-based crops, which are relatively easy to convert to ethyl alcohol, requiring either a simple hydrolysis, or none at all. The crops in this group most worth considering for power alcohol for Australia in the short term are sugar cane, sugar or fodder beet, and cassava.

Sugar Cane

This is a well established and important industry in northern coastal areas of Australia, particularly Queensland. Ethanol production, particularly from the industry's by-product, molasses, is also well established, and ethanol may also be readily obtained, by well-known methods. as the main product of sugar cane processing - the rapid expansion of this industry for this purpose in Brazil is well known (Stumpf, 1978). Fuel alcohol production from sugar cane is of course being studied extensively in Australia (Kelly, 1977; Hanks, 1978). The short term prospects appear to be relatively unattractive: the present product of the industry is a food commanding a much higher value than a fuel; land and fertilizer requirements and growing conditions are exacting, so that growing costs tend to be high and areas available for industry expansion are limited. The industry h_ e is also very tightly organised, so as to buttress it against widely varying international demand and prices, and a new and very different major product would have major socio-economic implications.

Sugar and Fodder Beet

The sugar beet is a well-known temperate crop, tolerant to a wide range of conditions of both soil and weather. While not at present grown in Australia it would appear that New South Wales, Victoria and much of Northern Tasmania would be very suitable. Trials in Tasmania have yielded 80 t/ha with a sucrose content of 20%, and in equivalent New Zealand conditions 50 t/ha have been obtained regularly. This latter yield has been taken as a basis for costing calculations, assuming 18% sucrose content and total fermentables of 20%. The corresponding farm gate price would then lie in the range of $12-18/ton of beets (McCann & Prince, 1978).

Fodder beet describes varieties of Beta vulgaris which fall in sugar content and growing habit between sugar beet and the mangel. New Zealand experience (Dunn, et. al, 1978) is that yields of 15-20 oven dried tons/ha could be realistically expected from farms regularly growing fodder beet as a cash crop with dry land agriculture, corresponding to 100-130 t/ha (at 15% dry matter) and leading to an expected alcohol production of 4.4-6.0 kl/ha. Corresponding figures for irrigated land are 25-30 ODt/ha, 170-200 t/ha fresh beets, and 7.2-9.4 kl/ha alcohol. These are substantially higher figures than for sugar beet, and as the soil and other growing conditions for the two are generally similar fodder beet might well be the crop of choice for alcohol production in the southern areas of Australia.

Cassava

Cassava (Manihot esculenta Crantz), tapioca, is the crop of choice for power alcohol production in the warmer parts of Australia. This plant is used as a staple food by people all through the tropical developing world. It is the highest known yielder of starch, and typically may contain 25% starch and 5% other carbohydrates (compared to say 16% fermentables in sugar cane).

The plant will grow on relatively poor soil, and requires less fertilizer and less water than sugar cane. It has strong predator resistance. Work on its cultivation is being carried out by a number of organisations in Australia, and one commercial company has established a large-scale trial plantation (N.V. Harris, 1978). From the data available it appears that a yield of 50 t/ha might reasonably be expected on north Queensland soils, at a cost of $10-$15 per ton of tubers (wet weight). The lower figure is consistent with the limited experience in this country.

Cassava with its lower growing costs and higher fermentables content will have a substantially lower farm gate price than sugar cane. Further it is a perennial, and can be allowed to grow for several years, if required, during which starch accumulates in the roots. Harvesting can therefore be carried out for a high proportion of the year, and limited storage may allow continuous processing to alcohol. In contrast the sugar cane growing and harvesting season is highly restricted: processing can only be carried out for part of the year, so that a processing plant must be considerably oversized, and the product will necessarily carry the corresponding increased capital charges (in a ratio of about 1.67 to 1, Hanks, 1978). Sugar and fodder beet may be stored for some time, so that the effective situation is intermediate between cassava and sugar cane.

PROCESSING TO POWER ALCOHOL

Fig. 1 shows the flow-sheet proposed for a cassava-based process (McCann & Prince, 1978). The tubers are washed, cut, sliced and disintegrated to produce a fine starchy cellulose pulp. The high fermentables to cellulose ratio for cassava (about 15:1) is expected to make cellulose separation at this stage unnecessary, and it can be removed during the distillation of the alcohol. The starchy pulp, after pH adjustment and amylase addition is cooked to liquefy the starch, which is then hydrolysed to fermentable sugars. These are fermented to alcohol, which in the conventional process is separated from water and waste materials by a two stage distillation which will produce 95.6% azeotropic alcohol, suitable as a pure fuel. For blending the alcohol has to be brought up to essentially anhydrous quality, requiring a third column.

This process produces large quantities of objectionable wastes, of high BOD content, particularly from the distillation section, and these wastes are usually seen as a major problem. One can dispose of them, charging the costs to the process, or one might treat them in a more positive fashion. In this latter approach all process wastes are combined (such as the stillage from the distillation section, the tuber peels after disintegration in a hammer mill, etc.) together with the direct crop residues, (such as the cassava tops), thus allowing whole crop harvesting. These are then anaerobically digested to methane. Sufficient methane may be produced to cover all process heat requirements, and process electricity generation. Alternatively if coal and/or electricity is used for these purposes the methane rich "biogas" may be made available for distribution to the local community. The fermenter sludge is rich in digestable protein and may be used as an animal feed material, while the liquid stream should contain practically all of the fertilizer elements (phosphorus, potassium, nitrogen) coming into the plant, as the main products, power alcohol and biogas, only remove carbon, hydrogen and oxygen. This liquid stream might then be recycled to the cassava plantations, thus greatly decreasing their net fertilizer requirements.

For sugar or fodder beet, processing would be generally similar. No hydrolysis section would be required, and there would be a rather different beet preparation section.

The resulting integration of agriculture and processing in an "agro-industrial complex" is, we think, central not only to the economics of such a process, but also to its long-term viability.

NEW TECHNOLOGY

The production of very large quantities of power alcohol at a low cost will require efficient agriculture and efficient processing technology. As will be clear from the process description, these are inextricably interrelated, and research and development which recognises this will be needed across the whole field. As chemical engineers we are particularly concerned with the processing side, and hence with research and development in the hydrolysis, the fermentation and the alcohol separation sections.

Fermentation

The fermentation step is the basis of the whole process, and the major research effort to date has gone into this. Alcohol fermentation has traditionally been a batch process and still is this, with very few exceptions. Continuous, steady-stage fermentation would present many advantages. The lag and growth phases of the yeast, which account for a large part of the cycle time in batch fermentation, will be eliminated. Appropriate mechanical design of the fermenter may avoid "wash-out", and hence allow operation at greater dilution rates; or this limitation may be overcome by separating out yeast from the effluent and recycling it. The required volume of alcohol production can then be achieved with a much smaller plant, thus reducing capital costs. In addition one would expect that quality control of the product would be more readily obtained; there would be lower labour costs, and improvements in efficiency and productivity as a continuous, steady-state process is more amenable to sophisticated control.

The Sydney process is based on tower fermenters of the type originally devised for the brewing industry by the APV Company (see e.g., Greenshields and Smith, 1971). The fermenter is sketched in Fig. 2. The medium is pumped in at the bottom of the vessel, which has an aspect ratio of about 10:1, passing through a dense suspension of yeast cells to the top, expanded, section. Here the yeasts settle, clear liquid product is drawn off and gas is separated out. Such a fermenter is simple to build and operate. No agitation is required to keep the yeast cells in suspension, nor are external yeast separation and recycling facilities needed.

Studies to date with a 7.5 cm diameter 12 litre working volume tower fermenter indicate that with the yeast strains being used, simple glucose substrates can be fermented without deflocculation (as the specific gravity of yeast cells differs only slightly from the substrates fermented, a flocculant strain of yeast is essential to prevent wash-out).

Available data on the fermentation suggests that an improvement in productivity, or a decrease in residence time (equivalent to a decrease in equipment size) of at least an order of magnitude can be expected between a batch and continuous system. Results to date are consistent with this expectation. The extent to which the limiting volumetric efficiency (throughput) can be improved by altering the substrate composition for any given concentration of fermentable sugars remains to be determined.

For the methane digestion a similar tower fermenter may be used. The work here is more advanced and in addition to a laboratory fermenter of the same size as the alcohol fermenter, a pilot plant fermenter has been operating for some 18 months. This has a diameter of 1m (main section), 2m (separation section) and height of 9m.

Hydrolysis

Prior to the introduction of commercially produced enzymes in 1958 the hydrolysis of starch to sugars was entirely by acid. Acid is still commonly used for the liquefaction step which may then be followed by an enzyme saccharifaction. Alternatively an enzyme process may be used for both steps. By suitable choice of enzymes and processing conditions a wide range of products containing varying proportions of glucose, maltose and maltotriose will be obtainable. A fermentation substrate may then be selected to suit processing requirements.

This hydrolysis stage may be simplified or perhaps eliminated altogether if yeasts can be developed which are capable of directly fermenting dextrose. Starch would be prepared by liquefaction with bacterial amylase, and fed directly to the tower fermenter.

A more detailed discussion of the considerations involved in hydrolysis and continuous fermentation is given by I.G. Prince & McCann (1978).

Alcohol Separation

The conventional separation process involves two or three distillation columns, depending on whether the azeotrope or 100% alcohol is required as product. The design is related to traditional potable spirit practice, where the relative quantities of small trace components are important and may determine product acceptability. This is not the situation for power alcohol; but non-volatile impurities may be more important here.

Again, distillation column operating conditions and hence design are based on a balance between column and heat costs. This balance may be different to the conventional one in a process producing energy. A re-examination of number and layout of columns required is then indicated.

The rather small temperature difference between top and bottom of the distillation columns suggests that heat pumps may be feasible, particularly if electricity continues to be available at a relatively low price. The savings in energy would then be traded against an increased capital expenditure.

Alternatives to distillation should also be examined for the whole or part of the separation.

ECONOMICS

The cost of production will depend on the size of the processing unit and its associated plantations: increased plant size will decrease production costs by the well-known scale factor, while the associated increased plantation size will increase transportation costs, both for the crop into the factory, and for fertilizer-rich wastes back to the land. The optimal plant size will also depend on local conditions, particularly the distribution of land around the proposed processing site. Estimates based on Sydney University research work over the last four years suggests optimal sizes of around 50,000 kl/a production.

Costs for such a plant size are summarised in the table: fuller details are given in McCann and Prince (1978). The costs are based on the flowsheet described earlier, and are reasonable expectations from the research work currently under way. Many of these expectations of course will need to be confirmed by larger-scale pilot plant work.

The costing has been carried out in considerable detail for cassava. For sugar beet and sugar cane we have used the same capital costs, which we think likely for process plants designed specifically for power alcohol production from these materials. If however an alcohol production facility is essentially added on to a conventional food oriented sugar beet or sugar cane mill, capital costs will necessarily be considerably higher. A processing season of 240 days per year has been taken in all cases. It may well be possible to extend this considerably for cassava, thus reducing the capital charges per litre of alcohol produced. For sugar the effective season may well be considerably less.

The New Zealand Energy Research and Development Committee Working Party on Biomass has made similar estimates, although all the studies concerned have not yet been published (G.S. Harris, 1979). For fodder beet they estimate 15-20¢/litre ex-factory, depending on the rates of uptake, plant size and the commercial and taxation assumptions made. These figures are about half those they found in earlier studies, based on less favourable crops.

A comprehensive listing of Australian sources and costs has been made by Sheehan, Greenfield and Nicklin (1978).

Smythe (1978) has made cost estimates for cassava based alcohol for a similar size plant to ours, and obtains 31-41¢/litre. These costs are based on current technology, and in other respects may also represent the more conservative assumptions, so that they may reasonably be regarded as giving a conservative, higher limit.

Smythe suggests a comparable figure of about 50¢/litre, for sugar cane based alcohol. Hanks (1978), from the same organisation, in a series of more detailed studies concludes that the ex-factory price would be about 41¢/litre for 100% alcohol from a larger (150,000 kl/a) plant. The capital costs quoted by Hanks are very much higher than ours, but apparently include capital costs for the agricultural operation (in our case the charges are included in the delivered cost of the raw material). That these figures are high is also suggested by Hanks' reference to proposals before the Thailand Government for large sugar cane based alcohol plants with capital costs quoted almost equal to ours.

A further variable in these estimates is the cost of the cane itself: Deicke et. al. (1978) of another Australian sugar growing and processing company regard as acceptable for power alcohol production sugar cane costs at the lower end of our estimates (15¢/litre alcohol), while Smythe uses a figure twice as large.

As indicated earlier we do not think it likely that sugar cane would form the major basis of power alcohol production in this country. However, sugar cane based costs have been seen as more readily available, as the industry is well established, and there has been a tendency to quote the rather high values obtained to imply that any crop-based alcohol would be unattractive. When allowance is made for the different factors incorporated in the different estimates, and particularly the relatively high cost of the raw material in sugar cane based processing (and its wide variability), as well as the use of present technology, it can be seen that those cane-based alcohol cost estimates do not give a good guide to likely costs for cassava or beet based processes.

Our cost estimates are consistent with other comparable studies (G.S. Harris, 1979), and they show that for a crop suited to power alcohol production, such as cassava, the raw material costs represent a much smaller proportion (around one-half) of the total cost than for sugar cane. Hence the total cost is less for cassava, but, just as important, this cost is then less sensitive to variations in agricultural costs and conditions for cassava than for sugar cane.

The costs shown in the table are ex-factory, and to them need be added distribution costs and resellers margin to arrive at pump prices. In the case of cassava and beet the final figure is already closely comparable to the present pump price of petrol. The latter (presently about 25¢/litre in Australia) includes excise (5.15¢/litre) and that is a component which need not necessarily be applied to power alcohol. The level of excise is a political decision, and a figure can be set so as to encourage the power alcohol industry, if that is desired. This is for example being done very successfully in Brazil (Stumpf, 1978).

The alternative replacement fuel in this country would be oil from coal. A wide range of cost figures have been published. These are generally estimates based on experimental plants, with assumptions which are very hard to track down. If we apply the same type of private enterprise costing* as we have here, to the one large commercial plant, for which actual capital costs are available, SASOL 2 in South Africa, we obtain a figure of about $80 per barrel. An optimistic allowance

* i.e. 20% R.O.C.E. Financing by various means (different loan: equity ratios, interest and return rates) will lead to widely varying capital charges and costs.

TABLE 1

COMPARATIVE ESTIMATE FOR POWER ALCOHOL FROM SUGAR CANE, SUGAR BEET AND CASSAVA: 50,000 kl/a

	CASSAVA	SUGAR BEET*	SUGAR CANE*
CAPITAL COSTS	$15M	$15M	$15M
WORKING CAPITAL	$2.25M	$2.25M	$2.25M
SUNDRY CAPITAL	$0.75M	$0.75M	$0.75M
TOTAL CAPITAL	$18M	$18M	$18M
	¢/1	¢/1	¢/1
RAW MATERIAL	6.0-8.9	10.9-16.4	13.8-20.7
FRONT END PROCESSING	0.5	0.8	2.5
FERMENTATION AND DISTILLATION	4.9	3.5	3.5
TOTAL OPERATING COSTS	11.4-14.3	15.2-20.7	19.8-26.7
20% R.O.C.E.	7.2	7.2	7.2
PRODUCTION COST	18.6-21.5	22.4-27.9	27.0-33.9
BY-PRODUCT CREDITS	(0-6)	(0-6)	(0-6)
EX-PLANT COST	12.6-21.5	16.4-27.9	21.0-33.9

*Capital costs calculated for process similar to cassava agro-industrial plant.

for progress with new processes under development could perhaps lead to halving the figure, i.e. $40 per barrel, giving an ex-plant cost for petrol of about 30¢/litre (i.e. pump price 40¢/litre). It seems reasonable to deduce that at least for this country crop-based alcohol will cost less than oil from coal.

DISCUSSION

Land Availability

The likely transport fuel requirements for this country in, say, 1985 are estimated to be about 20m kl (Smythe, 1978). It is quite unlikely that we would wish to make that amount of alcohol by that date: indeed we are unlikely to be able to do so. However, by the mid or late 1980's we should aim to make 10-20% of our requirements. This proportion can be blended into petrol readily, so it would be absorbed quite easily. Such production would represent a direct saving of foreign exchange, it would provide a strategic reserve in case of difficulties with overseas supplies, and would give us the necessary experience and basis for full replacement of petrol by alcohol if and when needed. A first target therefore is the production of 2-4m kl/year. This would require 250,000-500,000 ha for cassava or fodder beet, and perhaps 50% more under lower yield conditions than we have assumed. About 50% more might be needed for sugar beet.

Australia is a large country, of about 800 million ha total area but restrictions due to climate, soils and topology would leave only about 10% of this (around 80 million ha) available for crops (Nix, 1978). About 40 million hectares appear to be actually used for agriculture.

While the overall areas available seem more than adequate both for blending and eventual complete substitution, the constraints on any particular crop are quite severe, leading to relatively low estimates of land available for these. For sugar and fodder beet (the requirements for the two are very similar) it is estimated that about 1 million ha are available in the southern areas of Australia, including 200,000-400,000 ha in Tasmania. Crop rotation of four years is generally practised with these (avoiding nematode infestation) so that up to 250,000 ha would be cropped in any year. The beets could then meet a large part of the requirements. For cassava, which is in the long-term more attractive, particularly on the basis of costs, the picture is less clear. Various estimates (Nix; Smythe; Deicke et. al) suggest that about 150,000-300,000 ha might be available to meet the more rigorous sugar cane demands: a proportion of this land is then likely to be earmarked for future food sugar expansion. For cassava much more marginal land is suitable, and another ½ million ha might be available. A substantial contribution to our blending needs could then be met by cassava, perhaps even all of these needs.

We see these land availability estimates as very conservative, and would expect that much larger areas could in the long-term become available, making more than sufficient land available for complete substitution of petrol by power alcohol:

(i) The over all estimates are based on a broad analysis of continental resources (Nix). The history of oil and mineral exploration in this country suggests that motivated, detailed, "on the ground" surveys may change the picture considerably. Changes in agronomy and agricultural technology over the time scale we are considering will also relax the constraints which have been applied.

(ii) The areas quoted are those suitable for wet land production, i.e. do not include irrigated dry lands. These latter may well make a substantial contribution. The cost of irrigated land appears high, but not all of the real cost is necessarily chargeable to the crop as major irrigation schemes have been constructed in this country with public funds with long-term and political considerations in mind rather than immediate economic ones.

(iii) If a good size for an alcohol plant is 50,000 kl/a, 40-80 of these will be needed to meet 10-20% blending. We are then not looking for a few very large suitable crop areas, but a large number of smaller areas, not necessarily close to each other. We can then effectively exploit relatively small patches, in much the same way as the present sugar industry does with its 30-odd mills distributed over the Queensland coast.

(iv) This large number of processing plants will allow for considerable variability, while still maintaining efficiency, central production of plant components, common technical and human support systems etc. In particular it would certainly allow for two, three or even more different crops so as to exploit to advantage different local situations.

Ethanol as an Automotive Fuel

Very extensive work and experience in Brazil (Stumpf, 1978) as well as in other countries have shown that ethanol can be used efficiently and satisfactorily in spark ignition engines, in blends with petrol, as the pure alcohol, or even as alcohol-water mixtures. The oil industry sees some difficulties and disadvantages associated with the introduction of alcohol (Aust. Inst. Pet. 1978). These include: difficulties in the progressive introduction of blends throughout a large sparsely settled country; the cost and proper timing of existing car engine adjustments and modifications; and in the short term alcohol may devalue a large volume of light hydrocarbons which are part of the current petrol mixture, and which are in excess supply. The oil industry would rather favour spending the sort of money which would be required for a crop alcohol industry on further oil exploration, and the consequent oil production and refining facilities. If crop alcohol is to be made in large quantities the oil and motor industries might prefer that it be chemically converted into high grade petrol (by processes similar to the Mobil Methanol Conversion process (Penick et. al, 1978)). These are all clearly factors which the Government must take into account when formulating long-term national policies.

Use of Methanol

Methanol is an alternative alcohol suitable for spark ignition engines. Australia has large reserves of natural gas from which methanol could be made at considerably lower cost than crop alcohol (Bradley & Robinson, 1978). Against this, under our climatic conditions one can see methanol as a blending constituent only, not as a potential complete substitute, so that it does not offer the long-term prospects of ethanol. Also natural gas is a very desirable fuel in its own right and may have to be retained to fill this role.

CONCLUSIONS

Ethanol can be produced by fermentation from a very wide range of crops. For large scale power alcohol production under Australian conditions costs have been estimated as 16¢ to 50¢/litre. The most suitable crops for this purpose appear to be cassava in the northern (warmer) regions and sugar or fodder beet in the south. By combining these with technology currently under development costs might range from 19-28¢/litre (without allowing credit for any possible by-products), ex factory. These costs are higher than present petrol prices, by a factor of 1.5-2.5, but this difference will narrow as crude prices rise. At the lower end the difference is of the same order as Government imposed excise tax on petrol so that Governments, if they wished, will be able to set the relative prices of power alcohol and petrol by differential taxes, without raising the overall level of tax. These cost projections are also below the price of ethanol as a chemical and solvent. Exploitation of this market would allow development of first full-scale alcohol production plants, without at that time committing us to alcohol-fuel blending.

A major component of these costs is the cost of the crop delivered to the processing plant. The final costs will then respond to developments in crop agronomy, and will necessarily be sensitive to variations in agricultural conditions. However, for the best (cheapest) crops such as cassava, processing costs are expected to exceed the crop costs, so that large scale economic production will require very efficient processing. Specifically, continuous fermentation is expected to result in large savings in plant cost. Continuous processing would also lead to other benefits such as increased productivity by the development of micro-organisms for specific and set conditions, and through improved controllability of the process. Sydney research to date has shown the feasibility of continuous fermentation, and the results support our expectations in reduction of plant size and consequently of costs.

Crop-based power alcohol then represents an important option in our national energy policy. In the long term it is the only fuel which exploits a completely renewable source. In the medium term it represents a lower cost material than synthetic oil from coal. Furthermore very much lower capital investment is required at each stage of implementation for a power alcohol programme than for an oil from coal programme.

Power ethanol is a more flexible fuel than methanol, as it can be used as a complete replacement for petrol rather than as a limited blend component. Again comparable ethanol programmes can proceed through smaller incremental stages thus requiring lower capital investment per increment.

If then a choice is made on a national basis between possible locally produced synthetic fuels (ethanol, methanol, oil from coal) then crop-based ethanol would be preferred and we should aim in the first instance at sufficient production for a 10-20% blend with petrol.

Such a programme would provide a great range of other benefits. It would extend our agriculture, develop closely-linked agricultural industrial complexes, revitalise rural areas and perhaps most importantly it would allow the development of local technology both for our use and for export to other countries. These will be substantial benefits for this country.

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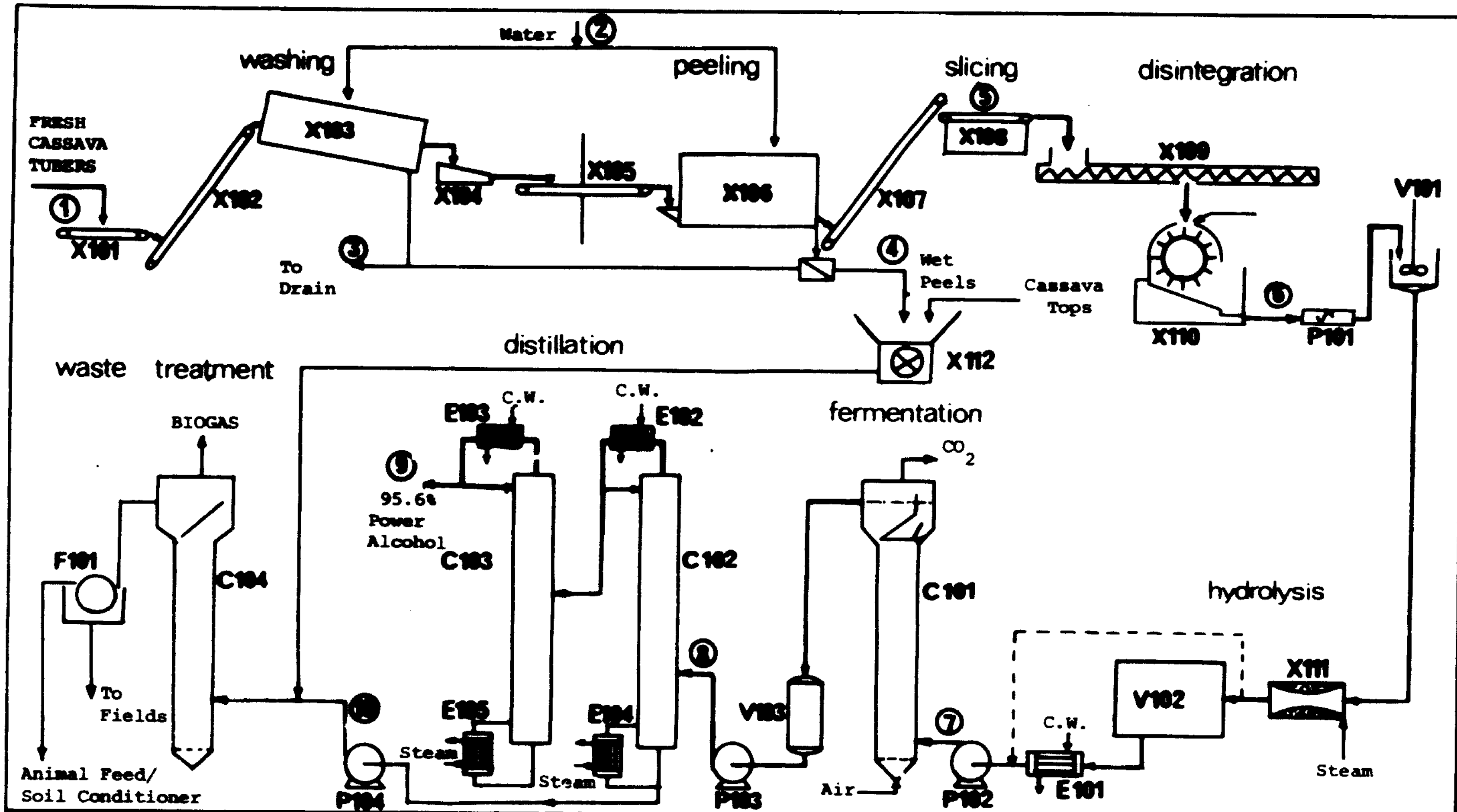

X101	INFEED CONVEYOR
X102	INCLINED ELEVATOR
X103	ROTARY ROD WASHER
X104	VIBRATORY ALIGNER
X105	ROOT CUTTER
X106	ABRASIVE PEELER
X107	ELEVATOR
X108	ROOT SLICERS
X109	DISINTEGRATOR FEED
X110	DISINTEGRATORS
X111	JET COOKER
X112	HAMMER MILL
V101	pH ADJUSTMENT
V102	HYDROLYSIS TRAIN
V103	STORAGE
P101	TRANSFER PUMP
P102	FERMENTER PUMP
P103	DISTILLATION PUMP
P104	STILLAGE PUMP
F101	SEPARATOR
C101	ALCOHOL FERMENTER
C102	'BEER' STILL
C103	RECTIFYING STILL
C104	WASTE FERMENTER
E101	HYDROLYSIS COOLER
E102	CONDENSER
E103	CONDENSER
E104	REBOILER
E105	REBOILER

QUANTITIES WEIGHT/TIME

STREAM NO.	1 FRESH TUBERS	2 WASH WATER	3 WASTE WATER	4 WET PEELS	5 PEELED TUBERS	6 CASSAVA PULP	7 FERMENTER FEED	8 DISTILLATION FEED	9 POWER ALCOHOL	10 STILLAGE
CARBOHYDRATES	30.0	-	-	2.7	27.3	27.3	0.8	0.8	-	0.8
CELLULOSE	2.0	-	-	0.5	1.5	1.5	1.5	1.5	-	1.5
PROTEINS	3.0	-	-	0.8	2.2	2.2	2.2	2.2	-	2.2
HCN	0.02	-	-	0.016	0.004	0.004	-	-	-	-
WATER	65.0	164.0	161.0	10.2	57.7	92.0	105.2	105.2	0.6	104.6
FERM.SUGAR	-	-	-	-	-	-	26.5	-	-	-
ALCOHOL	-	-	-	-	-	-	-	12.7	12.7	-
TOTAL	100.0	164.0	161.0	14.2	88.7	123.0	136.2	122.4	13.3	109.1

FIGURE 1 : SIMPLIFIED FLOWSHEET FOR CASSAVA ALCOHOL PRODUCTION (AGRO-INDUSTRIAL CONCEPT)

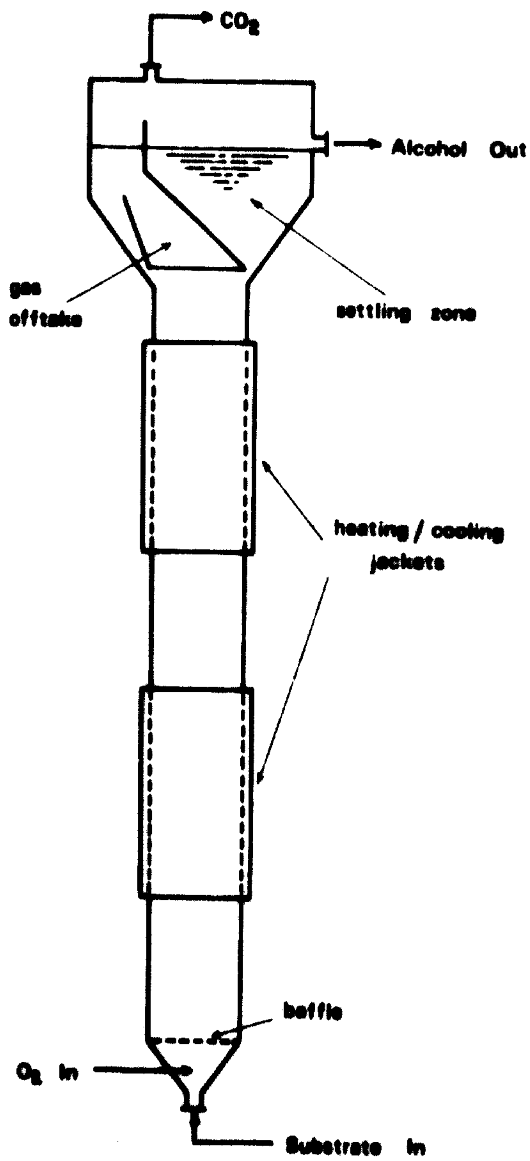

FIGURE 2: THE TOWER FERMENTER

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