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Fuel and Chemical Feedstock in Developing Countries,

Vienna, Austria, 26 - 30 March 1979

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by

F.H.C. Kelly**

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F.H.C. Kelly**

The author recommends discussion be entirely separated from crystal sugar industry.

Factors influencing the cost of agro-ethanol from sugar cane have been identified and listed under 6 for agricultural aspects and 5 groupings for process aspects. The paper extracts information from a detailed monograph prepared by the author in 1977 in which strongly defined exponential relationships between the estimated cost of ethanol ex-distillery and the log of the logarithm of the unit area of farm or plantation became evident. Use of the best known 20th century technology is predicated involving heavy duty agricultural machinery, a high standard of maintenance, extension of season to 39 weeks with 7 day week, 24 hours day operation. Irrigation facilities are important.

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An indexed system of amortization is suggested to cope with high interest rates for long term repayment of land and water storage development finance.

Factory flow sheeting is suggested for whole cane processing (including tops), primary juice extraction, cellulose hydrolysis us Ritter type heaps, continuous fermentation, high thermal efficiency distillation, slops recycling for fertilizer possibly after evaporation and fuel from lignin and residual cellulose with supplement.

Maximum economic size of factory unit probably determined by maximum size of distillation columns at about 10,000 tonnes cane per day. Double this size would introduce serious logistic problems for cane supply.

Minimum cost of ethanol ex distillery estimated at U.S.¢ 8.4/1 using space-age technology.

Introduction

This study is concerned essentially with the production of ethanol from sugar cane itself and not from molasses and results from a feasibility study carried out by the author[1] in the Department of Chemical Engineering at the University of Queensland in 1977. It was observed then that molasses could only be considered a satisfactory raw material for ethanol production if one or more of the following conditions operated:

(a) The sugar factory was very large ($\nless$15,000 tcd)

(b) The relative production of molasses was very high due to low quality cane or for some other reason.

(c) Transport costs for centralised collection were very favourable.

(d) Fuel costs for processing were very favourable.

A close study of the situation in Queensland as then prevailing revealed only limited prospects from this source which could not be considered as a prospective contributor to the national requirements of liquid fuel on a significant scale.

The prospect of using whole sugar cane for this purpose was examined in detail and under Queensland conditions revealed very interesting possibilities for development on a scale compatible with over-all national consumption of light liquid fuels and chemical feedstock (14Gl. year in 1976).

Although a wide range of technical aspects was included in the feasibility study the present submission is restricted to identification of cost controlling factors with some elaboration on directions for possible development.

Raw Material

In any study of ethanol production the cost of raw material features prominently. If "world price" of raw sugar as a possible source of ethanol is compared to "world price" of crude oil present day costs display a relationship which is very unfavourable to sugar as an alternative raw material. However it is well known that the "world price" of raw sugar bears only a marginal relationship to the real cost of production. It soon became evident that it would be unwise to tamper in any way with the structure of the present Queensland sugar industry for the purpose of obtaining low-cost ethanol, although full advantage should be taken of experience in growing sugar cane, the control of pests and diseases and the extraction of juice. Sugar cane grown in new areas specifically for ethanol production would, however, appear to have better prospects for lower cost development but would require the parallel development of an entirely new social and economic structure suited to its own needs. This includes such very important requirements as new contracts between management and employees based on the merits of the ethanol industry rather than existing practices in the sugar production industry, although such can form a useful basis for discussion. For example a mechanical harvester is a mechanical harvester whether cane is cut for crystal sugar or ethanol production, but in Australia whereas cutting is currently restricted to daylight hours and to five days a week the prospective employment of the high capital cost machines for 24 hours a day and 7 days a week needs to be envisaged and appropriate adjustments sought.

Diversion of cane from sugar to ethanol production is unlikely to be satisfactory economically and at the best to be only a short-term palliative. Whereas a community may tolerate certain high cost aspects of production for a semi-luxury product such as sugar it is unlikely to be so tolerant towards an industry producing large quantities of liquid fuel the costs for which would permeate every aspect of daily living.

In order to be able to identify high cost components in the production cycle the over-all flow sheet for this study has been divided into 11 sub-units as far as the storage of ethanol at the distillery site. To this needs to be added transportation and other distribution costs. This procedure also has the advantage that variations of even ±50% with respect to individual items only marginally affect the over-all cost and the possible scope of such variations in each sector can be individually examined.

Whilst sugar cane itself has been specified as the desirable raw material for this study it is necessary from a global or national point of view also to examine other possible sources of liquid fuel. It is not the purpose of this particular paper to do this, but it is pointed out that when making such comparison each source has both favourable and unfavourable conditions and it is necessary to be quite specific when dealing with such situations. The emphasis here is to define the most favourable conditions from all points of view for the production of ethanol from sugar cane. However, there is not a unique solution to the problem of over-all optimisation, the author will not attempt here to define such effects in detail but will draw attention to some of the situations which develop. For example it is not uncommon to compare best productivity conditions for a new crop with average conditions for sugar cane without examining the possibilities for best conditions for sugar cane or the likelihood of the new crop achieving less than best conditions under real-life large scale situations.

To expound on this example for sugar cane - we may examine average yields on a world basis and find that best country yields are at least twice as much as the average and the best area within the best country may yield twice as much as the average for that particular country and the best farm within the best area may yield twice as much as the average for that area or eight times as much as world average. Queensland is a country where very high productivity values for sugar cane have been achieved but the author estimates that the average yield of stalk cane per hectare is still only about 34% of the known achievable yield under optimum growing conditions, which means that many countries are probably operating at not better than 20% of achievable yield and some as low as 10%. The author has estimated the maximum achievable photosynthetic efficiency for sugar cane when grown as an economic crop under currently known conditions of technology to be around 8%.

For successful economic development of an agro-based ethanol industry it is considered essential to apply the best of 20th century technology at each of the agricultural, harvester, transportation and processing stages. The industry would not provide a panacea for unemployment, the minimum skill being that of the driver of a heavy duty tractor or truck or the general supervision of computer controlled processing.

Cost Component Items

In applying the principle of multi-component subdivisions for cost analysis the author categorized 55 subject areas for study, examined in detail 25 favourable combinations of conditions for cost estimations and required 35 sub-headings to summarize the findings effectively and tabulated under 20 sets of conditions recommendations related to areas of research and development considered to be important. The study was comprehensive but not necessarily exhaustive. The following costing sub-divisions were actually used:-

1. Development of land including net capital cost, drainage and irrigation development.
2. Cultivation costs.
3. Fertilizers and chemicals.
4. Irrigation application.
5. Harvesting.
6. Management of plantations or farms.

   A= total growing costs

7. Transportation of cane from field to factory.
8. Capital cost of factory.
9. Maintenance.

10. Labour and chemicals.

11. Management of factory

B = total processing costs

C = total cost of ethanol ex-distillery.

There is room for differences of opinion or custom within this subdivision and adjustments are permissible to accommodate personal preferences but this subdivision is adopted here as a primary basis for consideration of the problems.

All agricultural operations have become very highly mechanised and the sugar cane industry has shared in these developments. One very important requirement for the economic application of these developments is continuity of use of equipment. This requires firstly that a high standard of mechanical maintenance be achieved and secondly that the items of equipment be used for as large a proportion of available time as possible. The seasonal nature of agricultural operations reduces the time available for use in any one year and anything which can be done to extend seasonal operations must be of benefit from this point of view. Agricultural machinery is generally not distinguished for the standard of maintenance achieved, perhaps more so when smal. scale units are employed. The most costly and physically largest mechanical unit employed on the sugar cane plantation is the present day chopper type harvester. At present practically every stick of cane in Queensland is mechanically harvested, but a study of the statistical records indicates that these very costly machines are being used to only about 13% of their potential capacity. There lies within this segment a factor of 5 to 7 by which the capital cost component could be reduced. An analysis of lost time due to mechanical failures for agricultural equipment in general, reveals maintenance standards close to one tenth of those achieved within the factory. Continuity of operation of other agricultural operations (including irrigation) also has important economic benefit and optimisation is required at all stages e.g. cost/benefit of 24 hr/day ploughing and planting.

Sugar cane will grow in practically any type of soil, and those soils which are often classed as unsuitable can generally be suitably modified albeit at some cost. Water supply, fertilizer and sunshine are the three important requirements for satisfactory growth. The cost of developing land includes grading and draining as well as the storage and reticulation of water for irrigation. It has been preferred here to consider under a separate item, the cost of applying the irrigation. The earlier items are considered to be part of the capital cost of land development which is a quite significant item in the list of costs and special attention has been given to amortization techniques. The period for repayment of capital plus interest with respect to total land development costs can be spread over a much longer period of time than for machinery and for these studies a period of 75 years has been preferred with 20 years for processing plant and 5 years for agricultural machinery.

At the present time high interest rates are being charged for loan funds and are believed by economists to represent one antidote for high rates of inflation. This places a very heavy burden on amortization even if repayment is spread over a period as long as 75 years. One way of meeting this problem is to apply a system of indexation to repayments designed to keep the ratio of periodical repayments to sale price of product constant. It is of course difficult to predict the likely sale price for any commodity in 50 or 75 years time but it is not without interest in this context to look back for 50 or 75 years and to see just how the net prices of such commodities as petrol, ethanol, sugar and sugar cane have changed; an exercise which is rather more satisfying than a corresponding study of short term changes. For example for every $100 initial capital investment at 5% an equal annual repayment of $5.13 would be required for each of 75 years, whereas if an indexation increment of 3% per annum is employed then the median payment for the first 5 years would be only $1.55 although the payment in the 75th year would be $12.96. History seems to indicate that over long time spans annual inflation rates tend to average around 5% hence an indexation of 3% could be expected to have a reasonable margin of safety. Correspondingly an 11% loan fund interest rate indexed at 3% p.a. would require payments of $11.00, $3.31 and $27.79. The mathematical relationships are itemised in Appendix 1.

Whilst an indexed system of amortization is of considerable benefit for debts repayed over long periods such as 50 to 75 years it is of only marginal value for a 20 year period and of no significant value for 5 years.

The money spent on primary land development has a very strong influence on productivity in later years hence there is real value in enabling a thorough job to be done at this stage including the important items of flood prevention, drainage and adequate irrigation supplies.

Size of Farm or Plantation

This more than any other single item seems to have a dominating influence on the ultimate cost of ethanol, and the development of sugar cane culture for ethanol production as a new industry affords an opportunity to examine this aspect "ab initio". The over-all magnitude of full scale development to provide in full Australia's present requirements of 14Gl p.a. of liquid fuel would require an expansion 4 to 7 times the size of the present Queensland sugar industry which totals approximately 3250km^2 subdivided into 7300 units averaging 44.5 ha. Development on this scale would afford substantial scope for study.

Whilst increased scale of operation offers bright prospects for reduction in management and operating costs it is recognised that productivity tends to be lower as scale increases. A general relationship between productivity and unit area of growing which has been found useful, in the author's experience, with respect to sugar cane growing is evaluated in Appendix II.

Anticipating the over-all picture of the final cost of ethanol two complex exponential relationships became evident relating the estimated price of ethanol ex-distillery to the log of the log of the size of unit farm or plantation area. For this a gross area of 350km^2 per factory unit has been employed, the effect of variations from which being separately considered.

When considering economic optimization of the size of a single plantation-factory unit in this situation two factors are prominent - (1) the logistics of maintaining a continuous supply of fresh cane to the factory and (2) the absolute maximum size of a distillation column. A figure around 10,000 tcd seems best to satisfy these two requirements and for high productivity cane production corresponds to an area of approximately 350km^2 if the season can be operated for as long as about 270 days.

The proposal to extend the season to around 39 weeks from the present practice of approximately 28 weeks assumes that the total sugar content of the cane has a less well defined peak value than for recoverable crystal sugar. The practical limits then become more specifically the end and beginning of the wet season.

Changing these parameters plus that of the working week-end introduces a step change into the relationship between the size of farm or plantation unit and the cost of ethanol.

Figure I illustrates in summarized form general relationships between the estimated cost of ethanol (ex distillery) and the size of individual farm or plantation units incorporating also the direction and approximate magnitude of the influences of a range of additional variables.

The net result of these studies was to prefer plantation units of 1600 hectare area although managing the whole $350 km^2$ as a single plantation unit could have some financial advantages. There is a tendency in the present Queenslad sugar industry for some amalgamation of farm activities perhaps up to 150 or 250 ha and two factory-owned plantations still remain. Within the global picture a plantation of $300 km^2$ (net) supplies a factory in Argentina at the rate of 18,000 tcd and comparable sized complexes operate in Mexico and the Sudan.

Processing Cane

For producing crystal sugar only stalk juice is used and even this is required to be as fresh as possible. When ethanol is the end product deterioration which results in the formation of fermentable hexose at the expense of sucrose is immaterial and juice from the tops carrying a higher proportion of such hexoses should be quite acceptable. Furthermore a useful proportion of the fibre is fermentable after hydrolysis. It was estimated that under Queensland conditions whereas 96 l of ethanol could be expected from 1000kg. of juice extracted from the cane stalk this could be increased to as much as 164.5 l (a 71% increase in yield) if the tops are also processed and the cellulose component of the fibre is hydrolyzed and fermented.

Harvesting transportation and milling of tops together with the stalk of the cane should present no particularly difficult problems. However, cellulose represents only about 53% of the total dry fibre weight and is the only component hydrolyzable to fermentable hexose (glucose). The steps involved in these conversions still require much detailed study as any one of several routes is possible. The route preferred by the author is to minimise capital and operating expenditure at the milling stage by employing only a three roll crusher and a single three roller mill with appropriate pressure feeder device Two preliminary sets of knives are preferred and a shredder between the crusher and mill. The juice stream can then be processed through hydrolysis, fermentation and distillation. The fibre containing so e 25% of residual juice would be subject to treatment in a separate stream.

For fibre processing the author expresses a preference for employing a "heap" technique comparable to that of the Ritter system developed actually for bacterial preservation of fibre. The percolation of biological fluids through large heaps is also practised on tailings dumps in the metallurgical industry. The author has observed the Ritter process in large scale operation and is of the opinion that there should be no significant technical difficulties in converting its operation to use with a cellulase-rich percolating liquid phase. Fibre hydrolysis is difficult and slow, but any thermal technique aimed at accelerating the kinetics invariably results in loss of fermentable hexose. The Ritter bagasse storage system is ideally suited to slow treatment of large quantities of fibre at ambient temperatures. The residual fibrous material can be separated by passing it through perhaps two sets of standard 3-roller mills with pressure feeders, the extracted fluid joining the main stream of fluids passing to the fermenter.

The dried residual fibre would consist of a mixture of lignin and unhydrolysed cellulose- possibly 25% of the original amount. This lignin-cellulose mixture dried to a moisture content of 47% should be a very satisfactory fuel for those who are expert in burning bagasse. The fate of the pentosans forming some 23% of the dry fibre is uncertain, if hydrolysed (xylan) it would go out with the distillery slops as pentose whereas any non-hydrolysed fraction (araban) might well go forward with the lignin-cellulose stream as fuel. It is unlikely that the lignin-cellulose residue would provide sufficient fuel for the whole process but supplementation - probably with coal-still leaves the hydrolysis of cellulose an economically viable route. Careful costing is called for at this stage to determine whether some lesser efficiency of hydrolysis would be justified but it is a low cost route for converting coal into ethanol.

Fermentation

This is an important stage in the processing flow sheet and well worthy of careful cost-benefit as well as technical study. Important parameters are hexose concentration, non-hexose solute influences and effective application of continuous fermentation techniques.

Distillation

Also an important step for maximising thermal efficiency by multiple effect type operations attending also to the need for a high recovery of ethanol. It is anticipated at this stage that anhydrous ethanol would be the preferred product but the possibility exists of some or all of the ethanol being more economically markered as 95%.

Slops Disposal

The residue from the distillery becomes a very important and quite substantial by-product of the ethanol recovery. Disposal procedures which might prove satisfactory for a distillery processing only relatively small quantities of molasses become unacceptable for operations on the scale envisaged for whole cane processing. They do contain materials valuable as plant nutrients and in fact contain probably 90% of the nutrients removed from the field with the plant. If these can be effectively recycled they can result in a very substantial reduction in consumption of chemical fertilizers. There may be difficulties in justifying the economics entirely on the basis of present day costs of chemical fertilizers but it is close enough to make it a worthwhile undertaking from the point of view of conservation of energy and material resources.

Whilst recognising that there are technical difficulties the author believes that these are by no means insoluble and that concentration of slops by multiple effect evaporation is likely to afford the most satisfactory means for deali g with this problem.

Labour Saving Expedients

For agro-ethanol to be economically viable it would be reasonable to expect the standard of technology to be comparable with that of an oil refinery or a petro-chemical industry, correspondingly a R & D effort comparable in magnitude and expertise would be expected to have benefits of much greater magnitude than we could envisage today.

Perhaps the most obvious labour saving applications appear to be in the processing plant where the installation of automatic control instrumentation, micro-processor programming and over-all computer monitoring would be logical expectations for any new installation.

However there is an even greater potential for labour-conservation in the agricultural area if the energy at the disposal o, an individual operator can approach that which an operator in a modern sugar factory has at his command. This means bigger tractors, double row harvesters, double or multiple row planters as well as mechanized irrigation and fertilizer application.

The possibilities of applying space-age technology for remote control of either agricultural operations or factory processing is a topic of imminent interest. Whereas one man may drive one tractor during the 20th century, there are now no technical reasons why one man should not drive 10 tractors.

The master-minds of the industry could centrally activate controls through satellite transmission and closed circuit television observation requiring essentially only a maintenance team on site.

Government Charges

It should be superfluous in a discussion of this character to point out the very important and significant component of petrol prices which incorporates government charges in the form of a tax or taxes. When considering over-all relative economic benefits of agro-ethanol it is necessary to take cognisance of government charges although the nature and magnitude of their imposition will be largely determined by politico-economic considerations. The point may well be made that instead of imposing restrictive taxes on ethanol production or consumption as a motor fuel or chemical feedstock from agricultural sources it may be considered in the best interests of the nation actually to subsidise the industry with financial incentives for development, as benefits accrue within a country which also result in minimising the need for external payments.

Summary of Cost Estimates

Whilst the author has examined a very large number of possible combinations of production and processing variables from the point of view of probable cost contributions Table 1 represents the lowest cost conditions envisaged from these calculations and may serve as an indication of the nature of the problems with which the industry would be concerned.

TABLE I Estimated costs in U.S. ¢ (1977/78) per litre of ethanol produced in 1985 using reasonable maximum productivity of cane, whole cane harvesting, cellulose hydrolysis and fermentation, with application of space age technology.

Items	35,000 ha estate at 160 t. cane/ha.
Total annual production of ethanol	630 Ml
Capital cost of factory	U.S. $100 m.
Property development	0.83 ¢/l.
Cultivation costs	0.08
Fertilizer and chemicals	0.11
Irrigation application	0.27
Harvesting	0.06
Local management	0.08
Total agricultural cost	1.43
Transportation of cane	0.44
Capital assessment for factory	2.98
Maintenance	0.72
Labour and chemicals	0.11
Local management	0.06
Cost of coal	1.67
Total processing cost	5.98
Proportion of control centre cost (20% at 20 years for U.S. $560m. and 14 Gl/annum of ethanol)	
Capital assessment	0.81
Management and operation ($22 m/yr)	0.16
Cost of space age technology application	0.97
Total cost of ethanol ex distillery	8.38

It is interesting to note that whereas the price of sugar cane in the sugar industry is commonly assessed at around two thirds of the price of raw sugar or perhaps half of the price of refined sugar the largest component in the above list of cost items for ethanol production under space-age conditions of technology is the capital assessment for the processing plant with the total agricultural cost being only 17% of the ex-distillery figure. This proportion becomes progressively smaller as we pass from around 30¢/1 when associated with even the best of present-day sugar production as agro-technology is oriented more towards the ethanol problem itself and incorporating all of the developments related to the problem and known at the present day to minimise around 8.4¢/1, a figure which could justifiably be considered to compare more than favourably with petroleum based fuels of corresponding quality. Property development costs in this table relate to an indexed amortization (on 11% interest) and would rise to 1.29¢/1 (on 5% interest) for equal annual payments.

APPENDIX

1. Indexed Amortization Formulae:

$$R = (C * i)/(1 - (1 + i)\uparrow - n) \qquad \ldots\ldots\ (a)$$

$$Y_1 = (R * n * (1 + r))/(\sum_{0}^{n}(1 + r)\uparrow n)$$

$$Y_n = Y_1 * (1 + r)\uparrow n$$

$$I = R * n - C$$

R = repayment in equal amounts for equal time intervals

C = capital debt.

i = interest rate (uniform throughout period)

n = number of time intervals

Y_n = repayment for specific year n

I = total interest repaid to year n.

II. Productivity - Area Relationship

Productivity New = (((AREA OLD)/(AREA NEW))↑ 0.0184) * PRODUCTIVITY OLD

III. Cost-Area Relationships - equations to full line curves in figure I.

(a) for 5 day week, 28 week season and daily or 3 shift seasonal employment with short term living/firing.

$$K = 41.74 - 8.21 * \log_e (\log_e A)$$

(b) for 7 day week, 39 week season, daily or 4 shift roster employment system but with annual retainment.

$$K_L = 50.37 - 17.36 * \log_e (\log_e A)$$

(for 10 to 1000 ha unit area)

....20/-

$$K_H = 19.2 - 1.35 * \log_e (\log_e A)$$

(for 1000 to 100,000 ha unit area)

K = estimated cost of ethanol ex distillery in U.S. ¢/1

K_L = ditto for low area farm units

K_H = ditto for high area farm units

A = unit area of farm or plantation in hectares.

REFERENCE

I. A Feasibility Study of the Production of Ethanol from Sugar Cane

- F.H.C. Kelly. Dept. of Chemical Engineering, University of Queensland St. Lucia. Australia 4067. Monograph November 1977.

NOTE: The opinions expressed here are entirely those of the author.

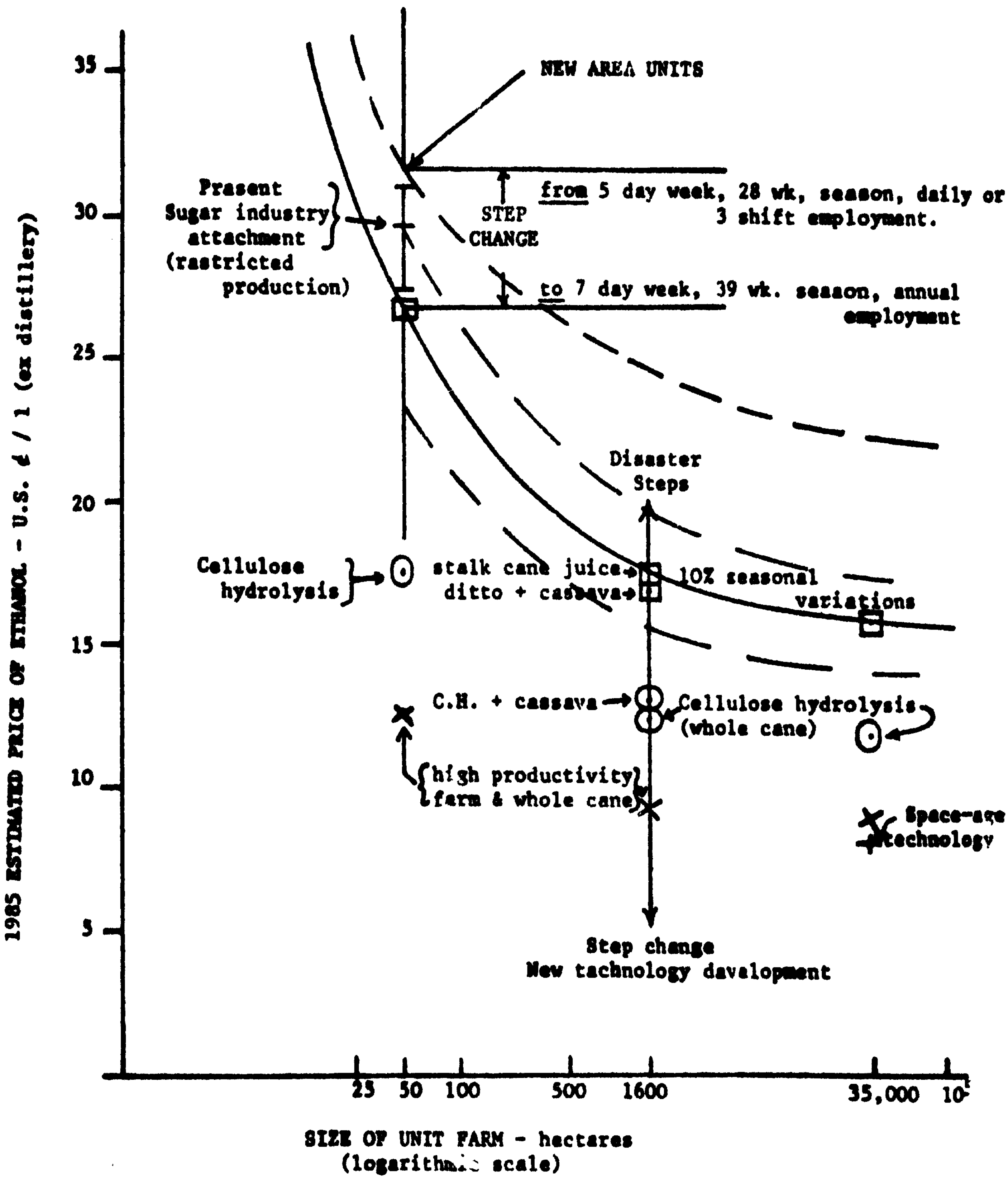
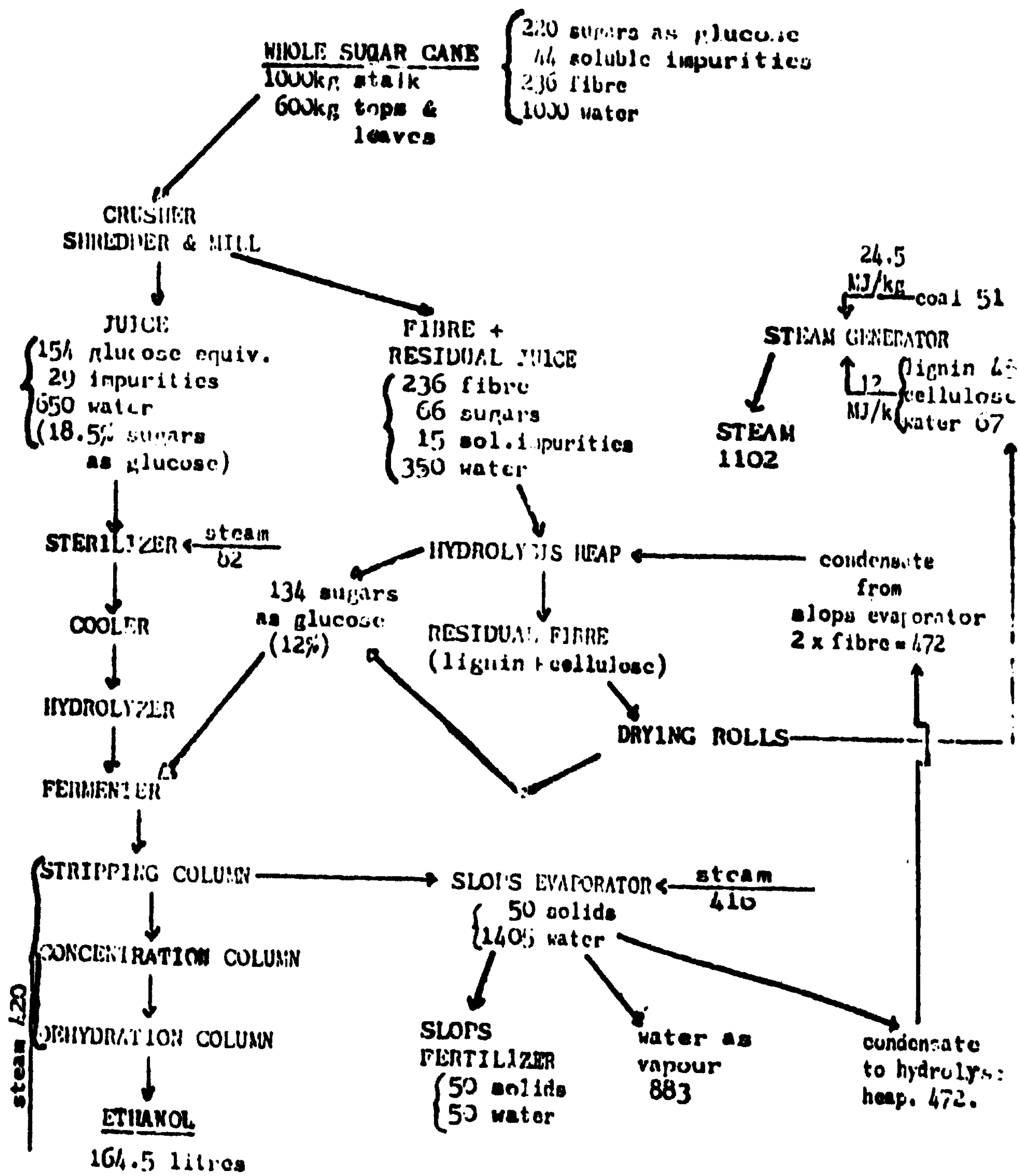


Figure 1: Relationship between estimated price of ethanol as related to the size of the farm unit.



STEAM USAGE

Power	40
Sterilizer	82
Distilltn.	420
Slops.evap.	360
Miscell.	200
total steam	1102

Figure 2: Simplified flow sheet for whole cane processing with cellulose hydrolysis.

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