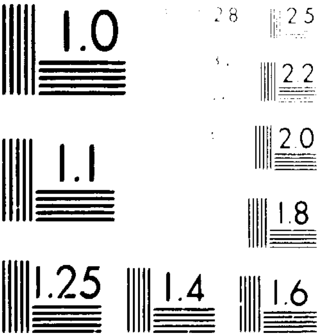
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Battelle
Columbus Laboratories

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Report

EVALUATION OF THE EX-FERM PROCESS

SI/RLA/8

to

UNIDO

December 29, 1982

EVALUATION OF THE EX-FERM PROCESS

SI/RLA/82/801

to

UNIDO

December 29, 1982

by

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SUMMARY

The United Nations Industrial Development Organization has requested Battelle Columbus to evaluate the EX-FERM process for the manufacture of ethanol from sugarcane, to determine the competitiveness of this process compared to conventional technologies, and to determine the feasibility of commercializing the EX-FERM process through establishment of a pilot plant. We have reviewed the published information on the EX-FERM Process and have visited the Central American Research Institute for Industry (ICAITI) to observe the process in operation.

Based on our review of the research conducted by ICAITI to date and our estimation of the overall economics of a commercial EX-FERM facility relative to conventional technologies, we believe that ICAITI should continue development of the EX-FERM process and that such development be directed at identifying and overcoming the technical barriers to commercialization. A pilot scale demonstration of the process will be needed to show that the process works and that technical risk of commercialization is small.

We have prepared an economic evaluation of the EX-FERM technology and of conventional sugarcane-to-ethanol technology. It appears that EX-FERM will offer significant economic advantage over conventional technology for a new ethanol-from-sugarcane plant at all plant sizes likely to be of commercial significance. If an existing sugar mill is to be converted to ethanol production, the conventional technology will be less expensive than EX-FERM. The estimated capital investment for ethanol production at the facility processing 2750 metric tons sugarcane per day with 180-day harvest season is \$41-\$44 million for EX-FERM compared to \$53 million for conventional technology. With sugarcane at \$17 per metric ton, the estimated manufacturing cost plus a 15 percent return on total investment is \$0.56 to 0.58 per liter for EX-FERM compared to \$0.64 per liter for the conventional technology.

The research on EX-FERM to date appears to have been conducted in a professional fashion. We believe that ICAITI is capable of scale-up and development of the process. We would recommend, however, that a mechanical

engineer with practical experience in materials handling be added to the ICAITI team.

Based upon our review of the research to date and our estimation of economics of the EX-FERM process, we have identified several key issues that need to be resolved. The three most important research tasks are:

1) demonstration that contamination is not a problem with fresh sugarcane

2) demonstration that ethanol can be easily recovered from pressed bagasse

3) demonstration that wet solids can be effectively handled on a large scale.

The first and part of the second task can be demonstrated at the current 30-liter scale, but a pilot scale demonstration will be required to finally resolve the second issue and to investigate the third. We are particularly concerned about the removal of the spent cane chips from the fermenter. Other areas for further research and development are identified in the report. We believe a pilot plant is needed before the process is commercialized to demonstrate continued trouble-free operation with yeast recycle over an extended period of time and to verify the capacity of the equipment.

While we believe that the pilot plant is needed for commercialization we also believe that much process research can be done at the current 30-liter scale. We suggest that process research be conducted at the 30-liter scale while the larger pilot plant is being constructed. This should speed commercialization.

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INTRODUCTION

The United Nations Industrial Development Organization (UNIDO) has requested Battelle Columbus Division to carry out a detailed and independent study on the competitiveness of the EX-FERM process and to determine the feasibility of developing the EX-FERM process through establishment of a pilot plant. EX-FERM is a process for the manufacture of ethanol from sugarcane which eliminates the need for cane milling. The process was conceived by workers at the Central American Research Institute for Industry (ICAITI), located in Guatemala City, Guatemala (1-11)*. ICAITI has conducted preliminary research on the process and plans to continue development through construction and operation of a pilot plant.

In the conduct of this study, Battelle staff reviewed publications on the EX-FERM process, visited ICAITI to observe the process in operation, prepared an independent evaluation and a conceptual design of a commercial EX-FERM process based upon the information available, and prepared an independent economic estimate for the manufacture of ethanol by both EX-FERM and by conventional ethanol from sugarcane technology.

This report summarizes the results of Battelle's investigation.

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* References indicated by numbers in parenthesis are located at the end of the report.

DESCRIPTION OF THE EX-FERM PROCESS

The concept of the EX-FERM Process is the simultaneous extraction and fermentation of sugars from sugarcane. The goal of this process is to reduce fixed investment and manufacturing costs for ethanol made from sugarcane by elimination of the cane milling step. This concept was initially proposed and has been partially developed by ICAITI and has since been adopted in one form or another by researchers at several other organizations.

For the purposes of evaluation, we have made a conceptual design of a commercial scale EX-FERM Process. Since the actual research to-date has been conducted primarily on laboratory scale and to a limited extent on a bench scale, there are many assumptions inherent in this conceptual design. A block diagram of the conceptual EX-FERM process is shown in Figure 1.

The initial section of the conceptual EX-FERM plant is cane receiving and handling. This section would be essentially the same as that found in a sugar mill or conventional ethanol-from-sugarcane factory. The cane handling area includes scales, cranes, inclined cane feed tables, cane conveying equipment and provisions for sampling. The cane handling area also includes intermediate storage so cane can be held overnight. Cane shipments will be received generally during daylight hours only. The cane handling area also includes an initial set of knives to cut the cane into small pieces which can be fed to the following parts of the system.

In the EX-FERM Process the next section is the cane chipper. ICAITI has successfully used a small unit designed to prepare wood chips to make suitable cane chips. There is also some conveying and intermediate storage equipment associated with the chipper.

The ICAITI EX-FERM concept includes year-round operation. To accomplish this, a dryer and storage facility are included. Very little work has been done on cane drying, however, except on a laboratory scale.

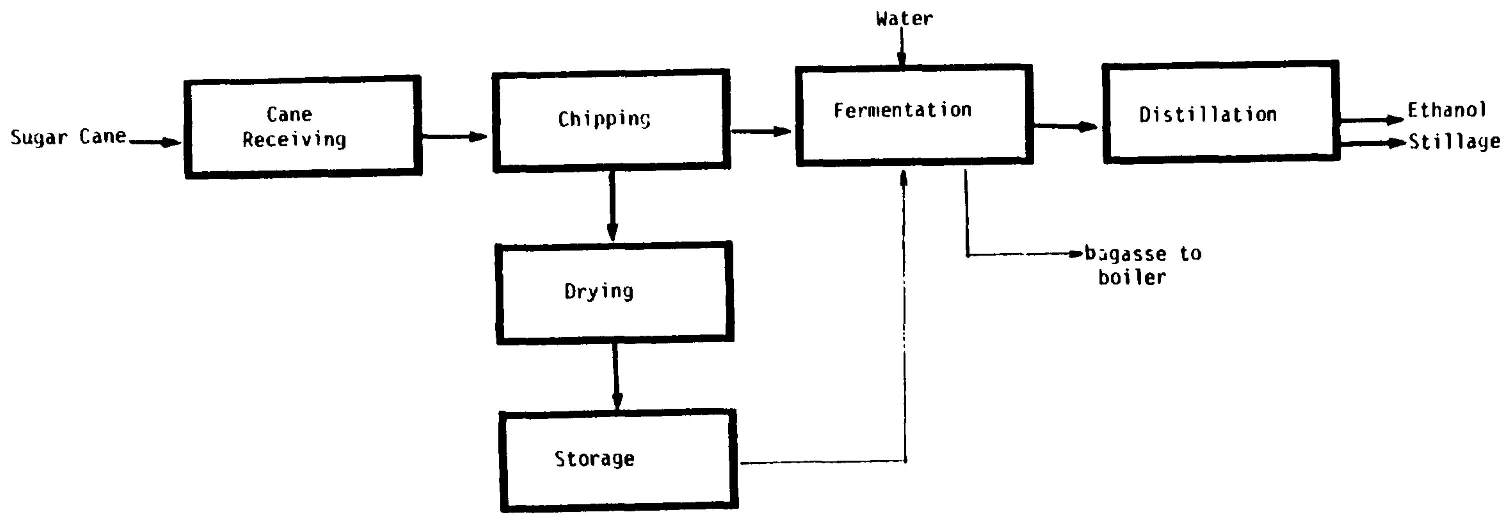

FIGURE 1. SIMPLIFIED EX-FERM PROCESS

For the purpose of this analysis it has been assumed that a continuous belt dryer would be used, and the design of this dryer is based on very limited information obtained by ICAITI. There is a great deal of uncertainty associated with the estimate of the drying cost. Storage is based on the design of a building actually constructed in Central America to store cotton seed. Conveying equipment to get the dry cane to and from storage is a significant part of the total storage cost. For the conceptual design it was assumed there would be eight storage buildings, each 50 x 50 meters located adjacent to the cane receiving and drying area with a space of 20 meters between buildings.

In a conventional cane milling operation or in an EX-FERM operation which operates only during the cane harvesting season, the drying and storage area is not required.

The fermentation section of the EX-FERM Process consists of two sets of fermenter towers. Chipped cane is conveyed into the first set of fermenters and a yeast suspension is then added to fill the fermenter with liquid. A very high yeast-to-sugar ratio is used and it was assumed that the fermentation time would be only nine hours in each set of fermenters. During the fermentation, liquid is withdrawn from the bottom of the fermenter and recirculated through a heat exchanger to provide temperature control. Upon completion of the fermention, the liquid is pumped to a second fermenter which has been filled with fresh cane chips and the solids are removed and conveyed to a press. The pressed liquid is screened to remove fine particles, added to the drained liquid and sent to the second fermentation. The pressed solids are assumed to contain 60 percent liquid and 40 percent fiber. This has been demonstrated at the laboratory scale.

The pressed solids are washed with water in a conveyor and the wash water is returned to the yeast mixing tank so that alcohol recovered from washing the bagasse is recycled to the fermentation process. A 90 percent recovery of alcohol from pressed solids is assumed. This is a key assumption which has not yet been demonstrated. The ethanol-rich wash liquid is screened to remove any suspended bagasse prior to recycling to the yeast preparation tank.

Most of the alcohol, yeast and water from the first fermentation is added to the fresh cane in the second fermentation. The alcohol concentration in the liquid from the first fermentation cycle is estimated to be 4.5

percent (w/w). It is significant to note that ICAITI has not demonstrated this high an ethanol concentration in the first cycle fermentation because they have used excess water in all their experiments. Nevertheless, we believe that based upon the liquid that they add to cover the chipped cane and fill the fermenter that the concentration of 4.5 percent ethanol could be achieved. The theoretical maximum if no water is added to the system is about eight percent ethanol.

The second fermentation has also been assumed to proceed for nine hours. Therefore, the total fermentation would be equivalent to an 18 hour conventional fermentation. This is a rather short fermentation time which may be made possible only by the very high concentration of yeast. As the process is developed, it may turn out that longer fermentation times are advantageous. Loading and unloading times for the fermenter were assumed to be three hours, bringing the total fermentation cycle to 12 hours in each of the first and second stage fermentations or 24 hours total. We consider this to be a relatively optimistic assumption. At the end of the second fermentation cycle, the ethanol concentration is 5.85 percent. The ethanol concentration may be higher when operating with dried cane.

At the end of the second stage fermentation, the liquid is drained, screened, and sent to a centrifuge where the yeast is concentrated and recycled to the first stage fermentation. Prior to being returned to the fermenters, the yeast is acidified with sulfuric acid to kill some of the potential contaminants. The acidification does not kill all the wild micro-organisms which may enter the system. The pH is readjusted to 4.0 to 4.5 before the yeast are returned to the first fermentation stage.

The fermented cane is pressed and the pressed liquids are added to the drained liquids and sent to the centrifuge. The pressed solids are again washed with water in a screw conveyor which permits countercurrent operation. The wash conveyor was designed for a ten minute residence time as suggested by ICAITI. This washer design is entirely speculative since no washing data has been obtained. The wash liquid from the second fermentation stage is combined with the drained liquids and sent to the distillation section. The bagasse is again pressed and sent to the boiler. Pressed liquids from this final press are discarded.

The distillation section is based upon a Katzen Associates distillation design (18). This design uses cascaded distillation columns to minimize energy consumption in the manufacture of 99.5 percent fuel-grade ethanol. The design was modified slightly to reduce overall equipment costs and to recover additional heat from the stillage before discarding. Less than two percent of the ethanol entering the still is lost with the stillage.

To provide a basis for economic comparison, a conventional ethanol plant utilizing sugarcane was also designed. A conventional ethanol technology consists of sugarcane receiving and handling, cane milling, juice cleaning, fermentation, and distillation. The receiving and handling section is identical to that of EX-FERM. The cane milling section consists of six three-roll mills. We estimate that this milling tandem is capable of recovering about 94 percent of the sugar present in the cane. The juice cleaning section includes addition of lime, heating, and clarification of the juice. This cleaning procedure will also pasteurize the sugar juice. The fermentation section consists of 10 fermenters with associated pumps and heat exchangers. It also includes yeast and mash preparation and yeast recovery and recycle equipment. The distillation section is essentially the same as that used in the EX-FERM design.

The conceptual process designs also include the necessary offsites. These include buildings, shops, laboratory, services like fire protection and electricity distribution, roads, steam generation, electricity generation, cooling towers, product storage, and storage for miscellaneous materials and supplies.

Additional details of the assumptions used for the conceptual process design are included in Appendix A.

PROCESS ECONOMICS

The overall process economics were estimated for the EX-FERM process described in the previous section. The estimates of EX-FERM economics have been compared with the economics of conventional technology for the manufacture of the ethanol from sugarcane. It appears that EX-FERM will be more economic than conventional ethanol technology if the assumptions inherent in the conceptual design can be demonstrated on scale-up.

Two versions of the EX-FERM process were evaluated. The first version is the process described in the previous section which includes drying of some of the sugarcane for use in a year-round operation. The ethanol facility in this version of EX-FERM was designed to operate 300 days per year, following suggestions by ICAITI. The second version of the EX-FERM process does not include provision for drying and storage of sugarcane, but rather operates only with fresh cane during the harvesting season. This plant operates 180 days per year. The conventional ethanol technology also operates only during the harvesting season or 180 days per year.

All three cases considered were designed to receive 2750 metric tons sugarcane per day, 180 days per year. This corresponds to a medium size sugar operation.

All costs are on a mid-1982 basis. The capital costs were estimated for the U.S. Gulf Coast while operating costs were estimated for Guatemalan conditions. We were unable to translate the capital cost estimates to Guatemalan conditions. The impact of building the facility in Guatemala on the cost will be discussed later.

It should be recognized that the cost comparisons for the three cases have been made to provide a similar basis. The relative values are more important than the absolute values. A simple return on investment of 15 percent has been included in the economics. This value is chosen for illustrative purposes only. In an actual situation, the combination of taxes (or taxes forgiven), special financing and other considerations could significantly change the required return. The reader may easily adjust the return on investment to facilitate his own analysis.

The manufacturing economics for the three cases are summarized in Tables 1, 2 and 3. It appears that the EX-FERM process operating only during the harvest season is slightly less expensive than the EX-FERM process operated year-round and that both processes have an economic advantage over conventional ethanol technology. The estimated fixed capital required for EX-FERM operating 180 days per year, EX-FERM operating 300 days per year, and conventional technology are \$41.4, \$43.4, and \$52.8 million. The estimated manufacturing cost (including a provision for sales, research and administration at 3 percent of direct manufacturing cost plus depreciation, and a return on total capital of 15 percent) is \$0.56, \$0.58, and \$0.64 per liter respectively.

The two largest cost items are the cost of sugarcane and the cost of capital. The economic estimates are based on a sugarcane price of \$17 per metric ton. This accounts for \$0.24 per liter of the total cost. This sugarcane price is believed to be a typical price for the 1982-83 harvest season in Central America. In 1981-82, the average cane prices were \$16.53 in Guatemala, \$14.30 with a bonus for high sugar content in Honduras, \$22 in El Salvador and \$15.80-17.00 per metric ton in Nicaragua. Sugar prices are quite volatile and subject to rapid change. At the current world sugar prices, a sugar mill could not operate profitably with these sugarcane prices unless it received a subsidy.

The economic analysis was performed assuming that ICAITI can achieve the projected 90 percent alcohol recovery from pressed bagasse by a simple washing. If this can be accomplished, then the overall yield obtained by EX-FERM is slightly better than that obtained by a conventional milling and fermentation. If this key assumption is indeed true, then the advantage of EX-FERM over conventional technology would increase with increasing sugarcane prices. The washing of pressed bagasse has not yet been demonstrated.

TABLE 1. MANUFACTURING ECONOMICS, EX-FERM 300 DAYS/YEAR

Product:	35.54 million liters ethanol (199 proof)
Raw Material:	2750 metric tons sugarcane/day, 180 days/year
Fixed Capital:	$43.45 million
Working Capital:	$ 5.66 million

		$1,000/yr	$/liter
Sugarcane @ $17/metric ton		8,415	0.237
Misc. Chemicals and Supplies		178	0.005
Labor Related Costs		138	0.004
Direct Labor	$89,000		
Supervision	$13,000		
Overheads	$36,000		
Maintenance @ 3% Fixed Capital		1,303	0.037
Insurance @ 1% Fixed Capital		434	0.012
Direct Operating Cost		10,468	0.295
Depreciation, 18-year straight line		2,414	0.0[illegible]
Sales, Research & Administration @ 3% above		386	[illegible]
Profit, Taxes, and Interest @ 15% total capital		7,366	0.207
		20,634	0.581

TABLE 2. MANUFACTURING ECONOMICS, EX-FERM 180 DAYS/YEAR

Product: 35.54 million liters ethanol (199 proof)
Raw Material: 2750 metric tons sugarcane/day

Fixed Capital: $41.4 million
Working Capital: $ 5.35 million

		$1,000/yr	$/liter
Sugarcane @ $17/metric ton		8,415	0.237
Misc. Chemicals and Supplies		178	0.005
Labor Related Costs		90	0.003
Direct Labor	$46,800		
Supervision	7,000		
Overheads	36,000		
Maintenance @ 2.5% Fixed Capital		1,035	0.029
Insurance @ 1% Fixed Capital		414	0.011
Direct Operating Cost		10,132	0.285
Depreciation, 18-year straight line		2,300	0.065
Sales, Research & Administration @ 3% above		379	0.011
Profit, Taxes, and Interest @ 15% total capital		7,012	0.197
		19,823	0.558

TABLE 3. MANUFACTURING ECONOMICS, CONVENTIONAL ETHANOL 180 DAYS/YEAR

Product:	34.9 million liters ethanol (199 proof)
Raw Material:	2750 metric tons sugarcane/day, 180 days/year
Fixed Capital:	$52.76 million
Working Capital:	$ 5.66 million

		$1,000/year	$/liter
Sugarcane @ $17/metric ton		8,415	0.241
Misc. Chemicals and Supplies		178	0.005
Labor Related Costs		79	0.002
Direct Labor	$37,260		
Supervision	$ 5,590		
Overheads	$36,000		
Maintenance @ 2.5% Fixed Capital		1,319	0.038
Insurance @ 1% Fixed Capital		528	0.015
Direct Operating Costs		10,519	0.301
Depreciation, 18-year straight line		2,931	0.084
Sales, Research & Administration @ 3% above		403	0.012
Profit, Taxes, and Interest @ 15% total capital		8,763	0.251
		22,616	0.648

The capital-related costs contribute about 50 percent of the total estimated selling price for ethanol. The largest portion of the capital related charges are depreciation, profit, taxes and interest or the total capital. The total capital related costs are very sensitive to both the fixed investment and to the required rate of return. The required rate of return can be effected by various creative financing methods, subsidies, and tax policies. Assuming that such changes in the rate of return would apply equally to EX-FERM and to conventional ethanol technology, the relative rankings would not be affected.

A breakdown of the capital cost is presented in Table 4. It may be noted that the offsite equipment (i.e., steam generation, electricity generation, cooling, storage) represent a significant fraction of the total capital investment. For the purposes of comparison, it was assumed that the storage capacity for 60 days product would be required for a EX-FERM plant operating year round while storage for 180 days would be required for an ethanol facility operating only during the harvesting season. All of this storage does not necessarily have to be at the ethanol manufacturing facility, but it will be required somewhere in the distribution system. Cooling tower costs are rather high because it was assumed that cooling towers would be designed for a 5F approach and 15F range. This is rather a conservative assumption and cooling tower costs might be reduced at many locations. Steam and electricity generation facilities were designed to handle the requirements of ethanol plants but not necessarily to consume all of the bagasse generated. The ethanol manufacturing plants are self sufficient in energy.

Within the battery-limits process area, the conventional technology requires higher investment due to the cane milling and juice cleaning operations. There is some question as to whether juice cleaning is needed or desirable. Some sugar technologists (19) claim that it is essential to clean the juice before fermentation while others (25) suggest that it is preferrable to take the juice directly from the mills. In either case, there is general agreement that the sugar juice should be pasteurized before fermentation. Pasteurization equipment would cost significantly less than the complete juice cleaning section. If the juice was not cleaned, maintainence costs in the fermenation and distillation sections would be expected to be increased somewhat. The

TABLE 4. COMPARISON OF EX-FERM AND CONVENTIONAL ETHANOL INVESTMENT FOR 2750 METRIC TON/DAY SUGARCANE HARVEST, 180 DAYS/YEAR
$1,000 - 1982 basis

	EX-FERM 300 Days	EX-FERM 180 Days	CONVENTIONAL 180 Days
Cane Receiving and Handling	1,850	1,850	1,850
Chipping	320	320	-----
Chip Drying	3,600	-----	-----
Chip Storage	4,320	-----	-----
Cane Milling	-----	-----	12,550
Juice Cleaning	-----	-----	4,800
Fermentation	12,768	18,250	10,050
Distillation	3,030	4,340	4,340
Subtotal Process	25,880	24,760	33,590
Steam Generation	5,290	2,850	4,060
Electricity Generation	1,430	1,330	790
Cooling Tower	1,350	1,900	2,020
Alcohol Storage	890	1,970	1,970
Misc. Offsites	2,280	2,280	2,280
	36,820	35,090	44,710
Contingency and fee @ 18%	6,630	6,310	8,050
TOTAL	43,450	41,400	52,760

cost of cane milling and juice cleaning in the conventional technology is partially offset by the higher cost of fermentation in the EX-FERM process. If the EX-FERM process is operated year round rather than just in the harvesting season, the size and cost of the fermenters can be reduced, but this is offset by the cost of drying and storing the chipped cane.

As mentioned previously, the capital investment was based on U.S. Gulf Coast construction costs. Although we were unable in this study to translate these to typical Central American costs, we were able to identify various factors which would affect these costs. One very important factor is the relative labor rates in Guatemala and in the United States. The Guatemalan labor rates are much lower, which tends to reduce both the installed equipment costs and the cost of equipment fabricated in Guatemala. On the other hand, specialized equipment like large cranes which are used in the construction and erection of large equipment are very expensive to rent in Guatemala. This tends to increase construction costs. Also, the cost of imported equipment delivered to the site is higher in Guatemala. We would expect that an alcohol plant would be constructed in southern Guatemala, probably near Escuintla. Since Guatemala does not have an adequate seaport on the Pacific Coast to receive large equipment, this equipment would probably be imported through El Salvador and be transported overland to the ethanol plant site. Therefore, the cost of imported equipment will tend to be higher in Guatemala than in the United States. When all these factors are considered, we believe that the cost of the EX-FERM process would be lower than our estimate and that the cost of conventional ethanol plants would be higher. As can be seen by the distribution of fixed capital costs broken down by plant section in Table 4, the sugarcane mills represent a large fraction of the cost of the conventional plant but are not required for EX-FERM. These mills would have to be imported. On the other hand, the fermentation section is much more expensive for EX-FERM than for the conventional technology. This is primarily due to the cost of the fermenters. We believe that Guatemala has the capability to manufacture such fermenters and therefore, they could be fabricated and erected at lower costs than estimated.

Impact of Plant Size. If the size of the ethanol plant is scaled down, the advantages of EX-FERM over conventional technology would increase. Similarly, if the plant size were scaled up, the advantage of EX-FERM relative to conventional technology would decrease. Nevertheless, we believe that EX-FERM would maintain its advantage over any reasonable range of plant capacities (i.e., up to 6000 tons sugarcane per day). Conventional technology is less sensitive to scale than EX-FERM because of the scale factor for conventional sugarcane mills is smaller than for most other equipment. Typically, the impact of size on cost can be estimated by the formula

$$\text{Cost Ratio} = (\text{size ratio})^n.$$

Whereas the cost of most equipment increases as the 0.6 to 0.7 power of the capacity, the cost of the mills only increases as the 0.25 to 0.35 power of capacity.

We have a basic difference of opinion with ICAITI over the optimum size for EX-FERM. While ICAITI believes that EX-FERM should be applied at a small scale so that a smaller sugar grower could make alcohol, we believe that economic operations should be conducted on as large as scale as possible. Of course, the economics of scale must be balanced against the cost of transporting the sugarcane from the field to the ethanol plant. This can only be done on a site specific, case by case basis. Nevertheless, we believe that operations based on less than 2,000 tons per day sugarcane will require significant subsidies and can only be justified on political or social rather than economic grounds. Furthermore, if ethanol fuel from sugarcane is going to make a significant impact on petroleum imports, then the ethanol should be manufactured in as large an economic plant as feasible. The final decision on optimum plant site will involve political, social, and capital availability considerations which go far beyond the scope of this study.

By-Products. Whereas the user of conventional technology may obtain a small by-product credit from the sale of yeast, the EX-FERM technology does not produce excess yeast. All of the yeast which is made in EX-FERM in excess of that needed for the process is lost with the bagasse. The net yeast recovery just balances the process requirements.

Carbon dioxide may be a saleable by-product from some fermentation facilities. However, this requires a unique location (for example, the plant may be located next to a beverage plant which requires carbon dioxide for carbonation of beverages). In general, one cannot count on carbon dioxide as being a viable by-product of a fermentation facility.

It may be possible to sell either excess bagasse or energy produced from excess bagasse. Again, the saleability of these products is very site specific. Bagasse can be used for manufacture of paper or it can be burned to produce steam which can then be turned into electricity. In the case where the EX-FERM process operates 300 days a year, the overall energy is about in balance, and any by-product credits would be negligible. In fact, in this case, bagasse must be stored during the rainy season to provide fuel for drying the sugarcane during the harvest season. In the case where EX-FERM is operated only during the harvest season, the excess bagasse is equivalent to about 128 million Btu per hour or enough to generate about 5 MW of electricity*. This electricity could only be generated during the harvesting season. Electricity generated from bagasse in this fashion should be significantly less expensive than electricity generated from petroleum, since the bagasse is essentially free. Nevertheless, a significant marketing effort could be required to sell electricity, particularly since it would be available only during the harvesting season. Furthermore, a new hydroelectric power plant is scheduled to come on line in Guatemala very soon and this hydroelectric power will supply electricity to the sugar producing areas in southern Guatemala. Although the opportunities to sell by-product electricity appears small, these should be further investigated as the EX-FERM process is developed. Additional capital investment would be required to generate and transmit electricity.

Other Considerations. In the foregoing analysis, a comparison was made between new EX-FERM and new conventional sugarcane-from-ethanol facilities. An existing sugar mill could be converted to an ethanol plant with the investment of only about $17 million.
The incremental cost to convert an existing sugar mill to an

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* Even more electricity could be generated if a high pressure boiler were installed.

EX-FERM fermenation plant would be about $29 million. Thus there may be cases where an existing sugar mill could be purchased and converted to ethanol production more economically with conventional technology than with EX-FERM.

Both the capital investment and the estimated manufacturing cost for the two EX-FERM cases are within 5 percent of each other. This is well within the limits of accuracy of our preliminary economic analysis. More detailed analysis might indicate a slight advantage for the year round operation rather than for operation during the harvesting season only. Nevertheless, it would appear prudent to continue the development effort to obtain data to evaluate both systems more thoroughly. There is great uncertainty in the estimated cost for drying and storing cane chips for the year-round EX-FERM case. The estimating of $3.6 million for the capital cost of drying equipment was based on an estimate by ICAITI and was confirmed by an independent estimate from a dryer vendor. However, another dryer vendor estimated the total installed cost at $10 million. More data is needed to resolve this discrepancy.

The conceptual design and economic analysis has been based upon the experimental data available to the extent possible. The key unproven assumption in this analysis is that 90 percent of the ethanol present in the pressed bagasse, which is removed from the fermenters, can be recovered by a simple countercurrent washing. Since over 16 percent of the ethanol made is contained in the pressed solids, the recovery of most of this ethanol is essential for an economic process.

CURRENT STATUS OF EX-FERM DEVELOPMENT

Summary of Laboratory-Scale Research

The EX-FERM Process[4] has been developed by the staff of ICAITI with the objective of reducing the production cost of ethanol from sugar crops (i.e., sugar cane and sweet sorghum). The primary feature of the process, which distinguishes it from conventional ethanol production processes, is the simultaneous extraction and fermentation of sugars from the sugar-containing plant stalks. Thus, costly sugar extraction equipment (i.e., three-roll mills or cane diffusers) are not required for the EX-FERM Process. Another distinguishing feature of the process is the ability to utilize dried cane (or sorghum) which could potentially reduce production costs by extending the length of the production season beyond the normal cane harvesting period.

Details of the laboratory-scale development work which has been accomplished to date have been described in numerous publications[1-11] and are briefly summarized below. An excellent summary table is provided in Reference 16. As practiced at the laboratory-scale, fresh or dried cane chips (or sorghum chips) are added to a batch fermenter along with varying amounts of water and yeast suspension. In most experiments, the total volume of water added was essentially that required to cover the cane chips plus, when packed-bed fermenters were used, an additional amount needed to fill an external liquid recirculation loop. The fermentation is conducted in a batch-wise manner. After the sugar in the cane has been converted to ethanol, the liquid is drained from the fermenter and the solids are pressed to recover additional liquid. The drained and pressed liquids are combined and then added to a second batch of cane. By repeating the fermentation cycle with a second batch of cane, the ethanol concentration in the liquid is substantially increased (doubled in some cases).

Initial trials(4,7,11) of the EX-FERM Process were conducted in 500 ml flasks. The objectives of these experiments were to:

(1) demonstrate the concept of extracting sugar and simultaneously fermenting it to ethanol,
(2) demonstrate multiple-cycle operation, i.e., using the fermented liquid from one batch of cane to inoculate a second batch of cane,
(3) determine whether the fermentation would be inhibited by soluble organic compounds present in the cane,
(4) determine ethanol yields,
(5) determine whether dried cane chips could be utilized in the process, and
(6) screen strains of S. cerevisiae to select those strains which would perform best in the process.

All of the above objectives were met in these studies.

A total of 115 different strains of S. cerevisiae were screened for their performance in the EX-FERM Process. The results with 37 strains are summarized in Reference 7. After the first 40-hour cycle, sugar consumption was above 99 percent with 10 of the 37 yeast strains tested. Ethanol concentrations reached 1.29 to 4.00 gm per 100 ml. During a second 24-hour cycle, final ethanol concentrations reached 4.27 to 5.37 g per 100 ml and sugar consumption was above 98 percent with three yeast strains. Acceptable ethanol yields (approximately 0.40 to 0.50 g ethanol/g sugar) were achieved in both cycles. The presence of the insoluble cane solids and possibly soluble organic compounds from the cane did not appear to affect the fermentation. The use of dried cane chips or shredded pith also did not appear to affect the fermentation. It should be noted that the rather long fermentation cycles used in these initial studies resulted from the use of very low yeast concentrations. Fermentation times were reduced in subsequent studies by using higher yeast concentrations.

Bench-Scale Fermenter Studies

Bench-scale fermentation studies of the EX-FERM Process have been conducted in packed-bed fermenters ranging in size from 0.7 l to 30 l. The published results of these studies are summarized in Table 5.

Initially, small bench-top fermenters (approximately 2 l and 0.7 l) were utilized. These experiments confirmed the results achieved in the earlier flask experiments. In the best case, sugar consumption was 94 and 93 percent respectively for the two cycles. The ethanol yield for both cycles was 0.46 g/g sugar; a final ethanol concentration of 4.7 gm/100 ml was achieved. As in the flask studies, low yeast concentrations were employed resulting in fairly long fermentation times (24 hours for both cycles).

In subsequent fermentation studies utilizing a 30 l fermenter, the effects of increased yeast concentrations were examined. At higher yeast concentrations the nominal fermentation times for both cycles were reduced to as little as 7 to 8 hours.

The experimental procedure used, however, left the yeast solution in contact with the cane chips overnight so the total actual time was closer to 23 hours. Examination of the data indicate that about 10 percent of the fermentation occurs overnight. The exact fermentation time needed has not yet been established. The general shape of the plot of ethanol concentration follows the classical Michaelis-Menten kinetics with a sharp decrease in fermentation rate at about 8 hours. More work needs to be done to establish the kinetics of the EX-FERM Process.

TABLE 5. SUMMARY OF BENCH-SCALE FERMENTER STUDIES

Fermenter Configuration and Scale	Substrate/Cycle	Yeast Strains	Cycle Time, hrs	Initial Yeast Concentration g/100 ml	Final Ethanol Concentration g/100 ml	Sugar Conversion %	Ethanol Yield g/g Sugar	Reference
2 l, vertical packed-bed reactor	Dried cane chips/1st cycle	12	24	0.37	3.6	94	0.46	2, 16
2 l, vertical packed-bed reactor	Dried cane chips/2nd cycle	12	24	0.28	4.7	93	0.46	
700 ml, horizontal packed-bed reactor	Dried cane & Tilby pith/1st cycle	12	12	0.24	2.8	93	0.47	1, 16
700 ml, horizontal packed-bed reactor	Dried cane & Tilby pith/2nd cycle	12	12	0.04	3.2	72	0.40	
2 l, vertical packed-bed reactor	Dried cane chips/1st cycle	2	24	0.43	3.6	92	0.50	9, 16
2 l, vertical packed-bed reactor	Dried cane chips/2nd cycle	2	24	--	4.6	89	0.42	
2 l, vertical packed-bed reactor	Dried cane chips/3rd cycle	2	24	--	5.9	84	0.42	
30 l, vertical packed-bed reactor	Dried cane chips/1st cycle	1	7	3.0	2.5	97	0.36	16
30 l, vertical packed-bed reactor	Dried cane chips/2nd cycle	1	8	--	6.0	97	0.36	16
30 l, vertical packed-bed reactor	Dried cane chips/1st cycle	1	9	2.0	2.8	98	0.44	16
30 l, vertical packed-bed reactor	Dried cane chips/2nd cycle	1	9	2.0	6.0	98	0.44	16
30 l, vertical packed-bed reactor	Dried cane chips/1st cycle	1	12	0.5	1.8	69	0.42	16
30 l, vertical packed-bed reactor	Dried cane chips/2nd cycle	1	11	0.5	4.0	69	0.42	16

(a) During a later run, in the 30 l reactor, which we observed, the fermentation broth was left in contact with the cane chips overnight. This procedure was evidently followed in all 30 l runs, so we would conclude that the cycle time was about 22 hours rather than the time published in the reference.

In the best case, ethanol yield and sugar consumption were essentially equivalent to those achieved with the smaller fermenters. A yeast concentration of about 2 percent (w/w) dry weight basis appeared to be the optimum level for use with the 30 l fermenter. Because relatively less water (i.e., water/cane ratio) was required than with tne smaller fermenters, the ethanol concentration after the second cycle was higher. With the 2 percent yeast concentration, an ethanol concentration of 6.0 gm/100 ml was achieved.

It should be noted that both fresh cane chips and dried cane chips (less than 10 percent moisture) were used in these initial studies. Most of the work was done with dry chips because they represent a source of uniform substrate that may be used over an extended period of time. When fresh chips were used in the early shake flask experiments, they were boiled in water for one minute prior to the fermentation (reference 7).

ICAITI has done very limited research with fresh cane, but in the later work the cane was not boiled. In these limited experiments no contamination was noticed when good quality (high sugar) cane was used. When green cane or cane stored without drying for about one week was used, there was noticable microbial contamination. The limited ICAITI research with fresh cane is inconclusive regarding potential for contamination although the results do indicate that drying cane will effectively eliminate contamination by wild microorganisms.

The only attempt to operate with fresh cane on the 30-liter scale was with cane obtained at the end of the harvesting season. This cane had a low sugar content and gave poor results. We are uncertain if the poor results were due to poor cane quality or to contamination.

Battelle has learned that researchers at the Audubon Sugar Institute in Louisiana have attempted to ferment chipped commercially harvested cane. They encountered much contaimination and had very low ethanol yields. Louisiana cane is mechanically harvested and contains much more dirt than hand-harvested Central American cane. Nevertheless, the potential for microbial contamination and methods for controlling it need more definitive investigation by ICAITI.

Although a great amount of the research has been aimed at identifying and selecting the optimum yeast strain, all bench scale (30 liter) runs have been made with commercial bakers yeast. This has generally been a matter of convenience and money.

The Battelle team observed a fermentation at the 30-liter scale which essentially duplicated an experiment made a year earlier. The results of these experiments are shown in Table 6. The more recent fermentation was somewhat slower, but this can probably be explained by the higher sugar to yeast ratio. There was also some difficulty with temperature control in the 1982 experiments which could account for some of the variation. Overall, we believe that the recent experiments did demonstrate the reproducibility of the EX-FERM process and suggest that further work is warranted.

TABLE 6. EX-FERM RESULTS, 30-LITER SCALE

Run Made	6-7 July, 1981	4-5 October, 1982
Feedstock	Dry Cane	Dry Cane
Fermentation Time First cycle, record cycle	9(22) 9(22.5)	10(23), 9.5(23)
% Complete in Nominal Time	93, 93	89, 89
Ratio sugar/water[b]	0.0626, .0717	0.0802, .0644
yeast/water[b]	0.0139, .016	0.0138, .0115
sugar/yeast	4.5, 4.5	5.8, 5.7
Ethanol Concentration g/100 ml	3.1, 6.49	2.8, 5.35
Sugar Conversion, %	97.5	97.9
Ethanol Yield, g/g Sugar Converted	0.477	0.455
Viable yeast Recovered, %	106	--
Viable Yeast Recovery Without Solids Wash, %	96	--

[a]Nominal time and actual time in contact with cane in parenthses, % complete in one day.

[b]Includes water in cane.

[c]When 2 figures are given they represent first and second cycles

STATUS OF SIMILAR TECHNOLOGIES

In addition to the ICAITI research on the EX-FERM process, a number of other organizations have investigated direct fermentation of sugar crops. Some of this work, which appears to have significance for the further development of EX-FERM is discussed below.

CSIRO. Researchers at Commonwealth Scientific and Industrial Research Organization (CSIRO) in South Melbourne, Australia are developing a process similar to EX-FERM (13,21-24). Both the CSIRO and EX-FERM Processes use direct fermentation of sugar crops to avoid the need for extraction of sugar juice. The major difference between the processes is that CSIRO uses only enough water to slurry the yeast. The yeast is applied as a 10-15% suspension directly to the sugar cane chips. This results in a higher ethanol concentration in a single cycle, whereas EX-FERM needs 2 cycles to obtain acceptable ethanol concentration.

Most of the CSIRO work has been done with sugar beets, but some experiments have also demonstrated the concept with sugarcane and sweet sorghum (24). The sugar conversion obtained with sugarcane in the CSIRO experiments to date are lower than those obtained with sugar beets or sweet sorghum. This is believed to reflect the lack of research in this area rather than any inherent limitation of the process. The higher fiber content of sugarcane compared to sugar beets may be one reason for the observed difference in conversion and may cause CSIRO to consider modifying their process.

Rather than dwell upon the difference between CSIRO and EX-FERM it is more important to consider the similarities. Both processes conduct the fermentation on solid sugarcane chips and will encounter similar materials handling problems on scaleup. Both use high yeast concentrations to speed fermentation time and to minimize the impact of wild microorganisms entering the process with the cane. Both will require pressing and washing of the fermented solids to recover the ethanol. Both will need to recover and recycle yeast for economic operation. Thus, both CSIRO and EX-FERM process development efforts can benefit by an open exchange of information on mutual problems and solutions.

It appears to us that the major difference between the EX-FERM and CSIRO processes is the amount of water added to the fermentation and the resulting impact on ethanol recovery energy requirements. The energy needed to distill ethanol increases with increasing water. If there is an excess of bagasse, then this is not a very important consideration. On the other hand, if all the bagasse is needed to dry part of the incoming cane, then the amount of water added and its impact upon ethanol concentration becomes important. The ethanol concentration has only minor impact on the capital cost of the distillation section. The conceptual EX-FERM process is self sufficient in energy at achievable ethanol concentrations.

In both EX-FERM and CSIRO processes, the fermenter cost is proportional to the volume of cane being handled and the time the cane is in the fermenter. As a first approximation, the cost will be independent of the amount of liquid if the liquid is used just to fill the voids between the cane chips. The CSIRO fermenter may not have to be liquid-tight and might cost slightly less than an EX-FERM fermenter. Nevertheless, the CSIRO fermenter must be designed so there are no drainage losses. We expect the fermentation time to be comparable in the two processes as this is probably more a function of the yeast/sugar ratio than other parameters.

In conclusion, we view the CSIRO process development to be complementary to the development of EX-FERM. They have many similarities, can be operated in similar pilot units, and upon optimization may evolve into even more similar technologies.

Hebrew University. Researchers at the Hebrew University in Israel have taken a different approach to increasing the ethanol concentration when fermenting cane chips (17). They devised a rotating drum fermenter in which the water to fresh cane ratio was 1:1. At any time, about half the solids were immersed and the drum was rotated slowly to allow percolation of the liquid over the solids.

In our opinion, this system is not feasible on a commercial scale, The rotating fermenter would be expensive to build and maintain, and the cane chips could not fill the entire volume if a true tumbling action were needed.

Therefore, larger fermenters would be needed than for the EX-FERM or CSIRO processes. Furthermore, the EX-FERM process produces enough bagasse to generate all the steam and power needed to run the process. The Hebrew University system does not appear to offer an advantage over what might be achieved in scaling up EX-FERM.

Audubon Sugar Institute. The Audubon Sugar Institute made an unpublished attempt to conduct a fermentation of commercially harvested Louisiana sugarcane chips in a pilot fermenter (19). Severe contamination was observed and the researchers, who have considerable experience in the sugar industry, concluded that the process was not practical and not worth further development.

The significance of this work is that it raises the question of contamination. Much of the published work on fermentation of cane chips was based upon chips that had been specially treated in some way that would reduce the microorganisms entering the process with the sugarcane. As discussed elsewhere in this report, this unpublished work suggests that additional research is needed by ICAITI to demonstrate that EX-FERM can be operated with commercial cane without significant contamination.

MAJOR ISSUES AND PROBLEMS

The ICAITI Team has done a good job in the preliminary rese..ch on the EX-FERM process. However, a number of major issues need to be resolved before the process can be commercialized. These major items needed in a development program are summarized below.

(1) Demonstration that contamination is not a serious problem with fresh cut commercial cane.

(2) Demonstration that higher ethanol concentrations (approaching) 5.8 to 6.0 percent) can be achieved by reducing the amount of water in the system.

(3) Definition of fermentation kinetics, in particular, optimization of fermentation time as a function of yeast concentration, cane chip size, and temperature.

(4) Determination of yeast requirements and yeast handling procedures suitable for large scale operations.

(5) Determination of the best method to recover ethanol from the wet solids, with particular emphasis on washing of the pressed bagasse.

(6) Development of an efficient dryer design.

(7) Development of a method to handle large quantities of wet spent cane chips, particularly removal of chips - the fermenters.

Of these research issues, the contamination issue is of p importance. It appears that the drying of cane will kill most microo. s present on the sugarcane and thereby remove the potential for serious contamination. In spite of the fact that ICAITI has not noticed contamination in the limited experiments with fresh cane, the gross contamination obtained by researchers at the Audubon Sugar Institute operating with commercially cut cane indicates that further verification is needed. A convincing demonstration that the EX-FERM process can be operated on commercially cut cane without severe contamination is essential to the further development scale up and commercialization of the process.

We believe that the second most important issue in the development of the EX-FERM process is the demonstration that the ethanol made in the fermentation can be economically recovered. ICAITI has demonstrated that approximately 84 percent of the ethanol made in the fermenters can be recovered in the drained liquid and pressed liquids. For economic operation, however, it is essential to recover the ethanol remaining in the pressed solids. ICAITI has demonstrated that this ethanol can be recovered by washing with water, but not under conditions which would simulate a commercial design nor enable obtaining design data. For the economic evaluation we have assumed that 90 percent of the ethanol contained in the pressed solids could be recovered by washing. ICAITI researchers believe that they can achieve this goal with contercurrent washing with a limited amount of water. Nevertheless, this needs to be demonstrated. The economic viability of the process depends upon recovery of this ethanol by simple washing with a limited amount of water. If a complex washing system like that used in a sugar diffuser is needed, then the process will probably not be economic.

The third most important problem, in our opinion, is the handling of wet cane chips. We are concerned that the wet chips will bridge and stick together in the fermenters. This problem cannot be addressed on a small scale and will require consultation with equipment vendors. The currently used method to discharge solids from the fermenter is to poke them with a stick until they fall free of the solid mass. Our other concerns on solids handling include the prevention of liquid loss while conveying wet solids, and the potential for dust formation and fire, and explosion hazards in the handling and storage of dry chipped cane. All of these problems are mechanical in nature and are similar to problems encountered in other industries. Nevertheless, they must be investigated and economic designs must be found before the process can be commercialized.

Each of the other items listed above need to be considered before the EX-FERM Process can be commercialized. Nevertheless, we believe that the three discussed above are of utmost importance and represent the greatest technical uncertaintities for the EX-FERM Process.

RECOMMENDED RESEARCH OBJECTIVES

Battelle recommends that ICAITI continue to develop the EX-FERM process towards commercialization. To accomplish this development, a integrated, adequately funded research program will be needed. We believe that ICAITI should prepare a proposal for all steps leading from the present laboratory and bench scale to demonstration of an integrated process. It appears that considerable momentum and much time has been lost due to the intermittent funding of research of the EX-FERM process. Therefore, we would recommend funding of the entire process development with a critical review at several checkpoints in the program. If specific objectives cannot be met then research on the project should be abandoned.

As indicated in the previous section, we believe it is most important that ICAITI demonstrate the contamination by wild microorganisms present on the cane is not a problem. Research on this problem should be conducted with commercial sugarcane, that is cane delivered to and taken by ICAITI from a sugar mill during the normal cane harvesting season. If any of the experiments show poor results, an effort should be made to determine the nature of the contaminants. For a convincing demonstration, we believe that the yeast should be run through at least ten cycles of fresh chipped cane. If this cannot be done, ICAITI researchers must either devise an economic method to pasteurize the fresh cane or abandon the process. The demonstration that contamination is not a problem could be conducted on a small scale, but the results would be more convincing if the experiments were run at the 30-liter scale.

ICAITI microbiologists have done much work selecting the best yeast strain for their fermentation. Nevertheless, all the bench scale experiments have been made with commercial baker's yeast. While this was economic and convenient for preliminary runs, we believe that more useful information can be achieved in future work if ICAITI will select the best yeast strain and work with it exclusively. This will require setting up a yeast production facility or contracting with a local yeast manufacturer to supply the desired strain.

Once the best yeast strain has been made in sufficient quantities, ICAITI needs to define the kinetics of the fermentation, in particular to define the optimum fermentation time as a function of temperature, yeast concentration, and cane chip size. This can be done at the 30 liter scale provided that equipment is modified for better temperature control. For all practical purposes, temperature is an uncontrolled variable in the current experimental system.

For economic operation, it is essential that a relatively high ethanol concentration be achieved. The energy consumption and distillation is a strong function of the ethanol concentration up to about 10 percent ethanol. For example, decreasing the ethanol content in the liquid from the fermenter from six percent to three percent would increase the steam requirements by about 65 percent (Reference 20). The reason for the fairly low ethanol concentrations obtained experimentally by ICAITI is the use of excess liquid above that needed to fill the bed of sugarcane. Minor modifications of the 30-liter experimental apparatus could significantly reduce the liquid in the system and should demonstrate that higher ethanol concentrations can be achieved with the EX-FERM Process. We have assumed the higher ethanol concentrations in our analysis of the economics.

In the development of a commercial process it will be necessary to determine how often the yeast may be reused. In addition, it will be necessary to determine how the yeast should be handled, whether an acid wash will be needed to sanitize the yeast, and to determine storage conditions for a concentrated yeast cream. Research should also determine the rate of loss of yeast viability in storage.

All of the above experiments can be conducted on the 30-liter scale. In addition, the effect of liquid velocity and pH in the fermentation could also be investigated at a small scale.

As mentioned in the previous section, the recovery of ethanol from the pressed spent cane is essential for an economic process. To date there has been no experimental work aimed at the design of a commercial washing method. A study is needed of the washing of pressed bagasse. This study should include the effects of the ratio of water to solids, temperature, and residence time on ethanol recovery. In conducting the experimental program, equipment manufacturers should be consulted so that data needed for design can be obtained. The initial work can be done at a small scale, but eventually the washing must be demonstrated at a large scale to guarantee reliable scaleup to commercial operation. When working at the larger scale, the pretreatment of the pressed bagasse, for example, the power used in the press, should be correlated with washing efficiency. The initial experiments conducted on a small scale, however, should demonstrate that there is a reasonable chance to economically recover ethanol from the pressed bagasse by simple countercurrent washing. These experiments represent one of the key milestones in the experimental program.

One of the most critical issue dealing with the fermentation step in the EX-FERM process is that of solids handling, i.e., how to remove the spent solids from the fermenter. This issue can only be addressed with a pilot-scale unit. The solids removal question impacts the process in a number of different ways: (1) it dictates the ease of operation of the fermenters, (2) it adds to the cycle time of each fermentation and thus effects the capital costs by decreasing the fermenter productivity, and (3) it is, perhaps, the major issue in the design of the fermenters and thus directly effects capital costs by dictating the configuration of the fermenter. Suggestions as to possible approaches for addressing the solids removal question are given below.

Alternative methods for removing the spent solids from the fermenter need to be evaluated. It is suggested that alternative designs for the pilot fermenters, based on the existing bench-scale data, be solicited from several organizations, (design companies, equipment vendors, etc.). The merits of the designs should then be evaluated based upon the reasonableness of the design, projected cost of the production fermenters, and on the capabilities, past experience, etc., of the suppliers. It then may be desirable to select at least two alternative designs for incorporation into the pilot process. This would allow for side-by-side comparisons and would increase the chances for successful commercialization of the EX-FERM process. It is also suggested that the designs be restricted to batch-fermenter designs unless the supplier can make a clear case for the potential economic advantages of a continuous process.

A pilot plant is needed to demonstrate the process and to evaluate a number of different process parameters and component systems. These include:

- the actual yield of ethanol from the overall process, i.e., ethanol losses in various stages of the process,
- The final ethanol concentrations from the fermenters,
- yeast viability, recoveries (yields), and contamination levels at various stages in the process, and
- the performance of various solids handling devices such as conveyors, presses, etc.

The above list is not inclusive of all the important parameters but is included to illustrate the type of information that can only be gained with a pilot-scale unit. It should also be noted that during the later stages of the pilot-plant development effort, a sustained period of operation of the complete pilot-scale unit will be very useful for demonstration purposes and to test the performance of the equipment.

The composition and potential useful value of the process by-products (stillage and cane solids) need to be addressed and potential disposal methods for the stillage need to be identified and tested. It is important that at least a beer still be included in the pilot plant so that potential fouling and corrosion problems can be evaluated. Also, stillage can be produced for evaluation purposes. Once the composition of the stillage has been determined, bench-scale work to evaluate disposal methods such as anaerobic digestion or larger scale studies of field disposal methods should be considered. It is our present opinion that by-product credits will make an insignificant contribution to the overall economics and, assuming an inexpensive disposal method like returning stillage to the cane fields is acceptable, the use of stillage should receive low priority.

Methods for drying and, in particular, storage of dried cane chips need to be evaluated. It is very important that studies be undertaken to identify and test at a reasonable scale methods for storage of dried cane. Sugar losses and microbial contamination levels under various storage conditions need to be measured for sustained periods (6 months). Alternative designs and construction costs for storage facilities also need to be addressed.

The original pilot plant design prepared for ICAITI contained a provision for continuous fermentation (14). We can see no particular advantage to continuous operation and believe that the mechanical problems likely to be encountered will hinder the fermentation research. Therefore, we recommend batch fermentation be continued unless some significant advantage of continuous operation is defined.

CAPABILITY OF ICAITI

In order to successfully develop the EX-FERM process, ICAITI will need both qualified personnel and will also have to handle the logistics of operating with significant quantities of sugarcane.

Personnel. To develop the EX-FERM process, ICAITI will require professional skills in microbiology, analytical chemistry, chemical engineering, and mechanical engineering. In addition, it will need the support skills of trained operators for the laboratory and the services of the appropriate shop personnel to manufacture and modify equipment. Based upon our personal observation of the ICAITI staff and analysis of their accomplishments to date, we are convinced that they have the microbiological, chemical, and chemical engineering skills needed to develop the process. In particular, we believe that the microbiology team led by Carlos Rolz and Sheryl de Cabrera and the chemical engineering activity headed by Ricardo Garcia and J. Francisco Calzada are capable of further developing the process. ICAITI appears to have a competent analytical chemical facility to support the process development activity.

ICAITI also has qualified pilot plant operators and a shop capable of making needed equipment modifications.

The ICAITI team does appear to lack qualified mechanical or agricultural engineers who could address the solids handling problems efficiently. Although ICAITI does have some mechanical engineers on their staff, these personnel appear to be specialists in combustion. We believe that one of the major impediments to full scale commercialization of the EX-FERM process will be solution of materials handling problems on a large scale. Of particular concern is the transport of chipped cane to the fermenters, the removal of the wet fermented cane from the fermenters, and the dewatering of the fermented cane. The addition to the team of a person with actual sugar mill experience or with experience in the design of agricultural equipment, in particular silos and associated transportation in conveying equipment, would greatly strengthen the ICAITI capabilities. The engineer should have a practical rather than an academic outlook.

Finally, we believe that the development program would benefit greatly by the addition of an outside consultant to review progress, suggest critical experiments, and most of all keep the program focus on early commercialization.

Logistics. With regard to the logistics of sugarcane handling for the experimental research and development program, we believe that ICAITI is capable of solving the problems which may be encountered. Nevertheless, we believe tnat these problems need to be given more attention than they have in the past. In the research conducted to date, most of the work has been done using dried cane. This is both an experimental convenience and a method to ensure that a uniform feedstock is used for a series of experiments. Nevertheless, we believe that a future development should concentrate on bench scale experiments using fresh sugarcane. Because fresh cane is perishable, it will be necessary to receive fresh material for use in the experimental equipment on a daily basis. Alternatively, it may be possible to find a means to preserve fresh cane without drying. Refrigeration might be one feasible alternative for small scale experiments. In its proposal for future work, ICAITI must deal with these issues and determine whether it will be more economic to bring sugarcane over 50 km to Guatemala City or build a small experimental unit at a sugar mill to ensure a continuous supply of fresh cane.

APPENDIX A

ADDITIONAL DESIGN AND ECONOMIC CONSIDERATIONS

TABLE A-1. EX-FERM ASSUMPTIONS FOR CONCEPTUAL DESIGN

Product Ethanol: Fuel-grade 199 proof,	99.5 v %, 99.19 wt %
Sugar Composition	
Fermentable Sugar (as glucose)	13.0%
Fiber	12.5%
Water	74.5%
Fermentation Yield	0.46 g ethanol/g sugar
Distillation Recovery	98% ethanol
No Loss of Sugars or Yield Upon Drying and Storage	
Pressed Solids Composition	
Fiber	40%
Liquid	60%
Ethanol Concentration	
From First Cycle	4.5% (w/w)
From Second Cycle	5.85%
To Still	5.8
Heating Value of Wet Bagasse	1820 Kcal/kg or 3276 Btu/lb
Steam Produced in Boiler	420 psig 200F superheat
Boiler Efficiency	53%
Turbine Generator Efficiency	65%
Ethanol Recovery from Pressed Solids (Washing Efficiency)	90%[a]
Fermentation Time	9 hr
Fermenter cycle time	12 hr

[a] Unproven Key Assumption.

TABLE A-2. EX-FERM DESIGN MATERIAL BALANCE

Sugarcane	1000
Fermentable Sugar	130
Ethanol Made (0.46 g/g sugar)	59.8
Ethanol Lost With Bagasse and Bagacillo	1.46
Ethanol Lost in Distillation	1.16
Ethanol Recovered	57.18

TABLE A-3. HARVEST SEASON ENERGY CONSUMPTION 180 DAYS/YEAR
(Million Btu/Hour)

	Fuel	Steam	Flue Gas	Power, kW
Distillation		37.1		
Drying (97% efficiency)		74.2	73.4	
Electricity Generation (65% efficiency)		13.7 [(a)]		(2607)[b]
Steam Generation (63% boiler efficiency)	198.4	(125)		
Bagasse Production	146.7			
Bagasse From Storage	51.7			

TABLE A-4. RAINY SEASON ENERGY CONSUMPTION 120 DAYS/YEAR
(Million Btu/Hour)

	Fuel	Steam	Flue Gas	Power, kW
Distillation		37.1		
Electricity Generation		3.9[(a)]		(738)
Steam Generation	65.1	(41)		
Bagasse Production	146.7			
Bagasse Excess	81.6			

(a) Net enthalpy reduction of steam assuming cogeneration

(b) Numbers in parentheses are energy production

TABLE A-5. WORKING CAPITAL ESTIMATE
($1,000)

	EX-FERM 300 Day	EX-FERM 180 Day	CONVENTIONAL
Product Inventory, 30 or 120 days	872	3,446	3,506
Dried Cane Inventory, 150 days	2,805	---	---
Parts Inventory, 2% Fixed Capital	869	828	1,045
Miscellaneous Inventory, 30 days	15	15	15
Net Receivables, 20 days direct operating cost	581	574	584
Cash at 10% of above	514	486	515
Total	5,656	5,349	5,665

APPENDIX B

CRITIQUE OF ICAITI PROPOSAL

APPENDIX B

CRITIQUE OF ICAITI PROPOSAL

As part of the assessment of the readiness of the EX-FERM process for investigations in a pilot plant, UNIDO asked Battelle to review and critique the proposal presented by ICAITI to the United Nations Interim Fund for Science and Technology for Development, dated March, 1982.

Our major criticism of the ICAITI proposal is one of emphasis. We believe that an overall objective should be to commercialize the EX-FERM process, which can best be done by identifying and overcoming the barriers to commercialization. It appears from the proposal that the primary objective of the program is to build and operate an EX-FERM pilot plant. While we agree that a pilot plant will be necessary to answer many of the questions which must be raised before EX-FERM can be commercialized, the pilot plant should not be considered an end in itself.

We believe that ICAITI could greatly strengthen their proposal by identifying some of the major areas for research in the proposed program. We have identified several key issues which we consider to represent barriers to commercialization in the report. The Katzen report (14) on the EX-FERM pilot plant also lists some potential barriers that need to be overcome by pilot scale investigation. ICAITI can probably expand on our list. While it is not necessary to provide a detailed work plan with the proposal, the proposal would be greatly improved if it outlined major milestones and identified the unanswered questions which would form the basis of the research and development program.

ICAITI can also greatly improve their proposal by including more information which indicates the considerable thought that they have given to the development of EX-FERM. We believe that the funding agencies, who are being asked to provide $3 million, would be reassured by more information that demonstrated that ICAITI has indeed thought through the development program and is proceeding in a logical fashion for its commercialization. This would involve identification of specific problems and approaches to these problems rather than generalizations like "we will establish a steering committee".

The ICAITI proposal could also be strengthened by being more specific about the location of the proposed pilot plant and the logistics of its operation. Will the pilot plant be located adjacent to a sugarmill, in which case the logistics would greatly be simplified but the operating and analytical support may be difficult, or will the pilot plant be located at the ICAITI facility in Guatemala City, in which case the logistics of using fresh sugarcane will be enormous? Also, it appears from the proposed operating crew of three shifts that ICAITI plans to operate the pilot plant only five days per week. For round the clock operation seven days per week, four shifts of operators would be needed.* We believe that some time during the program, continuous operation of at least three or four weeks would be needed to demonstrate convincingly the workability of the EX-FERM process.

The proposal would also be improved if some rationale for selecting the size of the pilot plant at one ton per day could be given. Based on the Katzen pilot plant design, this involves a scale-up in the fermenters from 15 cm diameter to 50 cm. This is not sufficient scale-up to demonstrate that the materials handling problems have been overcome. It is likely that these problmes will have to be investigated in a separate unit which is not integrated into the pilot plant. Such a unit might be at a vendor's location, so that ICAITI would not have to purchase a large unit to study the materials handling problems. We believe that the pilot plant should be sized so that reliable information on pressing and washing the fermented cane chips can be obtained. We presume that this was one of the considerations in establishing a one-ton-per-day size, but have not confirmed this with ICAITI.

Finally, we believe that the ICAITI proposal could be improved by inclusion of brief description of the qualifications of the ICAITI team. This would help to reassure the funding agency that they are investing wisely with a team of well trained professionals.

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* Assuming 8-hour rotating with 2 days off per week, shifts, only 3 shifts would work on any given day, but the shits rotate to provide complete coverage.

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