

Economic Evaluation of the Acetone-Butanol Fermentation

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The economics of producing acetone and 1-butanol via fermentation have been examined for a 45×10^6 kg of solvents/year plant. For a molasses substrate, the total annual production costs were about \$39 million vs. a total annual income of \$36 million, with about \$20 million total required capital. Molasses cost of about \$24.4 million/year was critical to these economics. Liquid whey was next evaluated as an alternative feed. Whey feed saved about \$11 million annually in feed costs and yielded about \$7 million net additional annual revenues from protein sale. These primary differences gave an annual gross profit of about \$15 million for the whey case and resulted in a discounted cash flow rate of return of 29%. It is concluded that waste based acetone-butanol production via fermentation deserves further attention in view of the attractive whey-based economics and the excellent potential of butanol as a fuel extender, especially for diesohol blending.

Introduction

Fermentation processes based on renewable raw materials have the potential for producing important large tonnage organic chemicals. Most of the attention to date in this area has focused on ethanol production with the goal of extending existing fuel supplies by mixing the ethanol with gasoline (forming gasohol) or with diesel (forming diesohol). The utilization of ethanol for gasohol or diesohol blending does create, however, a number of difficult problems. The chemical properties of the alcohol are quite different from the properties of gasoline or diesel fuel and problems such as vapor lock, phase separation, difficult engine start, and water pick-up are very common. Mixtures of diesel and ethanol are especially troublesome since the alcohol will promote phase separation at winter temperatures, particularly when water is present in the fuel mixture.

These problems might be solved, or at least partially alleviated, by using butanol for gasohol or diesohol blending. Because it has a longer hydrocarbon chain than ethanol, butanol has chemical properties that are closer to diesel or gasoline. Table I presents a list of the relevant chemical properties of butanol. Two characteristics are of particular importance with regard to the potential utilization of butanol as a fuel extender: (1) its low vapor pressure and (2) its low miscibility with water. In addition, butanol is completely miscible with diesel even at low temperatures.

Like ethanol, butanol can be obtained through fermentation of grain, molasses, or suitable waste materials that may be a source of sugars (Beesch, 1952; Faith et al., 1965; Shreve, 1967). Acetone and some ethanol are also normally present in the fermentation broth. Industrial production of acetone and butanol via fermentation has not been significant for about the past 20 years due to the superior economic position of petrochemical-based processes. At the present time, essentially all the butanol fermentation plants in the U.S. are sitting idle or are being converted into ethanol facilities. However, current prices of agricultural feedstocks coupled with 1940's fermentation technology are thought to give acetone-butanol fermentation economics nearly competitive with the petrochemical route (Perlman, 1977; Solomons, 1976). The objective of the economic study presented in this paper was to define more quantitatively the current economic position of this fermentation relative to the petrochemical processes for acetone and butanol production.

Table I. Chemical Properties of 1-Butanol

chemical formula:	$C_4H_{10}O$
molecular weight:	74.12 kg/kg-mol
specific gravity:	0.811 at 20 °C/4
boiling point:	117 °C at 1 atm or 1.013×10^5 Pa (243 °F)
melting point:	-79.9 °C (-112 °F)
heat of vaporization:	4.33×10^5 J/kg (186 Btu/lb)
heat of combustion:	3.67×10^7 J/kg (15 770 Btu/lb)
vapor pressure:	2.07×10^3 Pa at 37.8 °C (0.3 psi at 100 °F)
solubility in water:	9 g/100 mL of H_2O at 15 °C
stoichiometric air/fuel ratio:	11.2

Biochemistry of the Acetone-Butanol Fermentation

The acetone-butanol fermentation is carried on by bacteria belonging to the genus *Clostridium*. For the fermentation of molasses, *Cl. saccharo-acetobutylicum* is usually the preferred organism while *Cl. acetobutylicum* is normally utilized with other sources of fermentable sugars. It is known that the final solvent ratios obtained are a strong function of the *Clostridium* species utilized for the fermentation process (Beesch, 1952).

Based on the information available in the literature (Doelle, 1975; Stanier et al., 1976), the most probable metabolic reactions occurring during glucose utilization by *Clostridium* organisms are shown in Figure 1. Initially, glucose is metabolized via the Embden-Meyerhof-Parnas (EMP) pathway with formation of pyruvate which is then broken down to acetyl CoA with the release of carbon dioxide and hydrogen. Acetyl CoA itself plays a central role in the metabolism of the *Clostridium* bacteria by serving as a precursor to ethanol, acetate, and all the fermentation solvents. Of special interest here is the mechanism for acetone and butanol formation; two acetyl CoA molecules combine to form acetoacetyl CoA, thus initiating a cyclic mechanism that leads to the production of butyric acid. As butyric acid accumulates in the medium, the pH of the fermentation will continue to drop from an initial value of about 6. Eventually, the pH will drop to about 4.0 at which time a new enzyme system is activated leading to the formation of acetone and butanol. In this system, acetoacetyl CoA is diverted from the normal cyclic mechanism and is utilized via a transferase system for the production of acetoacetate which is then decarboxylated to acetone.

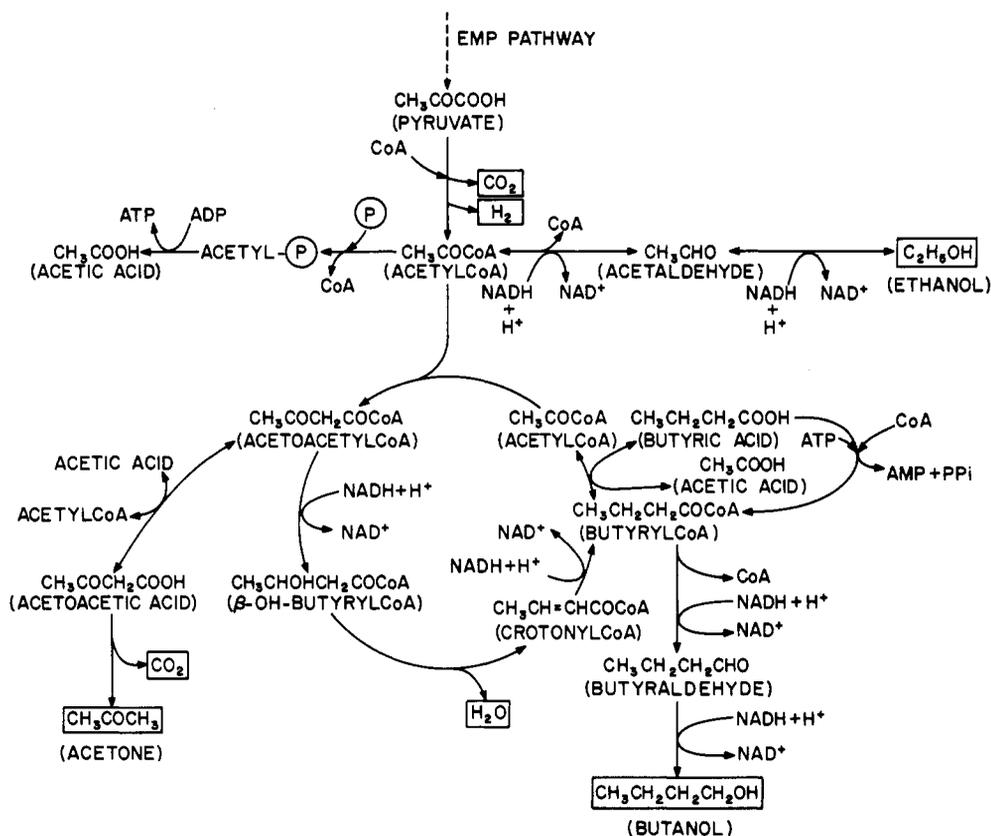


Figure 1. Metabolic pathway for glucose utilization by *Clostridium* bacteria.

Table II. Energy Analysis of the Acetone-Butanol Fermentation

product of fermentation	product yield ^a	sp heat of combustion $\Delta \hat{H}_c^b$	ΔH_c , J (Btu)	energy yield, %
butyric acid	4	2.18×10^9 (9.36×10^5)	8.72×10^9 (8.26×10^6)	
acetic acid	14	8.75×10^8 (3.76×10^5)	1.23×10^{10} (1.16×10^7)	
hydrogen	135	2.87×10^8 (1.23×10^5)	3.87×10^{10} (3.66×10^7)	
ethanol	7	1.37×10^9 (5.88×10^5)	9.59×10^9 (9.09×10^6)	
butanol	56	2.68×10^9 (1.15×10^6)	1.50×10^{11} (1.42×10^8)	
acetone	22	1.79×10^9 (7.69×10^5)	3.94×10^{10} (3.73×10^7)	
acetoin	6	2.25×10^9 (9.66×10^5)	1.35×10^{10} (1.28×10^7)	
$\Sigma \Delta H_c$			2.72×10^{11} (2.58×10^8)	97 ^d

^a Units: kg-mol/100 kg-mol of glucose fermented. ^b In J/kg-mol (Btu/lb-mol). ^c Estimated from heat of formation data. ^d Energy yield (%) = $[\Sigma \Delta H_c / (100 \times \Delta H_c(\text{glucose}))] \times 100$.

This interruption of the cycle causes the elimination of two steps which generate NAD^+ and consequently the *Clostridium* must find alternative reducing sequences for NAD^+ regeneration. This is essentially accomplished by reversing the last reaction in the cycle and reducing butyric acid to butanol through three consecutive reactions where butyryl CoA and butyraldehyde are formed as intermediate compounds. Butyryl CoA can also be generated by an alternative mechanism requiring ATP and CoA if acetyl CoA is found in insufficient levels at this stage.

From this brief description it becomes evident that the production of acetone and butanol by *Clostridium* bacteria follows a rather complex mechanism which leads to a large number of end products—carbon dioxide, acetoin, water, hydrogen, acetic acid, and butyric acid in addition to the desired acetone and butanol. In some *Clostridium* species (namely *Clostridium butylicum*) 2-propanol is also found in the fermentation broth as the result of a terminal acetone reduction step.

In spite of the large number of products formed during the acetone-butanol fermentation, it is interesting to note that about 97% of the energy content of the glucose fermented is conserved in the chemicals produced during the

Table III. Fractional Energy Recovery in the Acetone-Butanol Fermentation

fermentation product	% total energy recovered in product
butyric acid	3.2
acetic acid	4.5
hydrogen	14.2
ethanol	3.5
butanol	55.1
acetone	14.5
acetoin	5.0

fermentation. This is seen in Table II, where an approximate energy analysis for this fermentation is shown. This analysis compares the energy of combustion of glucose with the energy of combustion of the fermentation products using available product yield data (Doelle, 1975). In this analysis, the energy of combustion of the cells and the heat of fermentation were neglected since they account for less than 5% of the total energy. A similar analysis for the yeast alcohol fermentation shows that 98% of the energy present in the glucose fermented is conserved in the ethanol produced during the fermentation. This concentra-

Table IV. Equipment Costs for a 45×10^6 kg of Solvents/year Acetone-Butanol Fermentation Facility^a

item	size	cost, \$ $\times 10^3$
(1) molasses storage tank	13249 m ³ (3.5 $\times 10^6$ gal)	320
(2) cookers (4 units)	18.9 m ³ (5.0 $\times 10^3$ gal)	58.4
(3) coolers (4 units)	279 m ² (3.0 $\times 10^3$ ft ²)	82
(4) holding tank	2800 m ³ (7.4 $\times 10^5$ gal)	91
(5) fermentors (16 units)	1514 m ³ (4.0 $\times 10^5$ gal)	2000
(6) beer still preheater	100 m ² (1077 ft ²)	11.4
(7) beer stills (3 units)	2.44 m (8 ft) diameter	430
(8) beer still condenser	80.7 m ² (869 ft ²)	11.2
(9) batch column	1.83 m (6 ft) diameter	153
(10) batch column reboiler	8.4 m ² (90 ft ²)	9.3
(11) acetone condenser	62.7 m ² (675 ft ²)	9.6
(12) ethanol cooler	1.23 m ² (13.2 ft ²)	0.5
(13) butanol columns (2 units)	0.92 m (3 ft) diameter	69.4
(14) butanol condensers	89.7 m ² (965 ft ²)	11.9
	128.8 m ² (1386 ft ²)	14.6
(15) surge tank pre-evaporators	1514 m ³ (4.0 $\times 10^5$ gal)	125
(16) evaporators (5 units)	300 m ² (3200 ft ²)	1060
(17) spray dryer	5.9 m (19.5 ft) diameter	290
(18) butanol storage tank	3407 m ³ (9.0 $\times 10^5$ gal)	228
(19) acetone storage tank	1741 m ³ (4.6 $\times 10^5$ gal)	116
(20) ethanol storage tank	568 m ³ (1.5 $\times 10^5$ gal)	38
(21) culture inoculum tank	37.9 m ³ (1.0 $\times 10^4$ gal)	9.7
Purchased and installed equipment cost total		\$5139.

^a All costs are early 1979 values.

tion of chemical energy in a single compound is a distinct advantage for the ethanol fermentation relative to the acetone-butanol process. As seen in Table III, butanol accounts for only 55% of the total energy recovered; this means that applications must be developed for the remaining fermentation products, especially hydrogen and acetone.

Process Description

The base case process chosen for this economic analysis was one having the following characteristics: (a) traditional molasses feedstock; (b) about 45×10^6 kg per year (100 $\times 10^6$ lb per year) total solvents production (equivalent to about 57×10^6 L of solvents per year or 15×10^6 gal of solvents per year); (c) location in the southeastern United States; (d) 300 day/year operation.

The flowsheet for this base case process is shown in Figure 2 and is similar to that reported for past commercial operations (Beesch, 1952; Landy, 1979; Webb, 1979). In the process, molasses (80% solids, 57% sugars) is mixed with a recycle stream from the beer stills and then fed to cookers where steam heating to 121 °C (250 °F) sterilizes the feed. After cooking, the diluted molasses feed is sent to a battery of 16 batch fermentors (1514 m³ each), nutrients and culture inoculum (*Cl. saccharo-acetobutylicum*) are added, and fermentation proceeds for 48 h. Fermentor off-gas (primarily carbon dioxide and hydrogen) is vented continuously, and the fermentation broth is removed batchwise and fed to the beer stills, where an approximately 40/60 (wt %) solvent/water stream is removed overhead from slops (water and stillage). The slops, after heat exchange with the feed to the beer stills, are either recycled for mixing with the molasses feed or are sent to a battery of five multiple-effect evaporators and a spray dryer, thus producing a good quality distillers grain-type material for sale as an animal feed. The solvent/water stream from the beer stills flows to a batch column which separates acetone (low boiler) and the ethanol/water azeotrope (sidestream, intermediate boiler) from a butanol/water tail stream. Acetone and ethanol/water are sent directly to separate product storage from the batch column, while the butanol/water stream is sent to two additional columns and a decanter where water is purged, and 1-butanol is produced as a high-boiler and sent to storage.

Table V. Relative Magnitude of Equipment Costs for a 45×10^6 kg of Solvents/year Acetone-Butanol Fermentation Facility

process operation	% total cost
feed preparation	10.7
fermentation	39.1
distillation	14.0
product storage	7.4
stillage concentration	28.8
total	100.0

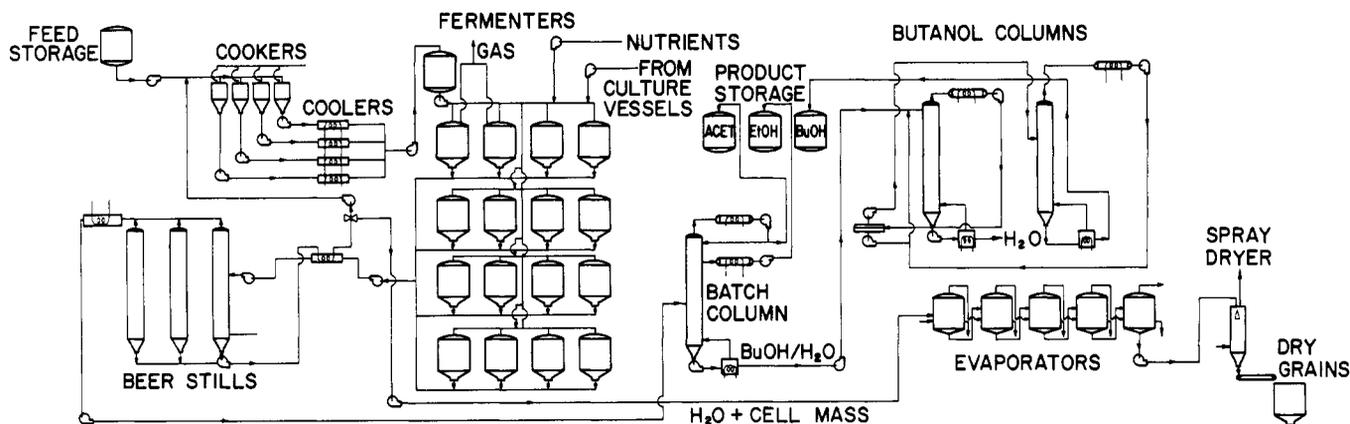
Due to the preliminary nature of this study, the formation of acetic and butyric acids and acetoin was not taken into consideration.

Base Case Economic Study

The economic study undertaken was of the preliminary estimate or study estimate type ($\pm 25\%$), and was based on the flowsheet of Figure 2. A summary of the equipment cost estimate for a 45×10^6 kg of solvents/year plant is given in Table IV; all costs reported in this paper are based on early 1979 figures. Table V shows the fractional contribution to the total equipment cost from each of the major process operations. It can be seen that fermentation equipment accounts for 39% of the total equipment cost while stillage concentration to obtain a final dried product contributes 29% to the total. Distillation equipment makes the third largest contribution at 14%.

These equipment costs were then utilized to generate fixed capital and total capital investment costs through classical chemical engineering cost estimation techniques (Peters and Timmerhaus, 1980). The results obtained are shown in Table VI. These capital cost figures were then used to generate the manufacturing and production cost estimates given in Table VII. The results indicate a total capital investment requirement of about \$20 million or the equivalent of \$0.35 capital investment/L of total solvents (\$1.33/gal). Total production costs are estimated at about \$39 million with molasses alone accounting for 62% of the total. Finally, the annual sales revenues were estimated as shown in Table VIII; the solvent values used in this table are those given in the *Chemical Marketing Reporter* in mid-1979.

As shown by Tables VII and VIII, total production cost and total income are very nearly the same without allowing



ANNUAL PRODUCTION:

ACETONE	=	13.2 × 10 ⁶ kg/yr	(29 × 10 ⁶ PPY)
BUTANOL	=	26.4 × 10 ⁶ kg/yr	(58 × 10 ⁶ PPY)
ETHANOL	=	4.5 × 10 ⁶ kg/yr	(10 × 10 ⁶ PPY)
CO ₂	=	72.0 × 10 ⁶ kg/yr	(159 × 10 ⁶ PPY)
H ₂	=	1.8 × 10 ⁶ kg/yr	(4.0 × 10 ⁶ PPY)
DRY GRAINS	=	6.4 × 10 ⁷ kg/yr	(1.4 × 10 ⁸ PPY)
MOLASSES FEED	=	220,000 kg/6hr	(582 × 10 ⁶ PPY @ 57% SUGAR)

ACETONE-BUTANOL FERMENTATION PROCESS FLOWSHEET

Figure 2. Process flowsheet for the acetone-butanol fermentation utilizing molasses feedstock.

Table VI. Fixed Capital and Total Capital Investment Summary for a 45 × 10⁶ kg of Solvents/year Acetone-Butanol Fermentation Facility

	based on fluid processing plant, \$
direct costs	
purchased equipment (delivered and installed)	5 139 000
instrumentation and controls (installed)	629 265
pipng (installed)	2 307 306
electrical (installed)	384 551
buildings (including service)	629 265
yard improvements	349 592
service facilities (installed)	2 447 144
land purchased	209 755
total direct plant cost	12 095 878
indirect costs	
engineering and supervision	1 153 653
construction expenses	1 433 327
total direct and indirect plant costs	14 682 858
contractor's fee	734 143
contingency	1 468 286
fixed-capital investment	16 885 287
working capital	3 006 490
total capital investment	19 891 777

Table VII. Estimated Annual Manufacturing and Total Production Costs for a 45 × 10⁶ kg of Solvents/year Acetone-Butanol Fermentation Facility

i. direct production costs	
raw materials at \$0.092/kg (\$84/ton) of 80% molasses	\$24 447 000
operating labor	352 000
direct supervisory and clerical labor	88 000
utilities	7 073 986
maintenance and repairs	1 013 117
operating supplies	151 967
laboratory charges	70 400
total	\$33 196 470
ii. fixed charges	
depreciation	\$ 1 688 529
local taxes	337 705
insurance	101 312
total	\$ 2 127 546
iii. plant overhead cost	\$ 1 768 496
total manufacturing cost	\$37 092 512
iv. general expenses	
administrative cost	\$ 176 000
distribution and selling cost	1 768 496
total	\$ 1 944 496
total production cost	\$39 037 008

for finance charges or a return on invested capital. This is the case even for the optimistic assumption of \$0.11/kg (5¢/lb) credit for carbon dioxide piped to a nearby use such as residual oil recovery where carbon dioxide is piped directly into the ground. The costs associated with carbon dioxide recovery were not taken into consideration in this initial study and if accounted for would make the process even less favorable. Since the values for the solvents are those from current petrochemical routes, this portion of the study shows very marginal economics for a molasses-based acetone/butanol fermentation process. It should be pointed out that molasses prices have increased dramatically recently (O'Sullivan, 1979) due to Brazil's withdrawal from the world export market in order to divert its molasses for domestic gasohol production. This tendency for feedstock costs to fluctuate substantially, and in particular

to increase greatly when a new demand appears, is not uncommon for fermentation feed commodities and is a potentially serious disadvantage of high-quality renewable feedstocks. We therefore next examined the possibility of using a waste-type fermentation feed, in particular, whey waste.

Whey Waste as a Fermentation Substrate

About 13.6 × 10⁹ kg of liquid whey (containing approximately 0.7 × 10⁹ kg of lactose) is currently available annually in the U.S., largely as a byproduct of the cheese manufacturing industry (Graf, 1976). This liquid whey has, on the average, the following composition: lactose, 5.00%; protein, 0.67%; ash, 0.50%; other solids, 0.33%; water, 93.50% (all wt %). Whey constitutes a major disposal problem to the dairy industry; tighter environmental pollution control regulations have forced the cheese industry to spend large sums of money for disposing of whey in an environmentally sound manner and many dairies

Table VIII. Income Summary for a 45×10^6 kg of Solvents/year Acetone-Butanol Fermentation Facility

item	annual quantity, kg (lb)	value, \$/kg (\$/lb)	income, \$/year
1-butanol	26.4×10^6 (58×10^6)	0.53 (0.24)	13 920 000
acetone	13.2×10^6 (29×10^6)	0.44 (0.20)	5 800 000
ethanol	4.5×10^6 (10×10^6)	0.40 (0.18)	1 800 000
dry slops	64.3×10^6 (142×10^6)	(@ \$0.094/kg)	6 000 000
hydrogen	1.8×10^6 (4×10^6)	0.29 (0.13)	520 000
carbon dioxide	72.0×10^6 (159×10^6)	0.11 (0.05) ^a	7 950 000
total			\$36 000 000

^a Value in pipe for oil recovery, etc.

have had to shut down due to financial difficulties. This situation has created the need for developing alternative methods for handling whey disposal and, among the emerging technologies, ethanol and single cell protein fermentations seem to be quite attractive (Bernstein et al., 1977; Reesen and Strube, 1978).

In this study we analyzed the possibility of utilizing liquid whey as the feedstock for the acetone-butanol facility described earlier since *Cl. acetobutylicum* does have the capability of metabolizing lactose as well as glucose (Buchanan and Gibbons, 1974). Such a whey-based acetone-butanol fermentation process would be identical with that shown on the base case flowsheet, except for the addition of an ultrafiltration step to recover valuable whey proteins and an anaerobic waste water treatment stage that generates methane.

Information relative to size and location of typical cheese manufacturing facilities was obtained from the Wisconsin Department of Agriculture (Krahn, 1979). This and other information (Pace and Goldstein, 1975; Reesen and Strube, 1978; Laugh, 1977) was integrated with the base case economics to give the whey-based economics summarized in Table IX. In this analysis it was assumed that the liquid whey is available at no cost since it is presently a disposal problem at the 5% lactose concentration, and that it must be trucked 160 km (100 miles) to the fermentation facility at present trucking rates (Laugh, 1977; Krahn, 1979); the average trucking distance is more likely to be 80 km (60 miles) (Krahn, 1979) and therefore, the calculations presented are likely to be conservative.

As can be seen from Table IX, the economics for the acetone-butanol fermentation using a liquid whey feed are strikingly different from those for molasses feed. The improved economics for the whey feed are primarily a result of lower feed costs (\$24.4 million annually for molasses vs. \$13.2 million to transport the whey feed), and about a \$9.3 million protein credit per year for the whey feed. An additional \$6.44 million fixed capital investment is required for the whey feed case, but the Net Return on Investment (NROI) of 30.8% (discounted cash flow rate of return, DCFRR, of 28–30%) is very attractive. Even if the investment estimate is increased by about \$4 million (since this design is only preliminary), the NROI is still 25%.

Conclusions

The economics of producing acetone and 1-butanol by fermentation was initially studied for a traditional high-quality molasses feedstock and found to be unattractive when current prices of petroleum-based commodities were used for the calculations. The total production costs were found to be slightly higher than the total annual income even when credit was taken for all the fermentation by-products. This was mainly due to the high cost of the molasses feedstock.

In an attempt to bring the production costs down, liquid whey waste was evaluated next as a feedstock for the fermentation facility. Our study shows the clearly superior

Table IX. Economics of a 45×10^6 kg of Solvent/year Acetone-Butanol Fermentation Facility Using Liquid Whey Waste as Substrate^a

A. total capital investment		
\$19 891 776	(base case)	
+ 4 640 000	(ultrafiltration, Pace and Goldstein, 1975)	
+ 1 800 000	(waste water treatment, Reesen and Strube, 1978)	
\$26 331 776	new total capital investment	
B. total production cost		
\$39 037 008	(base case)	
-24 447 000	(molasses cost)	
+13 200 000	(whey trucking cost, \$ 0.44/100 kg, Laugh, 1977)	
+ 644 000	(additional depreciation)	
\$28 434 008	new total production costs	
C. annual income		
\$36 000 000	(base case)	
- 2 270 000	(dry slops)	
+ 9 286 200	(whey protein, 20×10^6 kg at \$ 0.46/kg)	
+ 459 000	(methane)	
\$43 475 200	new total income	
D. gross profit		
\$43 475 200		
-28 434 008		
\$15 041 192		
E. after tax income = (0.54) (\$15 051 192) = \$8 122 244		
F. net return on investment (NROI) = (\$8 122 244 / \$26 331 776) × (100) = 30.8%		
G. for a 10–20 year plant life, the discounted cash flow rate of return (DCFRR) is 28–30% (from Linsley, 1979)		

^a Items B through G refer to an annual basis.

economic position of this feed for acetone-butanol fermentation and suggests that other low-grade or waste-type feeds such as other food wastes and sulfite waste liquors should be investigated as well. Lignocellulosic residues could be particularly well suited for this fermentation since the *Cl. acetobutylicum* has the capability of metabolizing pentoses as well as hexoses. The utilization of waste-type materials is plagued by two fundamental problems: they are not usually available in a concentrated form and they may have a seasonal character. This implies that a careful economic assessment should always be performed whenever such material is considered as a possible feedstock.

Although economically attractive when based on waste-type materials, the acetone-butanol fermentation has a number of drawbacks which must be addressed before any attempt for commercial production is made. The major one is the very low levels of butanol that are observed in the final fermented broth. With current technology such levels are only about 1.9% (w/v). This results in the need for large size vessels for fermentation and an energy-intensive distillation recovery of the solvents. Studies in the area of alcohol toxicity and improved fermentor design are currently underway in our laboratory.

Additional difficulties with this fermentation include the need for strict anaerobic conditions, delicate culture maintenance and propagation, and a tendency for bacteriophage infection and *Lactobacilli* contamination. If improved upon, however, the acetone-butanol fermentation has the potential of becoming a major source of highly valuable chemicals and fuels in future years.

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Nomenclature

AMP = adenosine monophosphate
 ADP = adenosine diphosphate
 ATP = adenosine triphosphate
 CoA = coenzyme A
 NAD⁺ = nicotinamide adenine dinucleotide (oxidized form)
 NADH = nicotinamide adenine dinucleotide (reduced form)
 PPI = inorganic pyrophosphate
 TPP = thiamine pyrophosphate

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Economics of Ethanol and D-Glucose Derived from Corn

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As a renewable source of chemicals, corn offers a number of advantages: ready availability in large quantities, established processing technologies, and low product costs. Subjected to the "wet-milling" process, it provides corn oil and high-protein animal feeds as valuable byproducts which reduce significantly the effective cost of products made from the corn's starch content. Operations are in place for the production of high-purity D-glucose solution with low ash and light color at low enough cost to merit its consideration as a potential replacement for some nonrenewable chemical materials. By combining the technologies of corn wet-milling, enzymatic starch hydrolysis, and petrochemical distillation, fermentation ethanol may already be highly competitive with synthetic alcohol produced from ethylene; its costs are significantly less than alcohol produced by traditional methods.

Rapidly increasing prices and diminishing supplies of petroleum products underscore the urgent need for solutions to fuel and raw material problems—immediate as well as long-range.

The mushrooming demand for ethanol from renewable resources to supply the gasohol program makes it imperative to start producing the largest possible quantities in the shortest possible time and at the lowest possible cost. The only possible solution, at least for the near to medium

term, is through fermentation of agricultural products, especially corn, since technologies and infra-structures for other processes are far from being in place.

Questions about the economic and other implications of using grains for this purpose are many, and they are not susceptible to easy general answers. However, this paper is intended to help answer the questions by providing background information and some technical detail on the nation's agricultural system's ability to support an inten-