THE FEASIBILITY OF ETHANOL PRODUCTION FROM CHEESE WHEY AND FRUIT POMACE IN NEW YORK STATE*

by

Eric Gabler
Robert J. Kalter
Richard N. Boisvert
Larry P. Walker
Roger A. Pellerin
Andy M. Rao
Yong D. Hang**

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**Authors are, respectively: Research Associate, Professor, and Associate Professor, Department of Agricultural Economics, Cornell University; Assistant Professor and Research Associate, Department of Agricultural Engineering, Cornell University; and Associate Professor and Assistant Professor, Department of Food Science and Technology, New York State Agricultural Experiment Station at Geneva.

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One of the most severe problems facing the United States during the decade of the 1980's is the lack of an available and secure liquid fuel supply. Recent problems with conventional sources of supply have created a strong interest in the development of alternatives, including the production of ethanol from biomass (for use in gasohol). The Northeast and the State of New York are particularly interested in this possibility, in view of their heavy dependence on conventional supply sources located outside the region.

In April 1980, the Departments of Agricultural Economics and Agricultural Engineering of Cornell University and the Department of Food Science and Technology of the New York State Agricultural Experiment Station at Geneva began a study of the technical and economic feasibility of using agricultural biomass to produce fuel-grade ethanol in five regions of New York. No constraints were placed on the type of biomass considered except that it must be suitable for conversion to ethanol using conventional, "off-the-shelf" technologies. To date, the feasibility analysis has been completed in all five study regions (Kalter et al., 1980, 1981a,b,c,d). The analysis of the regional economic impacts and other policy analyses are scheduled for completion in December, 1981.

Many proponents of ethanol as an energy source are concerned primarily with its potential in the Midwest grain belt, where the emphasis is on diverting large quantities of corn and other grains into the production of alcohol. Unlike the Midwest, the Northeast is presently a grain deficit region. New York is one of the Region's largest corn-producing states, but in addition to the 650,000 acres of corn grown locally, New York still imports substantial quantities of the feed grains utilized throughout the State (Riggins, 1977). Therefore, New York would require additional imports in order to develop an ethanol industry based primarily on the conversion of feed grains.

On the other hand, some regions within New York do have major agricultural sectors. Dairy dominates agricultural production, but significant quantities of other agricultural commodities are also produced (particularly fruits and vegetables). Because of their high value for human consumption, it would be difficult to justify the direct conversion of these commodities to ethanol production. However, the agricultural production and processing sectors generate dairy and other food processing wastes that may be suitable for conversion. The fact that many of these residues must now be disposed of at a high social cost in order to meet environmental regulations makes ethanol production from them even more attractive.

This paper discusses the technical and economic feasibility of commercial ethanol production from cheese whey and fruit pomace. Emphasis is given to potential ethanol production from cheese whey. Fruit pomace, although initially considered as potential feedstock in two study regions, was found in both cases to be unsatisfactory. A major source of waste biomass not considered is cellulosic materials. Cellulose may ultimately offer the greatest contribution to regional liquid fuel production, but commercially proven technologies for converting cellulose to liquid fuels were not available at the time of the project's formulation.

FRUIT POMACE

New York is a significant producer of apples and grapes, ranking second nationally in each. In 1980, 1.1 billion pounds of apples were produced statewide (New York Crop Reporting Service, 1981). Sixty-three percent of this production was subject to some form of processing, and 30 percent was processed specifically for juice or cider. In the same year, 350 million pounds of grapes were produced, of which 97 percent were processed for juice or wine.

The by-product of juice production is pomace, consisting largely of the skins and seeds of the pressed fruit. In a 30 percent solids form, pomace contains only 12 to 14 percent sugar when raw, and less than 9 percent sugar if subjected to secondary sugar recovery (Gaden et al., 1976; Kalter et al., 1981a). Pomace has limited use as an animal feed and is largely considered a waste product.

The utilization of pomace as an ethanol feedstock would help to alleviate a growing disposal problem for the fruit-processing industry. Unfortunately, the relatively low sugar-to-solids ratio in pomace effectively precludes this possibility. Low sugar-to-solids creates severe inefficiencies in both the fermentation and distillation of pomace substrates when using conventional technologies.

Acquisition of pomace is also a problem as existing processing plants are dispersed geographically and pomace is expensive to ship and difficult to handle and store. Pomace in 30 percent solids form is bulky, and costs in the neighborhood of $10 to $20 per ton to transport even over relatively short distances (Kalter et al., 1981a, d). Transportation costs alone, assuming the pomace is shipped from various processing plants to a centralized ethanol facility, would be approximately $1 per gallon of ethanol produced from raw pomace, and as much as $2 per gallon of ethanol produced from leached pomace. Given a current price of ethanol of approximately $1.75 per gallon, the acquisition cost of pomace becomes prohibitive.

Seasonality of pomace production in most of New York is quite marked. The bulk of the State's apple processing occurs from September through March, while grapes are processed primarily in October and November. Seasonality is not a problem if a feedstock can be stored, as storage allows even, year around, ethanol conversion. However, wet pomace does not store for more than a few days, and the low sugar level in pomace cannot be concentrated to levels that would prevent spoilage. Drying of pomace for storage would only add to the already prohibitive acquisition costs.

Fermentation and distillation problems associated with pomace substrates are perhaps the greatest barriers against the use of fruit pomace for ethanol production. The high relative fiber content of pomace complicates fermentation by necessitating a 4 to 5 parts dilution of the pomace for submerged fermentation to occur. Given the initial low sugar concentration of the pomace, this will yield a sugar concentration of less than 3 percent, and an ethanol yield of less than 1.5 percent. Ethanol concentrations of less than 2 percent are uneconomic to recover, given conventional distillation techniques. In addition, the fiber component of the beer may result in clogging of the distillation tower. Centrifuging the fiber from the beer prior to distillation would prevent clogging, but would also result in a loss of 20 to 25 percent of the ethanol with the fiber cake. Thus, along with the high cost of transporting a low sugar feedstock and the inability to smooth out seasonality through storage, these technical problems effectively rule out the economic production of ethanol from a pomace feedstock.

CHEESE WHEY

New York was the Nation's second largest producer of milk in 1979 at 10.6 billion pounds. Forty percent of this milk went to the production of cheese; New York ranked first in the production of creamed cottage cheese and third in the production of other cheeses.

Cheese whey is a by-product of all cheese production, consisting of lactose, protein, minerals, and minor amounts of fat. In general, two types of whey are produced in the manufacturing process: acid whey is a by-product of cottage and cream cheese production, while the manufacture of cheddar and other cheeses produce sweet whey. Acid whey in raw form has a lactose content ranging between 4 and 4.5 percent relative to an overall solids content of approximately 6 percent. Sweet whey has a lactose content ranging between 4.5 and 5.1 percent relative to a solids content of approximately 6.5 percent. Lactose, or milk sugar, may be directly converted to alcohol by yeast.

Cheese whey is often considered a waste product or, at best, a by-product with a cyclical price history. The methods of disposal and utilization of whey can vary substantially from plant to plant. Most small plants (under 25 million pounds of whey a year) use one of three methods--sewage disposal, land disposal or donation to farmers for animal feed. However, plants producing more than 25 million pounds of whey annually are generally unable to use these disposal options.

Whey has a biological oxygen demand (BOD) ranging between 32,000 and 60,000 mg/liter. One thousand gallons of whey imposes a load on a sewage system equivalent to 1800 people (Switzenbaum et al. 1979). A cheese plant with an annual production of whey of 50 million pounds would discharge 20,000 gallons of whey daily. The largest plants may discharge 100,000 gallons daily. Except in large municipal areas, these plants would rapidly overload existing sewage treatment facilities, and even spreading whey on land becomes environmentally risky. Thus, larger cheese plants must resort to processing whey for use as human food or animal feed.

Regardless of the manner of disposal used, whey will generally constitute an expense to the cheese plant. Responding to a survey conducted in the summer of 1979, only one of 24 plants in New York viewed whey as an economic asset (Switzenbaum et al., 1979).

However, the protein component of whole whey may, independently, be a highly marketable product. Recovery of protein, or deproteinization, can take place through ultrafiltration which can yield protein concentrations as high as fifteen times those found in raw whey (and higher with diafiltration). A 35 percent protein powder with properties very similar to nonfat dry milk can be obtained by drying a seven-fold whey protein concentration. However, few cheese producers are currently engaged in deproteinization due largely to problems in disposing of the deproteinized whey. Deproteinized whey retains virtually all the BOD of whole whey but has substantially reduced nutritive value. Ethanol production, offering a major demand for the lactose remaining in deproteinized whey, would in effect open the door for use of protein extraction processes.

Production of ethanol from deproteinized whey presents no unusual technical or biological problems. The yeast used in fermentation is Kluyveromyces fragilis, which can convert lactose directly to ethanol. As K. fragilis is somewhat intolerant to ethanol concentrations exceeding 5 percent, the lactose concentration of the initial substrate must be adjusted to 10 percent. Fermentation time is 16 hours. Allowing for lactose needed to grow yeast, approximately 16.6 pounds of lactose (350 pounds raw whey) are required to produce one gallon of ethanol.

Whey Supplies and Seasonability.

Total whey production for New York State in 1980 was estimated at 3.3 billion pounds. Monthly production in terms of raw whey and lactose equivalents is given in Table 1. An additional 900 million pounds of whey (41 million pounds of lactose) are potentially accessible to New York from Canada. However, actual lactose available for ethanol manufacture will be somewhat less if deproteinization occurs due to imperfect separation of the protein from the lactose.

In some regions of the State, cheese manufacturing is seasonal, resulting in monthly variations in whey availability of as much as 23 percent from the mean. However, it is technically feasible to store cheese whey for long periods of time without refrigeration or other special preparation, if the whey is initially condensed to a 60 percent solids content. At this concentration, the lactose concentration of the whey is sufficient to inhibit bacterial growth completely. Whey storage capacity facilitates year around production with uniform throughput. It is also useful to allow for plant shut down and/or other logistical factors such as short-term supply interruptions.

The spatial distribution of cheese whey is an important factor in determining the profitability of a potential ethanol facility. Given the dispersed location of cheese plants in New York State, transportation costs become important. The economic feasibility of moving whey to a conversion site depends directly on the cost of moving the large quantities of water present in raw whey or alternatively on the cost of removing a portion of

Table 1

TOTAL AND MONTHLY SUPPLIES OF WHEY/LACTOSE IN NEW YORK STATE, 1980
(1000 lbs.)

Month	Raw Whey	Lactose
January	270,547	12,573
February	260,656	12,099
March	290,363	13,388
April	302,228	14,029
May	317,300	14,790
June	324,826	15,101
July	275,904	12,851
August	258,138	12,027
September	264,068	12,243
October	251,153	11,635
November	256,936	11,853
December	266,586	12,285
TOTAL	3,338,705	154,874

Source: Individual cheese manufacturing plant surveys.

the water by condensing (thereby reducing transported volumes and transportation costs). At current fuel and shipping costs, it is advisable to consolidate the available whey at central locations by shipping it in concentrated form (at least 40 percent solids).

Plant Scale Selection and Plant Design

Using all the whey currently produced in New York, and accessible from Ontario, a total of approximately 10 million gallons of ethanol annually could be produced. However, given the regional orientation of the Cornell study, a conversion plant of this scale was not developed. Plants using only whey produced within a region were constrained by available supplies to 2.5 million gallons of annual ethanol capacity. Where two regions are in close proximity, their whey supplies can be combined to yield a plant scale of 5 million gallons annually. The smallest plant scale considered was 1.675 million gallons of ethanol capacity, developed to reflect natural geographic divisions within regions. Plants below this scale, i.e. at the cheese plant level, were not investigated due to several logistical and economic considerations. First, the production of fuel grade ethanol, while conceptually simple, entails a significant investment in capital equipment and a degree of managerial specialization that may be incompatible with the primary role of the cheese manufacturers. Second, significant economies of scale may be expected, particularly in distillation. Third, marketing of the ethanol and the process by-product will be facilitated through a centralized producer, as product volumes and homogeneity of product will be superior.

Thus, detailed plant designs were developed for three different scales of annual ethanol production capacity -- 1.675 million gallons, 2.5 million gallons and 5.0 million gallons. For each plant, process components are developed individually and matched, and detailed material balances and energy flows are specified. Only conventional, "off-the-shelf" technology is utilized. Incoming whey is either put into long-term storage by concentrating it to 60 percent solids or is prepared immediately for fermentation, depending on seasonal whey flows. Whey to be fermented is sterilized, diluted to a 12 percent solids (10 percent lactose) substrate, and pH adjusted using hydrochloric and phosphoric acids. Nutrients are also added. Fermentation occurs on a batch basis. The fermented beer then passes through two distillation towers which separate a 200° ethanol stream from the beer. Remaining solids are concentrated and dried to produce a by-product suitable for use as an animal feed.

Cost engineering techniques, principally those developed by Peters and Timmerhaus (1980), are used to determine both the capital and operating costs (and working capital requirements) for each plant scale. Tables 2 and 3 show the related capital and operating costs for the three plants.[1] Capital costs per gallon of annual ethanol capacity range from $5.26 for the smallest plant to $3.17 for the 5 million gallon plant. Operating costs per gallon also fall as plant scale increases; costs in the large plant are only 2/3 that in the small plant. More thorough discussions of assumptions underlying the derivation of the feedstock cost and by-product credit are given below in the economic evaluation.

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[1]Costs presented in these tables and presentation of subsequent data pertain to whey-to-ethanol plants developed for the Southern Tier East Region of New York (Kalter <u>et al.</u>, 1981b). These plants are representative of project analyses for those regions in New York where whey is a major feedstock source.

Table 2

PLANT CAPITAL COSTS: TOTAL AND PER GALLON OF ANNUAL INSTALLED ETHANOL PRODUCTION CAPACITY[a]
($)

Plant Design	Total	Per Gallon
1.675 mm Gallon Ethanol Conversion Plant (Whey)	8,815,607	5.26
2.5 mm Gallon Ethanol Conversion Plant (Whey)	11,362,299	4.54
5.0 mm Gallon Ethanol Conversion Plant (Whey)	15,836,609	3.17

[a]Capital costs include a minor (less than 2 percent) land acquisition cost.

Source: Kalter *et al.*, 1981b.

Table 3

PLANT OPERATING COSTS PER GALLON OF ETHANOL[a]
($)

Plant Design	Excluding By-product Credit	Including By-product Credit
1.675 mm Gallon Ethanol Conversion Plant (Whey)	1.13	0.78
2.5 mm Gallon Ethanol Conversion Plant (Whey)	1.03	0.68
5.0 mm Gallon Ethanol Conversion Plant (Whey)	0.88	0.53

[a]These values assume a zero acquisition cost for deproteinized whey.

Source: Kalter _et al_., 1981b.

Net Energy Balances

The question of net energy production is often raised with respect to ethanol production. For the three plant designs both net energy and net liquid fuel balances are generally positive if whey condensing is not considered as part of the production process (Tables 4 and 5). The inclusion of condensing energy requirements forces the balances to be negative, but depending on one's perspective, allocating these energy requirements to ethanol production may not be appropriate. Whey condensing occurs at the cheese plants, and while condensed whey would be a direct input into the ethanol production process, almost all of the whey in New York is currently condensed prior to disposal, to facilitate storage, shipping, and/or drying. Thus, it may be more appropriate to allocate the energy used in condensing whey to the deproteinization and waste disposal functions from the cheese manufacturing process.

These results illustrate that net energy balance analysis is highly dependent on the assumptions used. Depending on the approach, an analysis of a given plant can yield positive or negative balances. Thus, policy decisions based on such results will be highly subjective. For this reason, economic analysis must ultimately be used to decide plant or process commercial feasibility. Economic analysis can be used to capture the multitude of energy sources, other resources, and plant functions simultaneously and in accordance with the values society places on them through the market stucture.

Economic Evaluation

The economic evaluations are conducted with the help of a computerized simulation model designed to examine alternative assumptions about economic

Table 4

NET ENERGY BALANCE PER GALLON OF ETHANOL[a]
(Btu's)

Plant Design	Feedstock	Processing	Ethanol	By-Product[b]	Total
Including Whey Condensing					
1.675 mm	-88,500	-49,800	84,000	3,500	-50,800
2.5 mm	-89,000	-49,600	84,000	3,500	-51,100
5.0 mm	-90,000	-49,300	84,000	3,500	-51,800
Excluding Whey Condensing					
1.675 mm	-500	-49,800	84,000	3,500	+37,200
2.5 mm	-1,000	-49,600	84,000	3,500	+36,900
5.0 mm	-2,000	-49,300	84,000	3,500	+36,200

[a]Energy consumer (-) and energy credit (+).

[b]Energy is biological energy as animal feed.

Table 5

NET LIQUID FUEL ENERGY BALANCE PER GALLON OF ETHANOL[a]
(Btu's)

Plant Design	Feedstock[b]	Processing[c]	Ethanol	By-Product[d]	Total
		Including Whey Condensing			
1.675 mm	-88,000	--	84,000	3,500	-1,000
2.5 mm	-89,000	--	84,000	3,500	-1,500
5.0 mm	-90,000	--	84,000	3,500	-2,500
		Excluding Whey Condensing			
1.675 mm	-500	--	84,000	3,500	+87,000
2.5 mm	-1,000	--	84,000	3,500	+86,500
5.0 mm	-2,000	--	84,000	3,500	+85,500

[a]Energy consumer (-) and energy (+).

[b]Includes condensing and transportation energy.

[c]Non-liquid fuel sources.

[d]Organic energy content here assumed to represent opportunity cost of liquid fuels needed to produce the embodied biological energy.

conditions (Tyner and Kalter, 1977). The model assumes a competitive marketplace and profit maximization objectives for private firms that would undertake ethanol plant development. Costs and revenues are simulated over the expected life of the plant and discounted cash flow (DCF) techniques are used to estimate items such as after tax net present value, annual cash flow, price to produce (break-even price), internal rate of return and payback period. All economic calculations are in real, 1981 dollars, although inflation is taken into account in estimating depreciation allowances and nominal subsidies.[2] These estimates form the basis for determining the overall economic feasibility of potential investments.

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[2]The term "real" in economic analysis is used to indicate a unit of currency that is inflation free. A real dollar in one year has the same purchasing power as a real dollar in another year. "Nominal" dollars often devalue over time due to inflation. High and fluctuating rates of inflation generally complicate economic analysis. Consequently, real dollars are often used in preference to nominal dollars.

A nominal dollar in one year may be converted to a real dollar in another either by discounting the nominal dollar by the prevailing rate of inflation, as derived from an economic index such as the Consumer Price Index (CPI), or, more directly, by using a ratio of index values. For instance, if the CPI equalled 100 in 1967 and 274 in July of 1981, and the value of a 1967 dollar in 1981 "real" terms is desired, then

$$\$1_{1967} = 1 \left(\frac{274}{100}\right) = \$2.74_{1981}$$

Discount rates or loan interest rates may also be defined in real or nominal terms. A real rate may be converted to a nominal rate by the formula

$$r = (1+i)(1+R) - 1$$

where r equals the nominal rate, i equals the inflation rate, and R equals the real rate. Conversely, a nominal rate is converted to a real rate as follows

$$R = \frac{1 + r}{1 + i} - 1$$

For each of the three plant designs developed, a "reference case" DCF analysis is conducted. The "reference cases" use the costs contained in Tables 2 and 3 and a series of assumptions concerning other key variables which would be generally accepted as representative of current values, forecasts or practice (as the case may be). Table 6 displays these common variables and the values to be used. Categories defined include cost related input variables, product price, by-product price or value, plant production time frames, and economic and tax related variables. Most of the assumptions in Table 6 are self-explanatory, but some elaboration is necessary concerning feedstock cost, the price of ethanol, the by-product credit, and the procedure through which uncertainty in economic parameters is incorporated into the analysis.

The deproteinized whey feedstock is assumed to be acquired from the cheese plants in 40 percent solids form at no cost other than that incurred in transporting it to the ethanol plant. Most industry sources hold this to be a fair compensation, as the deproteinized whey is otherwise a disposal nuisance. Revenues gained by the cheese plants from protein recovery will more than cover the cost of concentrating the deproteinized whey. Transportation costs to the respective ethanol plants are determined through the use of existing transportation rates. The transportation costs of assembling the necessary volume of lactose were minimized for each plant scale and potential site location using linear programming. The least-cost location for each plant scale was then selected on the basis of the results.

Footnote 2 Cont.
Thus, a 10 percent real rate of discount is equivalent to a 21 percent nominal rate, given a 10 percent rate of inflation, while a nominal loan interest rate of 14 percent is equivalent to a 3.6 percent real interest rate.

Table 6

PRINCIPLE ECONOMIC, INSTITUTIONAL AND POLICY ASSUMPTIONS FOR "REFERENCE CASE" DCF ANALYSES

Item	Value
Cost Related Inputs	
Feedstock Cost	Transportation Cost Only
Investment cost contingency distribution	
Minimum	+5 percent
Maximum	+20 percent
Most likely	+10 percent
Operating cost contingency distribution	
Minimum	-10 percent
Maximum	+10 percent
Most likely	0 percent
Operating cost annual real rate of change	1 percent
Working capital factor	15 percent of annual operating costs
Price of Ethanol	
Base price (initial year of analysis)	$1.35/gallon
Annual rate of increase (normally distributed)	
Mean rate	4 percent
Standard deviation	1 percent
Price subsidy:	$.40 nominal tax credit through 1992
Price of By-Product	
Batch whey by-product	$140/ton
Planning Horizon	
Length of plant construction period	2 years
Length of plant production	20 years
Economic and Tax Values	
Discount rate (real rate of return)	10 percent
Loan Interest Rate (Nominal)	14 percent
Debt-Equity ratio	50/50
Depreciation	
Method	Sum of Years Digits
Lifetime	10 years
Salvageable Investment	5 percent
Rate of Inflation	10 percent
Federal tax credits	
Investment Tax Credit	10 percent
Energy Investment Credit	10 percent
Tax Rates	
Federal	46 percent
State	4 percent

The ethanol is assumed to be sold to petroleum distributors, who would in turn market the ethanol to the public in a one part ethanol - nine parts gasoline blend known popularly as gasohol. The price of ethanol for this purpose is initially assumed to be $1.35 per gallon. In addition to this price, a nominal subsidy of $0.40 per gallon is available to the ethanol producer through 1992.[3] The subsidy is added on each year after being discounted to real terms by an inflation factor of 10 percent.

Most projections hold that significant increases in the real price of liquid fuels will occur in the next ten to twenty years (Chase Econometrics, 1980). For this analysis, an annual increase of 4 percent in real ethanol prices is assumed. However, as this rate of increase is highly uncertain, a range of estimated increases up to 6 percent annually is tested in the subsequent sensitivity analysis.

The by-product from fermentation is a high-mineral, medium-protein feed (see Table 7). Use of a newly developed least-cost feed ration linear programming model reveals a retail value for the by-product of approximately $200 per ton (Milligan et al., 1980). The by-product, which would make up 3 percent of a feed concentrate, is assumed sold to a distributor at a whole-sale price of $140 per ton.

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[3]The federal government, in seeking to encourage the production of ethanol fuel from biomass, has exempted gasohol from the 4 cents per gallon nominal fuel tax which currently applies to gasoline. The impact of the federal exemption is a 40 cent per gallon nominal subsidy on ethanol, in that one gallon of ethanol is used to produce 10 gallons of gasohol at a 4 cents savings per gallon. It is assumed that this accrues to ethanol producers because of their relative bargaining power among market participants.

Table 7

BY-PRODUCT NUTRITIONAL VALUES

Dry Matter (%)	90
Megacalories/lb.[a]	.1
Protein (%)	29
NPN (%)	7
Crude Fiber (%)	--
Calcium (%)	1.4
Phosphorus (%)	3.2
Sodium (%)	3.3
Chloride (%)	1.7
Potassium (%)	6.1
Magnesium (%)	0.6

[a]Available caloric content of the by-product if consumed by a lactating cow.

Source: Actual by-product sample analysis.

Uncertainties in key variables, which are normally present in economic activity, are even more critical in the case of alternative energy investments. In this evaluation, uncertainty is simulated in two ways: by incorporating random fluctuations in operating costs and product prices directly into the DCF analyses through the use of Monte Carlo techniques, and by systematically varying key assumptions. Uncertainty from systematic changes in key assumptions is measured by comparing a number of alternative DCF outcomes against the appropriate reference case, and is the subject of the sensitivity analyses described below. However, uncertainty that is incorporated into DCF calculations through the use of Monte Carlo techniques affects both the base and sensitivity analyses. The magnitude of this type of uncertainty is most appropriately expressed in terms of a standard deviation around an expected after tax net present value.

Results. Table 8 summarizes the results of the "reference" DCF analyses using the assumptions outlined above, as well as the results of sensitivity analyses on these assumptions. For the three designs, the expected after tax net present values (ATNPV) are positive under the basic assumptions. ATNPV is the total of net receipts over 22 years (2 of construction and 20 of production) discounted to the present, or year 0, less the discounted value of the initial investment. Thus, a positive ATNPV indicates profitability, in that the actual return on investment exceeds the rate of return assumed for the discount rate.

The absolute magnitude of the average ATNPV is clearly related to plant size, with the 5 million gallon facility having the greatest ATNPV, at $47.74 million, and the 1.675 million gallon facility having the smallest at $10.67 million. There are numerous means for evaluating the relative

Table 8

RESULTS OF SENSITIVITY ANALYSIS

Assumptions	After Tax Net Present Value (Million $)[a]		
	1.675 mm Batch Whey	2.5 mm Batch Whey	5.0 mm Batch Whey
Reference Assumptions	10.67 (0.78)	18.99 (1.12)	47.74 (2.13)
Sensitivity Analysis[b]			
Highest Cost Location	7.69 (0.85)	15.14 (1.20)	47.32 (2.14)
Feedstock Cost			
Whey			
$.01/lb solids	8.10 (0.84)	15.16 (1.20)	40.08 (2.27)
$.02/lb solids	5.54 (0.91)	11.33 (1.30)	32.42 (2.45)
$.03/lb solids	2.97 (0.99)	7.50 (1.41)	24.76 (2.66)
$.04/lb solids	0.63 (0.82)	3.67 (1.54)	17.10 (2.90)
$.05/lb solids	-0.06 (0.13)	0.57 (0.97)	9.44 (3.15)
$.06/lb solids	--	-0.09 (0.10)	2.36 (2.69)
$.07/lb solids	--	--	-0.03 (0.53)
Price of Ethanol (initial price)			
$1.20/gallon	7.94 (0.72)	14.91 (1.02)	39.59 (1.93)
$1.25/gallon	8.85 (0.74)	16.27 (1.05)	42.31 (2.00)
$1.30/gallon	9.76 (0.76)	17.63 (1.08)	45.02 (2.07)
$1.40/gallon	11.58 (0.80)	20.35 (1.15)	50.46 (2.20)
$1.45/gallon	12.49 (0.82)	21.71 (1.18)	53.18 (2.27)
$1.50/gallon	13.40 (0.84)	23.06 (1.21)	55.89 (2.34)
Price of Ethanol (rate of increase)			
0% annual	1.63 (0.57)	5.50 (0.78)	20.76 (1.40)
1% annual	3.43 (0.60)	8.19 (0.84)	26.14 (1.53)
2 % annual	5.51 (0.65)	11.28 (0.91)	32.33 (1.69)
3 % annual	7.90 (0.70)	14.85 (1.00)	39.47 (1.89)
5 % annual	13.88 (0.86)	23.79 (1.25)	57.34 (2.43)
6 % annual	17.62 (0.97)	29.37 (1.42)	68.50 (2.78)
Price of Ethanol (variation of increase) +/- 5%	10.83 (3.43)	19.23 (5.12)	48.22 (10.26)
Structural Shifts in Ethanol Price			
$.40/gallon nominal through production life	11.03 (0.78)	19.53 (1.12)	48.82 (2.13)
$0/gallon through production life	9.22 (0.78)	16.82 (1.12)	43.40 (2.13)
Price of By-product			
$60/ton 90% solids	8.12 (0.84)	15.18 (1.20)	40.12 (2.27)
$80/ton 90% solids	8.75 (0.82)	16.13 (1.18)	42.02 (2.23)
$100/ton 90% solids	9.39 (0.80)	17.08 (1.15)	43.93 (2.19)
$120/ton 90% solids	10.03 (0.79)	18.03 (1.13)	45.83 (2.16)
$140/ton 90% solids	Base	Base	Base
$160/ton 90% solids	11.31 (0.76)	19.94 (1.10)	49.65 (2.11)
$180/ton 90% solids	11.95 (0.75)	20.89 (1.08)	51.55 (2.08)
$200/ton 90% solids	12.58 (0.74)	21.85 (1.07)	53.46 (2.06)
Production Time Horizon			
15 years	6.44 (0.53)	12.26 (0.75)	33.11 (1.04)
10 years	2.59 (0.34)	6.06 (0.47)	19.37 (0.84)
5 years	0.28 (0.23)	1.81 (0.25)	8.09 (0.41)
Real Discount Rate			
5 %	17.01 (1.10)	29.02 (1.59)	69.39 (3.06)
15 %	6.33 (0.57)	12.10 (0.81)	32.83 (1.52)
Loan Interest Rates			
11 % nominal (guaranteed)	11.98 (0.84)	21.06 (1.21)	52.51 (2.32)
20 % nominal	8.04 (0.65)	14.82 (0.93)	38.73 (1.76)
Debt/Equity Ratio			
80/20	21.42 (1.33)	36.00 (1.93)	84.43 (3.73)
60/40	13.41 (0.91)	23.33 (1.32)	57.11 (2.53)
40/60	8.21 (0.66)	15.09 (0.94)	39.31 (1.78)
20/80	4.50 (0.48)	9.20 (0.68)	26.55 (1.28)
0/100	2.02 (0.37)	5.24 (0.52)	17.94 (0.95)

[a]Data in the Table are based upon 100 Monte Carlo iterations. Mean values are shown, with standard deviations given in parentheses. All ATNPV values represent the present value of after tax net income over an assumed construction and production period, discounted at 10 percent, unless other wise specified. The construction period is 2 years in all cases, and unless otherwise specified the production period is 20 years.

[b]The sensitivity results embody the reference case assumption, except for the item noted in the stub.

profitability of the designed facilities. One of the most useful is the ATNPV per unit of capacity. On this basis as well, the largest of the three whey-to-ethanol plants is clearly a more profitable enterprise. In other words, ATNPV rises from $6.37 per gallon of capacity for the 1.675 million gallon facility to $7.60 per gallon for the 2.5 million gallon facility to $9.55 per gallon for the 5.0 million gallon capacity facility.

Although the expected ATNPV's provide an indication of the profitability of the three plant designs evaluated, the standard deviations are summary measures of the variability about the expected ATNPV's due to random variation in uncertain economic variables. Because the standard deviations are small relative to the expected ATNPV's in all cases (equivalent to 7 percent of the mean for the smallest plant and less than 5 percent of the mean for the largest plant), there is a low probability that actual ATNPV's will deviate significantly from the average values reported.

Another means of evaluating commercial feasibility is to determine the market price for ethanol that is necessary to obtain a given rate of return on equity capital. Such an analysis is performed on each of the plant designs given the basic assumptions. Assuming 50 percent equity and a required real rate of return of 10 percent, these market prices are $0.76 per gallon of ethanol for the 5.0 million gallon facility, $1.01 per gallon for the 2.5 million gallon facility and $1.27 per gallon for the 1.68 million gallon facility.[4]

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[4]These values are derived assuming the nominal $0.40 per gallon federal fuel tax credit and should be interpreted as the required constant wholesale price, over 20 years of production, necessary to obtain a 10 percent real rate of return on equity.

Sensitivity Analyses. For the "reference" DCF results, several key assumptions are made with respect to the cost of feedstock, ethanol and by-product prices, plant time horizon, discount rate, debt-equity ratio, commercial loan rate and government mandated economic incentives. In addition, optimal plant sites play important roles in plant economics. Table 8 shows the results of sensitivity analyses with respect to each of these assumptions.

First, sensitivity with respect to plant location is tested. When the highest cost location within a region is designated as the plant site, ATNPV decreases by as much as 28 percent relative to the reference case for the smallest plant scale, and by as little as 1 percent for the largest plant scale. The reduction is greater for the smallest plant scale because all regional whey supplies are not utilized, and transportation costs are minimized by locating near large producers of whey. Although a 28 percent drop in ATNPV is significant, it is clear that plant feasibility does not hinge on the ability to acquire sites at any one location within a study region.

Next, the sensitivity with respect to feedstock cost is tested. For the "reference cases", deproteinized whey is assumed obtained at no cost other than that of transportation. However, this assumption does not account for anticipated competition for the deproteinized whey as the ethanol industry expands. Thus, sensitivity evaluations are conducted; the price of deproteinized whey per pound solids (approximately 21 pounds of whey solids are needed to produce one gallon of ethanol) is varied upward in one cent increments to a maximum of seven cents per pound of solids.

In all three plants, expected ATNPV's are still positive for whey permeate prices up to and including 4 cents per pound solids. At prices above 4 cents per pound solids the results are mixed. At 7 cents, the expected ATNPV's are negative in all cases. The 2.5 million gallon facility remains feasible at 5 cents, while the 5.0 million gallon facility has a positive ATNPV at 6 cents per pound solids.

Several critical assumptions are made for the "reference cases" concerning the price of ethanol, the future price trend of ethanol and the role of the fuel tax subsidy. Given the fundamental role of ethanol price in determining plant revenue streams over time, a wide range of sensitivity analyses on these assumptions is conducted.

Sensitivity analysis on the initial (1981) price of ethanol indicates that every $0.01 per gallon change in ethanol price alters ATNPV by $108,800 per million gallons of annual capacity regardless of plant scale. Thus, the relative impact is elastic in that a 2 percent change in ATNPV will result from a 1 percent change in the assumed base price (exclusive of the fuel tax subsidy).

The key assumption concerning the price of ethanol is that an annual escalation of 4 percent in real terms will continue over the plant production time horizon. Given the uncertainty surrounding expected fuel price trends, sensitivity analysis is performed over an entire range of annual price increases from 0 to 6 percent. As expected, profitability is highly sensitive to this parameter. The ethanol facilities, however, are feasible at any assumed positive rate of price increase. The 5.0 million gallon facility yields an ATNPV in excess of 21 million dollars even given no annual increase in ethanol price, despite the presence of a 1 percent annual increase in real operating costs.

Instability in ethanol price is simulated in the "reference cases" by allowing up to a 1 percent fluctuation in the rate of annual price change to occur randomly by years. To test the impact of much greater instability, a 5 percent fluctuation is tested. In the ethanol plants, this augmented instability has a substantial effect on the ATNPV standard deviations (equal to 32 percent of the expected ATNPV for the smallest plant scale and 21 percent of the expected ATNPV for the largest plant scale). The greater uncertainty does not, however, jeopardize plant feasibility.

The structural shifts in ethanol price require some explanation. In the "reference cases", a federal subsidy of $0.40 per gallon of ethanol through 1992 is assumed in correspondence with current legislation. The plants are examined under the assumption that the subsidy is completely eliminated and that market forces, alone, would dictate ethanol prices. Again, all facilities remain profitable; ATNPV is reduced by 14 percent for the 1.68 million gallon facility, by 11 percent for the 2.5 million gallon facility, and 9 percent for the 5.0 million gallon facility. If the $0.40 per gallon subsidy is extended beyond 1992, the impact would be relatively small.

The sensitivity of results to the estimated by-product credits is tested by varying the credit independently of feedstock cost. The ATNPV's of the three whey-to-ethanol facilities appear to be relatively insensitive to changes in the by-product price. A $20 per ton decrease in by-product value results in a loss of $380,000 of ATNPV per million gallons of annual capacity for all plants. Variations of plus or minus $40 in the whey by-product price lead to changes in estimated profitabilities of no more than 12 percent relative to the "reference cases".

Although a production time horizon of 20 years is often assumed for new facilities, many potential investors may demand a shorter payback period. Thus, time horizons of 15, 10, and 5 years are considered. Though ATNPV falls precipitously, even at the highly restrictive assumption of 5 years production all plants remain profitable.

Real rates of return of 5 and 15 percent are considered as extreme alternatives from the "reference" assumption of 10 percent. As one would expect, ATNPV declines significantly as the required real rate of return (as measured by the real rate of discount) increases. In moving from a 5 to a 15 percent discount rate, the expected ATNPV falls by 62, 57, and 52 percent for the 1.68, 2.5 and 5.0 gallon plants, respectively. However, ATNPV remains positive in all cases and still is over $6 million for the smallest plant.

As interest rates at which money may be borrowed may vary from the 14 percent nominal rate assumed, an 11 percent rate -- representing a guaranteed loan -- and a 20 percent commercial rate are also tested. Although a 20 percent commercial rate has the effect of lowering ATNPV's by as much as 25 percent, it is clear that relative to an assumed 10 percent rate of inflation, no threat to plant feasibility is presented over a realistic range in borrowing rates.

Throughout the analysis, the ATNPV is assumed to be the present value of net revenues in excess of a 10 percent real return on equity capital. Therefore, as the amount of equity capital committed to an ethanol facility rises, ATNPV tends to fall (all other factors remaining constant). For this reason, debt-equity ratios other than 50/50 are tested. The results prove to be extremely sensitive to the equity position; therefore, further sensitivity testing in conjunction with other variables is conducted. Table 9 indicates that a number of the more sensitive parameters of the previous sensitivity analyses lead to negative ATNPV's under the extreme assumption of 100 percent equity. The 1.675 million gallon facility proves to be quite vulnerable at 100 percent equity, becoming infeasible within the range of each sensitivity parameter. The 5.0 million gallon facility, however, holds up very well. It is the only plant that still remains feasible given any assumed positive rate of ethanol price increase, and under any tested production time horizon. The real internal rate of return, calculated with respect to a 100 percent equity holding, ranges from 14 to 24 percent for all plant designs.

SUMMARY

In April of 1980, a multidisciplinary study was initiated at Cornell University to ascertain the technical and economic feasibility of a commercial fuel-grade ethanol industry in New York State. New York's agricultural sector is a major producer of dairy products, fruits, and vegetables. Although economics preclude the direct use of these commodities as ethanol feedstocks, wastes associated with the processing of agricultural produce are often available in significant quantities and at little or no cost other than transportation. This paper focuses on the project findings concerning two such wastes products - cheese whey and fruit pomace.

Based on the study's analysis, the development of one or more centralized ethanol conversion facilities in New York State is likely to be commercially feasible if locally produced cheese whey is used as a feedstock.

Table 9

SENSITIVITY ANALYSIS RESULTS USING 100 PERCENT EQUITY FINANCING[a]

Assumptions	After Tax Net Present Value (million $)		
	1.675 mm (Whey)	2.5 mm (Whey)	5.00 mm (Whey)
Base Assumptions Run (50/50 Debt/Equity)	10.67 (0.78)	18.99 (1.12)	47.74 (2.13)
Base Assumptions with 0/100 Debt/Equity	2.02 (0.37)	5.24 (0.52)	17.94 (0.95)
Sensitivity Analysis on 0/100 Debt/Equity			
Feedstock Cost			
Whey			
$.01/lb solids	0.64 (0.43)	3.20 (0.57)	13.86 (1.04)
$.02/lb solids	-0.05 (0.10)	1.15 (0.65)	9.79 (1.15)
$.03/lb solids	--	-0.05 (0.19)	5.71 (1.27)
$.04/lb solids	--	--	1.66 (1.37)
$.05/lb solids	--	--	-0.08 (0.29)
Price of Ethanol (rate of increase)			
0 % annual	--	-0.06 (0.15)	6.57 (0.72)
1 % annual	--	0.70 (0.46)	8.91 (0.76)
2 % annual	0.00 (0.19)	2.04 (0.46)	11.55 (0.81)
3 % annual	0.87 (0.37)	3.54 (0.49)	14.54 (0.88)
Production Time Horizon			
15 years	0.83 (0.33)	3.35 (0.44)	13.79 (0.77)
10 years	--	0.95 (0.36)	8.45 (0.58)
5 years	--	--	2.81 (0.36)
Real Discount Rate			
5 %	8.04 (0.65)	14.82 (0.93)	38.73 (1.76)
15 %	--	0.29 (0.38)	7.23 (0.60)

[a]Data in Table are based upon 100 Monte Carlo iterations. Mean values are shown, with standard deviations given in parentheses.

Development is shown to be profitable (e.g. the present value of after tax net revenue over the life of the plant is positive) over a broad range of potential economic conditions and technical considerations. Fruit pomace, on the other hand, is found not to be a viable feedstock due to numerous problems in its acquisition, fermentation, and distillation.

Fermenting of deproteinized whey to produce ethanol and drying the resulting distillation slops for animal feed completely utilizes the original cheese whey (itself a by-product of cheese manufacture) and eliminates a difficult disposal problem which currently exists. By providing an outlet for deproteinized whey, ethanol production allows cheese manufacturers to recover the valuable protein component of the whey. Thus, the techniques developed in this study facilitate the profitable production of three valuable products from a by-product currently viewed as an economic liability.

References

Chase Econometrics, Inc. Noted in The Wall Street Journal. September 4, 1980, p. 1.

Gaden, E., M. Mendels, E. Reese, and L. Spano, ed. Enzymatic Conversion of Cellulosic Materials: Technology and Application. New York: John Wiley & Sons, 1976.

Kalter, R., R. Boisvert, E. Gabler, L. Walker, R. Pellerin, A. Rao, and Y. Hang. Ethanol Production in Northern New York: Technical and Economic Feasibility. New York State Energy Research and Development Authority (NYSERDA) Report 80-22, September 1980.

_______. Ethanol Production in Southwestern New York: Technical and Economic Feasibility. NYSERDA Report 81-3, January 1981.

_______. Ethanol Production in Southern Tier East Region of New York: Technical and Economic Feasibility. NYSERDA Report 81-7, March 1981.

_______. Ethanol Production in Suffolk County, New York: Technical and Economic Feasibility. NYSERDA Report 81-X, June 1981, (forthcoming).

_______. Ethanol Production in Dutchess County, New York: Technical and Economic Feasibility. NYSERDA Report 81-X, October 1981, (forthcoming).

Milligan, R., L. Chase, C. Sniffen, and W. Knoblauch. Least-Cost Balanced Dairy Rations: Newplan Program 31, Form 4, Computer Program Users' Manual. A.E. Ext. 80-25, A. S. Mimeo 52, October 1980.

New York Crop Reporting Service and the U.S. Department of Agriculture Economics and Statistics Service. New York Agricultural Statistics 1980. Albany, NY, June 1981.

Peters, M. and K. Timmerhaus. Plant Design and Economics for Chemical Engineers. New York: McGraw-Hill Book Co., 1980.

Riggins, S. The Corn Buying Market in Western New York. A.E. Ext. 77-30, Cornell University, Dec. 1977.

Switzenbaum, M., S. Danskin, and D. Nados. "Mechanic Generation from Whey for Energy Production and Pollution Control". Paper presented at DOE Conference on Energy Optimization of Water and Waste Water Management for Municipal and Industrial Applications, New Orleans, December 10-13, 1979.

Tyner, W. and R. Kalter. "A Simulation Model for Resource Policy Evaluation". A.E. Staff Paper No. 77-28, Cornell University, Sept. 1977.