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Alcohol Fuel from Fodder beets: Economic Feasibility of a Small Scale Plant

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Economic feasibility of a small-scale plant

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To the Reader:

Research on the technical and economic feasibility of fuel alcohol production from biomass has been underway for several years now at SDSU. Work during the first few years (1979-1983) focused primarily on conversion of corn to hydrous alcohol. More recently (1984-1986), our work has concentrated on other feedstocks, such as fodder beets and sweet sorghum. This publication covers our recently completed work on the economic feasibility of converting fodder beets to alcohol in a small-scale plant.

Although this report is authored by agricultural economists, it benefits from ongoing multidiscipline research on fuel alcohol at SDSU. In particular, we acknowledge the research of SDSU microbiologists Carl Westby and Bill Gibbons, which has provided essential process technology information for our economic feasibility analysis. We have also benefited from information and advice provided by Zeno Wicks (SDSU Plant Science Department), Ralph Alcock (SDSU Agricultural Engineering Department), and Ben Bruce (formerly in the SDSU Animal and Range Sciences Department). Fellow SDSU agricultural economists Herbert Allen and Richard Shane have provided valuable advice and review. While we greatly appreciate the inputs from and interaction with all of these individuals, none is responsible for any errors that might exist in our analysis and report.

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Summary and conclusions

The principal focus during the first years of fuel alcohol research at South Dakota State University (SDSU) was on corn as the feedstock. Findings indicated considerable economic feasibility problems for small-scale, corn-based alcohol plants—at prices of petroleum-based fuels prevailing in the early 1980s. Feasibility problems are likely to be even more pronounced if petroleum prices should remain for several years at the levels to which they have fallen during early 1986.

Recently, we have examined fuel alcohol production from feedstocks other than corn, such as sweet sorghum and fodder beets. Here we report on the economic feasibility of producing fuel alcohol from fodder beets in a small-scale plant.

Average total costs of producing fodder beets (at 1984 input costs) were estimated to be approximately $17.50/T when the yield is about 25 T/A. This feedstock cost was used along with other operating and capital costs to estimate the total costs of producing 185-190 proof ethanol. Total costs were reduced by a credit for the value of the Distillers Dried Feed (DDF), estimated to be $.53/gal of alcohol. Estimated costs of producing ethanol **net** of the feed byproduct credit amounted to $1.87 on a per gallon of alcohol basis.

Fuel alcohol returns were estimated to be $.84/gal of alcohol (at 1984 price and income tax credit levels). Thus, net costs of producing ethanol from fodder beets in a small-scale plant substantially exceed probable returns on the ethanol.

The sensitivity of net production costs to several key parameters—such as potential alcohol yield, feedstock price, interest rate, feed byproduct value, and storage period—was estimated in the study. The results are summarized in Table 1. The final column of the table shows a cost elasticity measure. That cost elasticity shows the responsiveness of net production costs to a 1% change in a given parameter. The formula is as follows:

$$\text{Cost Elasticity} = \frac{\%\ \Delta\ \text{in net production cost}}{\%\ \Delta\ \text{in a given parameter}}$$

For example, an increase in alcohol yield from 21 gal/T (baseline case) to 23 gal/T results in a decrease in net production costs from $1.87 (baseline case) to $1.74/gal of alcohol. Therefore, the cost elasticity is calculated as follows:

$$\%\text{ change in net production cost} = \frac{1.74 - 1.87}{(1.87 + 1.74) \div 2} = -7\%$$

$$\text{and \% change in alcohol yield} = \frac{23 - 21}{(23 + 21) \div 2} = +9\%$$

$$\text{therefore, cost elasticity} = (-0.07) \div (+0.09) = -0.78$$

The findings indicate that net production costs are more sensitive to changes in alcohol yield than to changes in fodder beet cost, storage life, or interest rate.

Economic feasibility prospects are clearly not promising for small-scale plants producing hydrous alcohol from fodder beets. Production costs exceeded potential ethanol returns by $1.03/gal of alcohol in the baseline case. Even in the most optimistic case—when the alcohol yield is 23 gal/T, fodder beets cost $14.00/T, and the interest rate is 10%—returns net of costs were estimated to be –$.63/gal of alcohol. (The cost of fuel alcohol as estimated in this study is considerably higher than were prices of comparable petroleum-based fuels during the early- and mid-1980s.)

An additional cost consideration involves the 10% regular business investment credit and the 10% energy investment tax credit for plants which use energy crops as a primary substrate for ethanol production. Though both types of tax credits were in effect in 1984, the reference year in our analysis, the energy tax credit expired at

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Table 1. Summary of economic feasibility analyses.

Item	(1) Returns on ethanol	(2) Total production costs/gal of denatured alcohol	(3) Average feed byproduct credit/gal of denatured alcohol	(4) Production costs net of feed byproduct credit (2-3)	(5) Returns net of costs (1-4)	(6) Cost elasticity
	Dollars/gal of alcohol produced					
Alcohol yield						
17 gal/T	0.84	2.74	0.53	2.21	-1.37	—
21 gal/T*	0.84	2.40	0.53	1.87	-1.03	- 0.81
23 gal/T	0.84	2.27	0.53	1.74	-0.90	- 0.78
Fodder beets cost						
$14/T	0.84	2.26	0.53	1.73	-0.89	—
$17.5/T*	0.84	2.40	0.53	1.87	-1.03	+0.35
$21/T	0.84	2.56	0.53	2.03	-1.19	+0.44
Interest rate						
10%	0.84	2.31	0.53	1.78	-0.94	—
15%*	0.84	2.40	0.53	1.87	-1.03	+0.12
20%	0.84	2.49	0.53	1.96	-1.12	+0.16
30%	0.84	2.69	0.53	2.16	-1.32	+0.24
Storage period						
8 months	0.84	2.63	0.53	2.10	-1.26	—
12 months*	0.84	2.40	0.53	1.87	-1.03	- 0.29
Most optimistic case						
23 gal/T, $14/T, and 10% interest rate	0.84	2.00	0.53	1.47	-0.63	—

*Denotes baseline case.

the end of 1985. Some assets qualified for both the business and the energy credits (U.S. Dept. of the Treasury). When this was the case, both credits (20% combined) could be applied to the same property; this constituted a decrease in cost per gallon of alcohol of about $.11.

Another form of incentive consists of the income tax credit for blending or selling denatured 185-190 proof alcohol. In 1984, this tax credit was worth $.375/gal of 185 proof alcohol. On January 1, 1985, the credit increased to $.45 for alcohol of that proof; this constitutes an increase in fuel alcohol returns of approximately $.07/gal of alcohol. However, the higher credit only serves to slightly reduce the loss on each gallon of alcohol produced.

Clearly, neither the investment tax credits nor the 1985 increase in the income tax credit for blending or selling hydrous alcohol is sufficient (separately or combined) to make small-scale alcohol plants using fodder beets economically feasible. Current prices of petroleum based fuels and of the variable inputs used in small-scale alcohol plants do not combine to make use of fodder beets as an alcohol crop look promising at present.

Although cost estimates for hydrous alcohol derived from corn and from fodder beets are quite similar in their respective baseline cases, neither is presently feasible in small-scale plants. Moreover, various factors—including necessary crop production machinery investments and storage problems—make fodder beets appear even less promising than corn at the present time.

Large-scale plants producing tens of millions of gallons of alcohol annually from corn have generally proven to be more efficient than the kind of small-scale plants which we have focused on in our research at SDSU. Thus, it is reasonable to assume that large-scale alcohol plants using fodder beets could also produce at lower costs per gallon than we have found in our analysis of a small-scale plant. The findings reported in this bulletin confirm that fodder beets might be competitive with corn as an alcohol feedstock **if** storage were to permit year-round production, although small-scale plants appear uneconomic with either corn or fodder beets as the feedstock.

Two developments since 1984—the reference year for cost and return estimates in this study—require brief mention. One is the price outlook for corn. South Dakota corn prices for 1986 are likely to remain closer to $2.00/bu than to the $2.50/bu baseline case in our previous analyses of alcohol production from corn. This could make corn more favorable, relative to non-grain crops, as an alcohol feedstock. However, recent years' declines in land, machinery, and fuel costs could also reduce the costs of feedstocks such as fodder beets.

The second development is the decline in oil prices which occurred in early 1986. By March 1986, crude oil prices were roughly 50% lower than they were in 1984. If oil prices were to stay anywhere near their current, relatively low levels for the next few years, it would be very difficult for newly constructed alcohol plants to produce fuel that is economically competitive with petroleum-based fuels. This would be true regardless of the size of alcohol plant and type of feedstock being used.

Finally, it must be emphasized that costs reported in this bulletin for the kind of alcohol plant and process described may differ from costs for other kinds and sizes of alcohol plants. Also, care must be exercised in comparing the results of this analysis of fodder beets to results of our earlier studies of alcohol plants using corn. For one thing, SDSU's process for fodder beets is continuous, whereas alcohol production from corn at SDSU has involved a batch process. In addition, the feed byproduct from our fodder beet process is dry (only 5% moisture), whereas the byproduct from our corn process is high in moisture (70% moisture). Although the moisture differences have been accounted for in figuring byproduct values, differences in handling characteristics have not necessarily been fully reflected in the economic calculations.

Introduction

Several studies conducted over the past few years have focused on the use of corn as a feedstock for fuel alcohol (ethanol)[2] production. Economic studies at South Dakota State University (SDSU) have documented costs and returns for corn based alcohol production in small- or community-scale plants (Hoffman and Dobbs; Dobbs and Hoffman; Dobbs, Hoffman, and Lundeen). Those studies indicated that prospects are not good in the near future for profitable production of fuel alcohol from corn in small-scale plants.

Attention at SDSU has therefore increasingly shifted to possible alcohol feedstocks other than corn. A wide range of possible starch and sugar crops was explored through literature reviews and preliminary analyses (Dobbs, et al). Fodder beets and sweet sorghum were identified as meriting further study as potential alcohol feedstocks under South Dakota conditions. Preliminary processing and cost analyses already underway at SDSU (Gibbons, Westby, and Dobbs, 1984) indicated that fodder beets might be competitive with corn as an alcohol feedstock.[3] Whether use of fodder beets could actually be expected to result in more profitable small-scale fuel-alcohol plants required more detailed technical experimentation and economic analysis, however.

The study reported in this publication was undertaken to answer with greater confidence the question of how economically feasible fodder beet based alcohol production might be. Specific research objectives addressed in the study were the following:

1. to estimate costs of growing fodder beets under South Dakota conditions.
2. to determine the costs of processing fodder beets in a small-scale plant into 185-190 proof alcohol and a feed byproduct;
3. to determine the likely value of the feed byproduct (the high-protein feed remaining after the alcohol is removed);
4. to estimate the value of 185-190 proof alcohol; and
5. to combine this cost and return information ("1" through "4") to determine the probable economic feasibility of small-scale fuel alcohol production using fodder beets.

Findings for each of these objectives are reported in the following sections. More detailed findings and explanations of procedures are found in a Master of Science thesis at SDSU (Habash).

[2]The terms alcohol and ethanol are used interchangeably in this publication.

[3]We have also recently published findings of preliminary analyses of sweet sorghum as an ethanol feedstock (Gibbons, Westby, and Dobbs, 1986).

Costs of growing fodder beets

Fodder beet growing costs were estimated on the basis of several information sources, since only limited agronomic research has been conducted on fodder beets at SDSU. Various agronomic conditions and assumptions were specified to establish cost estimates used in the study.

Agronomic conditions and assumptions

Fodder beets have been cultivated in Europe as a forage crop for livestock feed, but only limited attention has been given to use of this plant as a potential alcohol crop. The fodder beet is a very close relative of the sugarbeet, but it has a larger root size, higher root yield per acre, and lower sugar content than the sugarbeet. Fodder beets were formed by a cross between two members of the beet family—sugarbeets and mangolds (SERI). Doney and Theurer (1980) suggest that fodder beet-sugarbeet hybrids may have potential as an alcohol fuel crop, provided that such hybrids produce 10% more fermentable sugar per acre than do locally comparable sugarbeet varieties. They feel that a long-term breeding program involving crosses between U.S. disease resistant sugarbeet varieties and good fodder beet varieties would be needed to develop the optimum "fuel beet".

Like sugarbeets, fodder beets might be restricted to cool, temperate climates, such as those in the north-central states and the Northern Plains in the U.S. (Dobbs, et al). Growing requirements for fodder beets are similar to those for sugarbeets. Planting usually starts as soon as possible after the last spring frost (Hayes). Harvest is about 5 to 6 months later, when roots are full grown (averaging about 1 foot in length).

Fodder beets are more resistant to late season frost than are sugarbeets. Therefore, they may be harvested in October and November (Hayes). In harvest operations, defoliators are first used to remove the green tops from the beet crowns. The green tops can be fed to livestock. Lifter machines then remove the beets from the ground and convey them to trucks driven alongside.

Fodder beets in the U.S. are highly susceptible to curly top disease and fairly susceptible to *Cercospora* leaf spot. A breeding program has been underway in Utah to produce varieties that are resistant to curly top disease and that have higher amounts of fermentable sugar than current hybrids (Doney and Theurer). Since sugarbeets have been bred to be resistant to curly top disease, it should be possible to develop this resistance in fodder beets.

Since beet crops are susceptible to soil nematodes, they are generally grown only once every 4 years in any given field. Above-ground crops are grown the other 3 years of the rotation.

Given the paucity of information on field operations for fodder beets under U.S. conditions, we have borrowed and adapted much information from experiences with growing and harvesting sugarbeets. Details of field operations which we assume would closely approximate ones for commercial fodder beet production in the Northern Plains region are found in Habash's thesis.

Production cost estimates

Production cost data were drawn from various sources. Swenson and Johnson's report (1984) on sugarbeet production costs in North Dakota and Minnesota was used extensively. Habash also visited sugarbeet growers in Minnesota in the summer of 1984 to discuss growing and harvesting practices. SDSU budget information (Allen) and an SDSU computer program called MACH1983 were used in estimating machinery and certain other input costs. Land and other production costs represent east-central South Dakota and 1984 price levels. It is assumed that the input levels represented by the costs would result in fodder beet yields of approximately 25 T/A.

Expected costs of producing fodder beets are shown in fixed and variable categories in Table 2. The fixed portion represents those costs that do not vary with levels of input and output. Depreciation, taxes and insurance, interest on machinery investment, farm overhead, real estate taxes, and land and management charges are examples. The variable portion consists of those costs that vary directly with levels of output. Examples are expenditures for fertilizers, beet seed, herbicides, insecticides, machinery labor, fuel and lubricants, crop insurance, and interest on operating capital.

Total production costs represent the sum of total fixed and variable costs. Total variable costs of production per acre were estimated to be $262.94, representing 60% of total production costs. Total fixed costs per acre, including land charges, were estimated to be $174.06, constituting 40% of total production costs.

According to these estimates, total costs are $437.00/A, or $17.48 (rounded to $17.50) per ton when yields are 25 T/A. (Keep in mind that the fodder beet growing practices and costs, as well as the yields, are here based on a synthesis of information from various sources and on several assumptions.)

Sugarbeets may require more intensive crop monitoring (with respect to fertilizer levels, insecticide and herbicide applications, etc.)—to obtain a beet composition that ensures ease of sugar recovery and crystallization—than do fodder beets. Hence, since our "expected" fodder beet production costs are based in part on sugarbeet production costs, actual costs might be slightly lower than our "expected" figures.

Table 2. Expected fodder beet production costs (assumed yield =25 T/A).

Description	*Cost/A ($)*	*Percentage of total costs*
Variable costs:		
Beet seed	47.44	10.86
Fertilizer	36.40	8.33
Herbicides	36.78	8.42
Insecticides	38.60	8.83
Machinery labor	15.36	3.51
Custom hauling	25.00	5.72
Fuel & lubricants	11.78	2.70
Machinery repairs	16.67	3.81
Crop insurance	15.28	3.50
Miscellaneous	7.11	1.63
Interest on operating capital (5% of $250.42)*	12.52	2.86
Total variable costs	262.94	60.17
Fixed costs:		
Machinery depreciation, ins., and taxes	39.19	8.97
Interest on machinery investment	27.84	6.37
Farm overhead	8.40	1.92
Real estate taxes (1% of $800)	8.00	1.83
Management charges (10% of $346.37)	34.63	7.92
Total fixed costs	118.06	27.02
Production costs/A	381.00	
Production costs/unit	15.24	
Land charges (7% of $800)	56.00	12.81
Total cost/A	437.00	100.00
Total costs/unit	17.48 (rounded to $17.50)	

*Equivalent of 12% interest/year, for 5-month time period.

Costs of processing fodder beets into alcohol and protein feed

Costs of processing fodder beets into alcohol were based on a continuous, solid-phase fermentation process. Preliminary work at SDSU indicated that this process might have considerable technical and economic promise for small-scale alcohol plants (Gibbons, Westby, and Dobbs, 1984). In making our cost estimates, some of the equipment and operating assumptions were based on pilot-scale equipment at the SDSU fuel alcohol plant. However, hypothetical scale-up of these processes and equipment was done to estimate costs for a larger production capacity, one of approximately 175,000 gal of fuel alcohol per year.

It should be noted that some of the equipment—such as the press, dryer, conveyors, beet storage, etc.—do not currently exist at the SDSU pilot plant. However, these types of equipment are commonly used in either alcohol plants or sugar processing plants and would not be difficult to obtain. Cost figures for these equipment items were estimated in ways to represent likely commercial plant situations as closely as possible.

Plant design

Figure 1 is a process-flow diagram depicting the major equipment items used in the continuous, solid-phase fermentation process examined in this study. Major components of the system are briefly described below, and additional detail is contained in Annex A. Discussions of the actual processes performed in each component of the system can be found in Habash and in Gibbons, Westby, and Dobbs (1984).

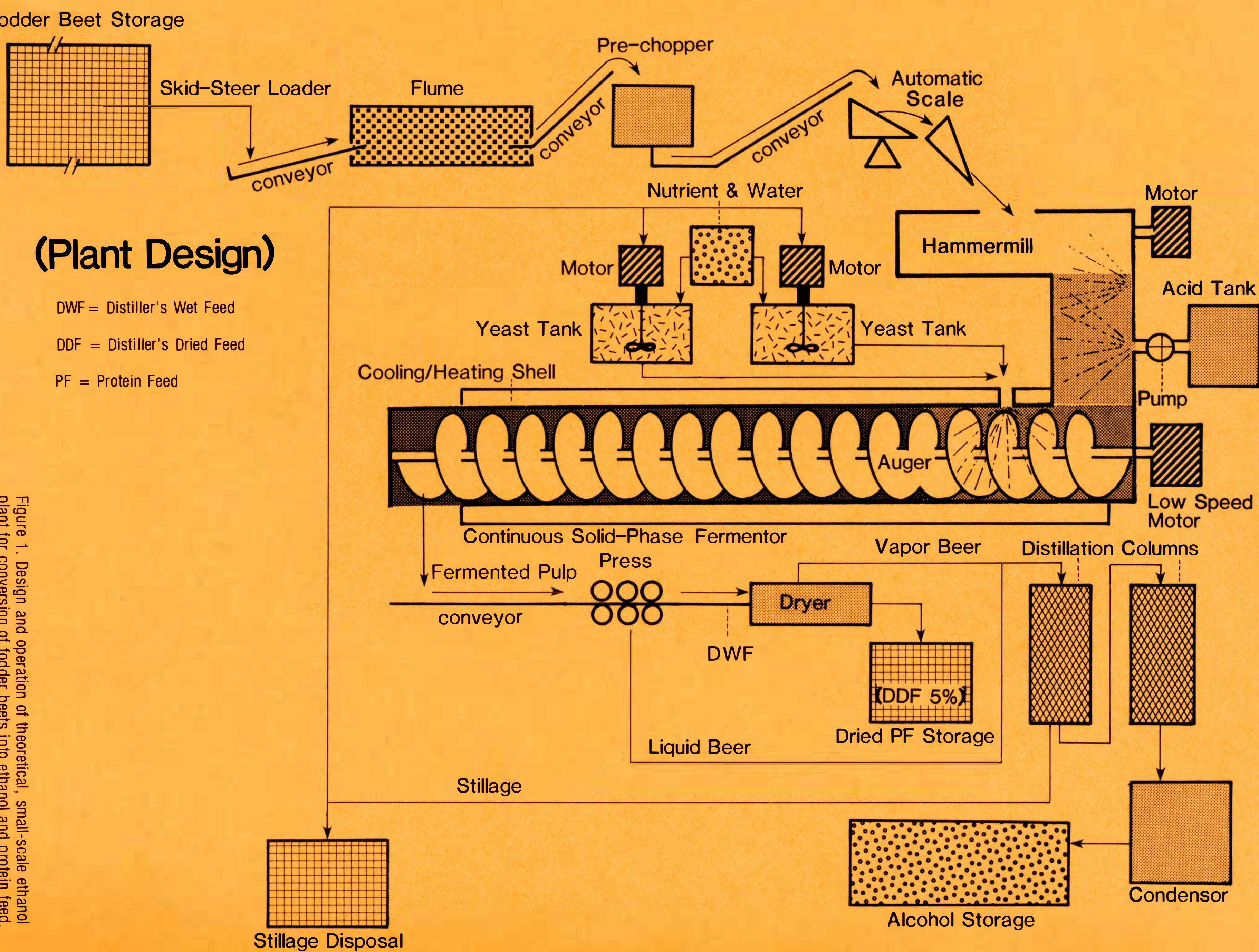

Figure 1. Design and operation of theoretical, small-scale ethanol plant for conversion of fodder beets into ethanol and protein feed. (Equipment items and tanks are not drawn in equivalent scale.)

Fodder beet handling system. The beet handling system is made up of four components—a fodder beet storage unit, a flume, an automatic scale, and a set of belted conveyors. The fodder beet storage unit is assumed to be located outside the fuel alcohol building, and a skid-steer loader would be used for transporting beets from storage to the conveyor.

Fodder beet preparation system. The beet preparation system consists of a pre-chopper, hammermill, and acid tank.

Continuous, solid-phase fermentor. The fermentor system at SDSU's fuel alcohol plant is constructed entirely of mild steel. In an actual commercial plant, such a system is likely to be constructed of stainless steel—to withstand the high acid levels needed to prevent contamination of beet pulp during fermentation. In addition, two yeast tanks are required to provide a constant stream of yeast broth to inoculate acidified beet pulp.

Press and dryer. A press is used to remove as much free liquid (beer) as possible from the fermented pulp. The dewatered pulp, referred to as Distillers Wet Feed (DWF), is then dried to 5% moisture in a rotary drum dryer, forming the Distillers Dried Feed (DDF) byproduct. Liquid beer from the press and beer vapors from the dryer are routed to the distillation columns for alcohol recovery.

Distillation columns and condenser. Distillation involves evaporating the alcohol from the alcohol-water mixture (beer). After that, the ethanol vapors are passed through the condenser. At the SDSU plant, the end product is 185-190 proof alcohol.

Ethanol storage unit. Storage for the alcohol must be provided. Prior to storage, the alcohol must be denatured according to government requirements (U.S. Department of the Treasury, Bureau of Alcohol, Tobacco, and Firearms).

Other items of equipment, such as pumps, motors, a steam boiler, a heat exchanger, and control equipment, are also needed to perform necessary functions.

Costs of production

Costs of producing alcohol from fodder beets were estimated by utilizing the same budgeting framework that was previously employed at SDSU in economic analyses of corn-based alcohol production. Data for the cost analysis came in part from operation of the SDSU experimental fuel alcohol plant. In some cases, costs were adjusted and adapted from the earlier work on corn at SDSU (Hoffman and Dobbs). More detail on the cost estimation procedures are found in Annexes A and B.

The cost estimates represent a small-scale fuel alcohol plant, capable of producing 175,074 gal of 185-190 proof alcohol and 1,030 T of DDF annually. Annexes C and D contain explanations of the alcohol and feed byproduct production estimates.

The cost elements for alcohol production are arranged in this report into two major groups, as follows: (1) capital and other fixed costs; and (2) operating costs.

Capital and other fixed costs. Capital costs reflect the investment costs that are amortized and recovered over the life of the plant. A lifetime of either 5 or 10 years was assumed for each piece of equipment, and 20 years was assumed to be the useful life for the building, skid-steer loader, and storage facilities. Amortization periods in our analysis were based on useful lives, rather than on depreciation periods defined by tax law. The salvage value for all capital components was expected to be zero at the end of the amortized lives. A 15% interest rate (base case) was used in amortizing the capital costs. Annual amortized costs were divided by the total annual denatured 185 proof alcohol output (175,074 gal) to obtain costs per gallon.

Capital and other fixed cost data were derived in part from the study done by Dobbs and Hoffman, in which 1981 cost data were used. Those cost data were adjusted, using the Producer Price Index (PPI), to reflect changes in prices between 1981 and 1984. Other cost estimates (such as for the solid-phase fermentor, press, dryer, flume, and other equipment) were made after obtaining information through contact with different suppliers and industry personnel.

As shown in Table 3, total capital and other fixed costs amounted to $97,493 annually—with assumptions of 175,074 gal of 185 proof alcohol, 1,030 T of DDF, a 15% interest rate, $17.50/T cost of fodder beets, and an alcohol yield of 21 gal/T of fodder beets. This is the so-called "base case". Sections A and B of Table 3 contain the initial capital costs, useful lives, annual amortized costs, and costs per gallon of denatured alcohol for each item.

The most costly items, on a per gallon basis, are as follows: (1) the solid-phase fermentor, at $.06/gal; (2) the press, at $.04/gal; (3) the dryer, at $.06/gal; (4) insurance, at $.09/gal; (5) maintenance, at $.07/gal; and (6) real property taxes, at $.05/gal. These items have annual amortized costs estimated to be $65,962, representing 68% of total capital and other fixed costs, or $.39/gal of alcohol. Other costs come to $31,531 per year (32% of total capital and other fixed costs), or $.16/gal of alcohol. Capital and other fixed costs therefore sum to $.55/gal of 185 proof denatured alcohol.

It should be emphasized that the cost of $50,000 for the solid-phase fermentor is an estimate. The actual cost of building or contracting for such a fermentor might turn out to be substantially different. Also, the reader should keep in mind that the process considered here for fodder beets uses both a press ($37,000 estimate) and a dryer ($56,000 estimate); our previously analyzed process for corn (Hoffman and Dobbs) used only a centrifuge (costing around $36,000 in 1984 dollars). Thus, comparisons between our fodder beet and corn processes should be viewed with these differences in mind.

Operating costs. Operating costs are those costs associated with the use of variable inputs for plant operation (such as beets, chemicals, fuel, labor, and other supplies). An interest charge—15% for 3 months per year—on operating capital was charged to reflect the opportunity or borrowing cost for outlays for different input purchases. The annual costs of the various inputs are summed to obtain the value of the inputs invested annually in alcohol production. Dividing annual operating costs for each item by total annual alcohol output results in the estimated cost per gallon of alcohol.

Total operating costs were estimated to be $322,387 annually for the base case, or $1.84/gal of alcohol. Section C of Table 3 contains the number of units of each item required per gallon of non-denatured alcohol, the cost per unit, the cost per gallon of non-denatured alcohol, the annual cost, and the cost per gallon of denatured alcohol.

The most costly items, on a per gallon basis, are the following: (1) beets, at $.79/gal; (2) sulfuric acid, at $.15/gal; (3) labor, at $.61/gal; and (4) interest on operating capital, at $.07/gal. These items constitute a combined annual estimated cost of $282,703 (88% of total operating costs), or $1.62/gal of alcohol. Other items (such as yeast, electricity, water, fuel, and denaturant) are estimated to be $39,684 (12% of total operating costs), or $.22/gal of alcohol.

Cost summary. Total production costs are estimated by adding the capital and other fixed costs to operating costs. Capital and other fixed costs were estimated to be $97,493 annually, or $.55/gal of alcohol. Operating costs amounted to $322,387 annually, or $1.84/gal of alcohol. Therefore, total production costs would be $419,880 per year, or $2.40 (rounded)/gal of 185 proof denatured alcohol. This cost estimate was derived under the base case set of assumptions. Some of these assumptions were altered in sensitivity analyses, the results of which are presented later in this report.

It is important to note that the $2.40 estimate contains no allowance for byproduct credits. Valuation of the feed byproduct is covered in the next section.

Table 3. Fuel alcohol production costs (175,074 gal of 185 proof alcohol, including denaturant, and 1,030 T of DDF, 15% interest rate, $17.50/T of fodder beets, alcohol yield of 21 gal/T of fodder beets).

Item	(1) Capital cost ($)	(2) Useful life (yr)	(3) Annual amortized cost at 15% interest rate ($)	(4) Cost/gal of denatured alcohol (3÷175,074) ($)
A) Capital costs				
Coal-fired boiler	28,295	10	5,638	0.032
Solid-phase fermentor	50,000	10	9,963	0.057
Flume	2,050	10	408	0.002
Pre-chopper	5,000	10	996	0.006
Automatic scale	3,500	10	697	0.004
Hammermill	2,200	10	438	0.003
Conveyors	4,550	10	907	0.005
*Alcohol storage	5,556	10	1,107	0.006
*Heat exchanger	1,945	10	388	0.002
Feed byproduct storage	2,400	20	383	0.002
*Water softener (2)	1,111	5	331	0.002
*Building	28,894	20	4,616	0.026
Press	37,000	10	7,372	0.042
Dryer	56,000	10	11,158	0.064
Yeast tanks	3,700	10	737	0.004
*Distillation columns	21,115	10	4,207	0.024
*Temperature meters	333	10	66	0.000**
*Pressure gauges	55	10	11	0.000**
*Pumps and motors	2,611	5	779	0.004
*Pipes and accessories	1,111	5	331	0.002
*Flow meters	167	10	33	0.000**
*Differential pressure cells	278	10	55	0.000**
*Cooling tower	4,334	10	864	0.005
*Laboratory	3,334	10	664	0.004
*Skid-steer loader	22,226	20	3,551	0.020
Beet storage	24,073	20	3,864	0.022
Plastic sheets	400	1	460	0.003
Subtotal capital costs (A)	312,238		60,024	0.341

	(1)	(2)	(3)	(4)
B) Other fixed costs				
Insurance 5%	—		15,612	0.089
Maintenance 4%			12,490	0.071
Real property taxes 3%	—		9,367	0.053
Subtotal other fixed costs (B)	—		37,469	0.213
Total capital and other fixed costs (A+B)	312,238		97,493	0.554

(Table 3, continued)

(1) Item	(2) Units/gal of non-denatured alcohol	(3) Cost/ unit ($)	(4) Cost/gal of non-denatured alcohol (2 x 3)	(5) Annual costs ($) (4x166,320)	(6) Cost/gal of denatured alcohol ($) (5÷175,074)
C) Operating costs					
Beets	0.0476 T	$17.5/T	0.833	138,600	0.792
Sulfuric acid	10 oz	$0.016/oz	0.160	26,611	0.152
Ammonium hydroxide	.25 oz	$0.011/oz	0.003	499	0.003
Yeast	.021 lb	$1.20/lb	0.024	3,992	0.023
Electcricity	1.28 kwh	$ .056/kwh	0.073	12,141	0.069
Fuel (10,000 btu/lb coal)	1.95 lb	$49/T	0.048	7,983	0.046
Water	7.6 gal	$1.67/1000 gal	0.013	2,116	0.012
Labor	—	—	—	105,840	0.605
*Lab tests	—	—	—	2,475	0.014
Denaturant	.053 gal	$1.19/gal	0.063	10,478	0.060
Interest on operating capital (15% for 3 mo/yr)		—	—	11,652	0.067
Subtotal operating costs (C)				322,387	1.843
Total production costs (A+B+C)				419,880	2.397 (rounded to $2.40)

*Items marked by an asterisk were derived from Hoffman and Dobbs; the 1981 data in that publication were adjusted to 1984 price levels using the Producer Price Index (PPI).

**Annual cost per gallon is so small that it rounds to zero at three decimal places.

Feed byproduct returns

Small- or community-scale alcohol plants need to generate a substantial return from their feed byproducts if they are to have any chance of being economically feasible. Since it is generally not possible to economically capture and market the carbon dioxide byproduct from small-scale plants, as it is from very large-scale operations, our analysis of byproduct returns is confined to animal feeds. We assume that the feed byproduct of a fodder beet-based alcohol plant might be fed to beef or dairy animals in the local area.

Method of analysis

The first step in estimating feed byproduct values is to determine the form and quantity of the byproduct. Fermented pulp with 88-90% moisture and 8-10% alcohol is obtained from SDSU's continuous, solid-phase fermentation process. In a commercial alcohol plant, that fermented pulp would be mechanically pressed to remove as much free liquid (beer) as possible. The resulting DWF (60-75% moisture) would be dried in a rotary drum dryer to approximately a 5% moisture level. The free liquid (beer) from the press and the ethanol vapors from the dryer would then be injected into the distillation columns.

About 260 lb of this 95% dry matter byproduct (DDF) can be obtained for each ton of fodder beets that is processed into alcohol. In an alcohol plant producing about 175,000 gal of denatured alcohol (or around 166,000 gal before denaturing) annually, about 1,030 T of DDF could be produced each year (refer to Annex D).

It is worth noting here that the feed byproduct in our previous analyses of corn-based alcohol production (Dobbs and Hoffman; Hoffman and Dobbs) was a higher moisture (70% moisture) product. Hence, handling and storage properties and values per ton of byproduct were quite different than are reported here for the fodder beet byproduct.

Determining the nutrient content of the DDF derived from fodder beets was the next step in ascertaining byproduct values. The following values were estimated for DDF when figured on a 100% dry matter basis: (1) crude protein = 20.4%; (2) digestible protein = 6.3%; (3) Total Digestible Nutrients (TDN) = 79.1%; (4) roughage = 5.5%; and (5) fiber = 24.2% (Gleaves, et. al; Habash).

The next step was to determine the feeding value of DDF by using the AGriculture computer NETwork (AGNET) system. The DDF was valued through the use of a computerized model called "Feedmix" in this system. The "Feedmix" program is designed for least-cost feed formulation—finding the combination of feeds which will meet ration requirements at the lowest total cost. Byproducts of fuel alcohol plants tend to come into livestock rations primarily as protein sources in this least-cost approach.

Feed byproduct research at SDSU in 1981-82 focused on the use and marketing costs for Distillers Wet Grain (DWG) from corn in beef and dairy rations (Dobbs and Hoffman; Hoffman and Dobbs). Livestock assumptions similar to those used in that earlier research were used in the present study.

Based on those assumptions (Habash), we selected a combination of possible feeds to be available to meet the requirements of the beef and dairy rations. Moisture percentages and prices were determined for each feed. Finally, rations were selected, taking into account cattle weight and Average Daily Gain (ADG) per head. The feed prices, for other than the DDF, were based on mid-year 1984 prices.

In this study, the following two price levels were considered: (1) baseline prices and (2) higher prices. Table 4 shows all selected feeds, moisture percentages, and baseline and higher prices utilized for the beef and dairy rations.

By entering a fairly high price for DDF into the Feedmix program and then successively lowering the price, we can determine the marginal value of DDF at different quantity levels. In other words, this "parametric programming" approach determines the supposed willingness-to-pay price for successive increments of DDF as the proportion of DDF in the ration increases. In effect, a demand curve for DDF in rations of specific livestock types and sizes can thereby be traced out. For any given quantity of DDF, there is a corresponding price on that demand curve. If we specify the proportion of the ration that DDF is expected to constitute, we are thereby picking a quantity and associated price (or value) of the DDF.

Table 4. Selected feeds, percent moisture, and price levels.

Feed name	*% Moisture*	*Lb/unit*	*Baseline price[1] ($)*	*Higher price[2] ($)*
Corn	14	56/bu	2.75	3.00
Barley	11	48/bu	2.35	—
Corn silage	65	2,000/T	20.00	30.00
Alfalfa hay (mid-bloom)	10	2,000/T	45.00	55.00
Soybean meal solvent**	11	2,000/T	200.00	—
Oats	11	32/bu	1.65	—
Distillers dried feed	5	100	—	—

[1]Source: Aanderud, et al. These prices represented SDSU Extension farm management planning prices for the 1984 calendar year.

[2]These are subjectively adjusted prices for some of the key feeds in typical livestock rations.

**Contains 44% crude protein.

Value as beef cattle feed

The Feedmix program was run with both "baseline" and "higher" prices for alternative feeds (Table 4) to determine price-quantity relationships for DDF from fodder beets fed to beef animals. An earlier SDSU publication has indicated that distillers feed for growing and finishing cattle should be limited to 2-3 lb/day (Kuhl, Voelker, and Schopper). Following that guideline, DDF in beef rations was estimated to have a value of $133 to $149/T, depending on whether the baseline or the higher price assumptions are used for alternative feeds. DDF constitutes 8-10% of the beef ration at 2-3 lb/head/day.

Value as dairy cattle feed

Results of the Feedmix analysis for DDF as a dairy cattle feed indicated values of $58.20 and $94.20/T in the cases of baseline and higher prices, respectively, of alternative feeds. It was assumed that DDF would provide about 3 lb/head/day of the dairy ration, or 12-13% of the total.

Transportation costs

Transportation costs involved in marketing DDF for local on-farm use depend on (1) the number of farms required to consume the annual output of DDF and (2) the number of farms in the surrounding territory that are willing and able to use DDF in lieu of other protein supplements. Beef and dairy farms were the only assumed users of DDF in this study.

For simplicity, beef fattening farms were used as the basis for calculating transportation costs associated with the delivery of DDF from the hypothetical alcohol plant to local farms. In addition, we assumed that the hypothetical small-scale plant is located in the central part of Moody County in southeastern South Dakota. Data indicate that Moody County had an area of 528 square miles and 237 beef fattening farms in 1978 (U.S. Department of Commerce, Bureau of the Census).

To find the number of farms required to consume the total annual output of the feed byproduct from the alcohol plant, data concerning (1) the number of beef animals per farm, (2) the total daily consumption per head, and (3) the total annual output of DDF had to be used. The 1978 South Dakota Agricultural Census indicated that an average-sized Moody County beef fattening farm has 81 head. We assume total daily consumption of DDF (5% moisture) per head of fattening beef to be 3 lb. The hypothetical alcohol plant is capable of producing 175,000 gal of 185-190 proof alcohol and 1,030 T of DDF (5% moisture) per year.

Given the preceding data and assumptions, the total annual consumption per farm is calculated as follows:

Annual consumption per farm = (daily consumption/head) (number of head/farm) (number of days/year in the feedlot)

Therefore, annual consumption per farm = (3 lb/head/day) (81 head/farm) (145 days/yr in feedlot) = 35,235 lb of DDF per farm per year, or 17.62 T. As a result, the total number of farms needed to consume the 1,030 T of DDF per year would be 59 farms (1,030 T ÷ 17.62 = 59).

Costs of transporting DDF to these 59 farms were estimated by using travel routing and budgeting procedures developed previously in the study by Dobbs and Hoffman. The resulting marketing territory for DDF—assuming the DDF is utilized on one of every two beef farms located closest to the hypothetical alcohol plant—is shown in Figure 2. Costs of delivering the DDF to beef farms within this marketing territory come to $0.11/gal of alcohol.[4]

Byproduct value summary

Transportation costs for DDF were estimated to total $0.11/gal of alcohol in the case of beef. We assume that figure would be roughly applicable for dairy, as well. Feed byproduct values were estimated for DDF fed to beef and dairy cattle using (1) baseline and (2) higher prices for other potential feeds in the rations. In the case of the baseline prices, the DDF value was estimated to be $133/T in beef rations and $58.20/T in dairy rations. However, with higher prices, the DDF value was estimated to be $149/T in beef rations and $94.20/T in dairy rations.

An average of all four estimates comes to $108.80/T. With 1,030 T of DDF produced in the alcohol plant, total annual revenue would be $112,064 (1,030 × $108.80), or $.64/gal of alcohol ($112,064 ÷ 175,000/gal).

Since DDF has a very low moisture percentage (i.e., 5%), it was assumed that there is no need to add any type of preservative to extend the DDF storage time without spoilage. Therefore, the feed byproduct returns were calculated as follows:

Return on feed byproduct = average value of feed byproduct in livestock rations - transportation costs
= $.65 - .11
= $.53/gal of alcohol

The estimated feed byproduct return is therefore $.53/gal of denatured alcohol. That return can be used in calculating the **net** production cost for alcohol. This is done in Table 5. The net cost, after allowing for the byproduct credit, is shown to be $1.87/gal of alcohol.

[4]Fixed and operating costs associated with DDF delivery are found in Annex E.

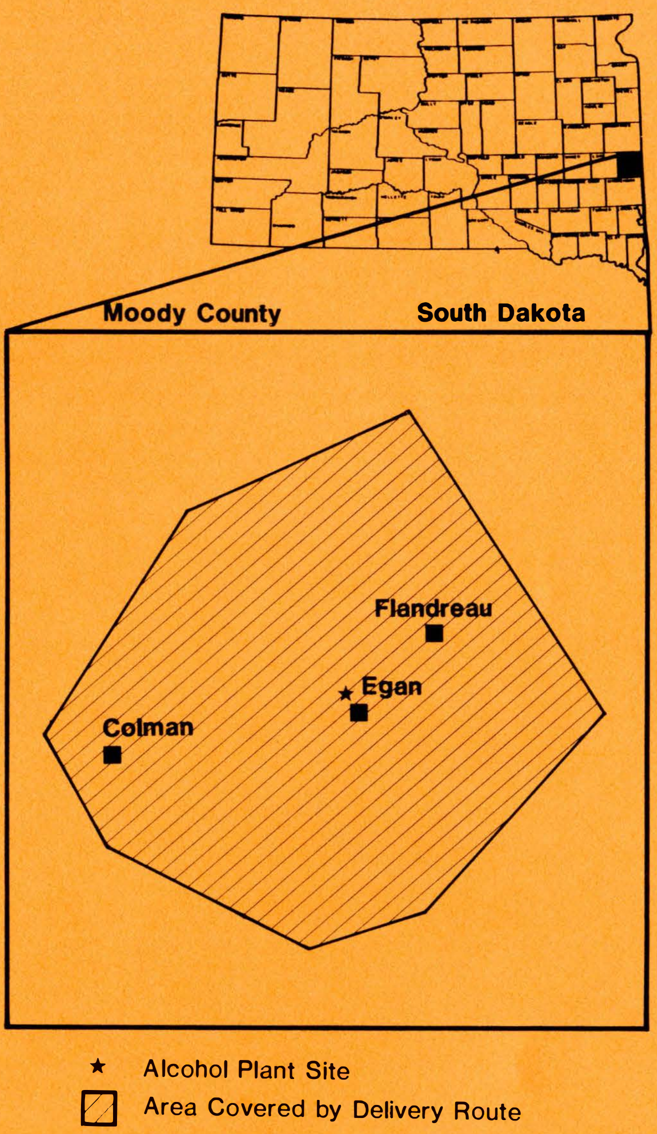

Figure 2. Marketing territory encompassing DDF delivery to 59 beef fattening farms, assuming every other beef farm closest to the alcohol plant utilizes DDF.

Table 5. Fuel alcohol production costs net of byproduct returns (175,074 gal/yr alcohol plant).

Item	*Annual amortized cost ($)*	*Cost/gal of denatured alcohol ($)*
Total production costs[1]	419,880	2.397
Less feed byproduct credit	92,814	0.530
Net production cost/gal of denatured alcohol	327,066	1.867 (rounded to $1.87)

[1]Source: Taken from Table 3.

Fuel alcohol returns

Returns for the fuel alcohol product in this study were based on 185 proof material, which would generally be expected from a plant like that at SDSU. It was assumed that the fuel would be used in equipment on area farms. The method of valuation, based on the approach used previously by Dobbs and Hoffman, accordingly considered the farmer cost of fuels likely to be displaced by ethanol.

Method of analysis

Returns were estimated by determining (1) tractor modification costs needed to utilize ethanol, (2) cost savings on conventional fuel that would be made possible by using ethanol, (3) amounts of ethanol likely to be used per modified tractor and per farm, and (4) costs of delivering fuel from a community-scale alcohol plant to area farms. All of these estimates were combined to arrive at an estimated return per gallon of ethanol.

Returns estimates

We assumed that the ethanol would be used in gasoline and diesel engine tractors. As in the case of previous work at SDSU (Dobbs and Hoffman), we also assumed that ethanol can be substituted for gasoline in farm tractors at a ratio of 1:1.65 and for diesel fuel in farm tractors at a ratio of 1:1.54. This means, in other words, that 1.65 gal of ethanol are required to replace 1 gal of gasoline and 1.54 gal of ethanol are required to replace 1 gal of diesel fuel. From these ratios, one could estimate the gross value of ethanol used with both gasoline and diesel engines.

In calculations presented here, however, it is assumed that the on-farm use of ethanol is only in one gasoline tractor per farm. The amortized annual cost of converting a gasoline tractor to run on ethanol was estimated to be $89. Dobbs and Hoffman's earlier study indicated that the potential annual fuel alcohol use on an average-sized farm in Moody county would be about 883 gal of 185 proof alcohol, if 25% of each farm's gasoline consumption were replaced by 185 proof alcohol. Spreading the $89 annual tractor conversion cost over that many gallons results in a $.10/gal conversion cost.

The tax-adjusted retail price of gasoline at the farm level in South Dakota in mid-1984 was approximately $.97/gal ($1.19 minus $.22 in state excise tax rebates and federal income tax credits available to farm users of gasoline). If it takes 1.65 gal of ethanol to replace 1 gal of gasoline in farm tractor use, then the replacement value of ethanol would be $.59/gal ($.97 ÷ 1.65 = $.59).

The assumed site of the hypothetical fuel alcohol plant is in the central part of Moody County, in southeastern South Dakota. The plant is assumed to be capable of producing 175,074 denatured gallons of 185 proof alcohol per year. Agricultural Census data indicate that Moody County had 782 farms as of the late 1970s, an average of three farms for each 2 square miles of territory (Dobbs and Hoffman). If 883 gal of ethanol were utilized per farm, it would take 198 farms to utilize the output of the 175,074 gal/yr plant considered here. This would involve a market distribution area of about 132 square miles, shown in Figure 3.

Fuel delivery costs were based on the lowest possible delivery mileage. A set of assumptions was made to satisfy this condition (Dobbs and Hoffman), including the following:

1. a bulk gas truck with a tank capacity of 2,500 gal is used;

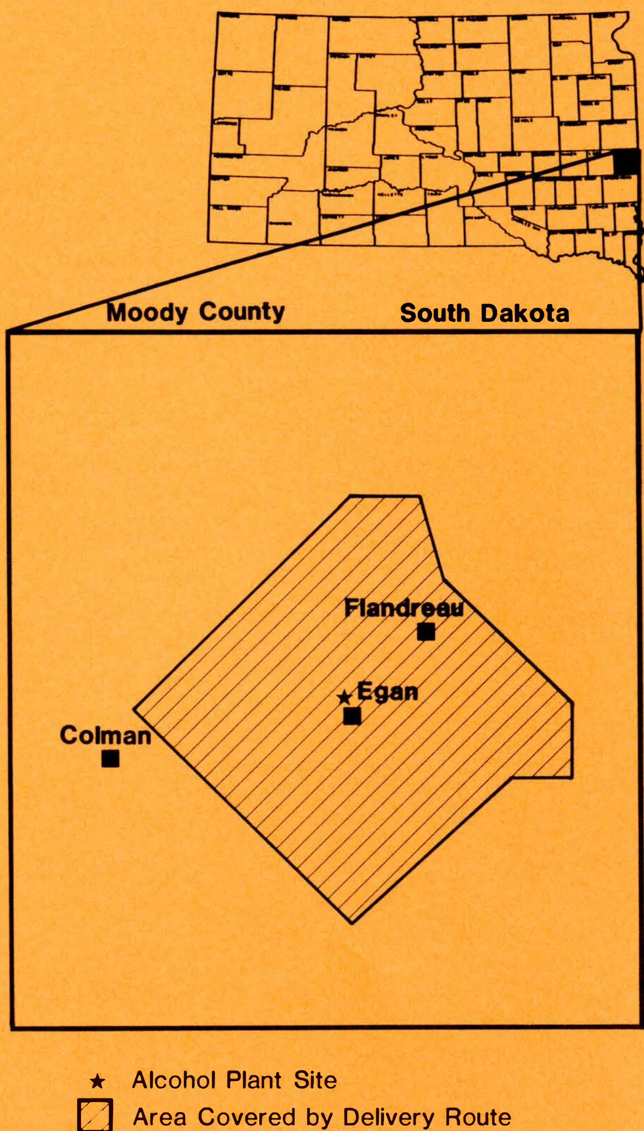

Figure 3. Marketing territory encompassing fuel alcohol delivery to the 198 farms nearest the alcohol plant.

2. daily deliveries, as scheduled, would supply 400 gal of alcohol to each of 12 farms;
3. fuel alcohol would be delivered twice a year to each of the 198 farms. A third trip would be made to supply the remaining 83 gal to each farm. Thus, deliveries would be as follows:

(198 farms) (2 trip/yr) (400 gal/trip) = 158,400 gal
(198 farms) (1 trip/yr) (83 gal/trip) = 16,434 gal
Total = 174,834 gal

Total deliveries (i.e., 174,834 gal/yr) round up to total alcohol output (i.e., 175,074 gal/yr).

Total alcohol delivery mileage per year was calculated to be 1,093 miles. Based on the routing schedule and this delivery mileage, and using a delivery truck budget format developed earlier by Dobbs and Hoffman, costs of delivery were estimated to be $.03/gal of alcohol.[5]

An income tax credit is available to individuals using straight (unblended) alcohol, as would be the case with farmers using hydrous alcohol from a community-scale plant. This credit was $.375/gal of 150 to 189 proof alcohol in 1984 and increased to $.45/gal in 1985 (Dobbs). We assume here that competitive forces would result in farmers passing the full credit through to alcohol producers in the form of higher prices paid for alcohol than would be paid in the absence of the credit. In 1984, this would have meant an additional $.375/gal paid for 185 proof alcohol.

Although the income tax credit for use of alcohol is scheduled to expire at the end of 1992, we have included the credit for the entire useful life of an alcohol plant in our analysis.

The fuel alcohol net return estimate can be arrived at by adding all costs and returns based on the assumptions mentioned above. The resulting equation is as follows:

Return for ethanol = replacement value of ethanol − engine conversion cost − fuel delivery cost + income tax credit

Calculations are as follows when ethanol substitutes for 25% of the gasoline used annually on a typical eastern South Dakota farm.

1. Replacement value of ethanol = the value per gallon of 185 proof alcohol as it replaces gasoline ($.59).
2. Engine conversion cost = amortized annual cost of modifying a gasoline engine to run on alcohol ($89 ÷ 883 gal of alcohol/farm = $.10).
3. Fuel delivery cost = the total cost of delivering fuel alcohol to the farms that use it ($.03).
4. Income tax credit = persons using fuel alcohol will be entitled to a federal income tax credit. In 1984, this credit was worth $.375/gal of 185 proof alcohol.

Putting these data together, the return per gallon of ethanol is calculated as follows:

Return on ethanol = $.59 − $.10 − $.03 + $.375 = $.835, which rounds to $.84/gal.

The return would have been $.07/gal higher in 1985, or $.91/gal, due to the higher income tax credit in effect then.

Economic feasibility prospects

The economic feasibility of fodder beets as a fuel alcohol crop was examined under a "baseline" set of assumptions, as well as under several alternative sets of assumptions.

Feasibility under baseline conditions

"Base case" conditions are those described in each step of the analysis up to this point. They include the following: (1) an alcohol yield of 21 gal/T of fodder beets; (2) a fodder beet cost of $17.50/T; (3) a 15% interest rate in the cost analysis; (4) a value for the feed byproduct (DDF) of $108.80/T; and (5) a permissible storage life for fodder beets of up to 12 months prior to processing.

Total capital and operating costs in the base case were shown in Table 3 to be $419,880/yr, or $2.40/gal of denatured alcohol. Base case returns on the DDF byproduct, net of transportation costs, were $.53/gal of alcohol. Returns on alcohol under 1984 (base case) tax conditions were $.84/gal of alcohol—after subtracting for costs of transporting the fuel. Returns net of costs can be derived from this data with the following formula:

Returns net of costs = returns on ethanol − costs net of product credit

where:

1. Costs net of byproduct credit = costs of producing the ethanol & feed byproduct − returns on feed byproduct

and

2. Returns on on ethanol = replacement value of ethanol − engine conversion cost − fuel delivery cost + income tax credit
3. Returns on feed byproduct = value of feed byproduct in livestock ration − transportation cost
4. Costs of producing ethanol and feed byproduct = costs before deduction of feed byproduct credits

In this base case, net returns per gallon for the alcohol plant using fodder beets can therefore be determined as follows:

Costs net of byproduct credit = $2.40 − $.53 = $1.87/gal
Returns net of costs = $.84 − $1.87 = −$1.03/gal

[5]Fixed and operating costs associated with fuel alcohol delivery are found in Annex F.

The results indicate a loss of more than $1.00/gal of alcohol produced under baseline conditions. Net losses would have been slightly less in 1985, since the income tax credit was $.07/gal higher at that time than in 1984. Recomputed returns net of costs would be as follows:

Returns net of costs = $.91 − $1.87 = − $.96/gal

Sensitivity analyses

Several of our base case assumptions were tested for their effect on the feasibility findings. "Sensitivity" analyses were conducted by varying the following cost component assumptions, one at a time: (1) the potential alcohol yield; (2) the cost of fodder beets; (3) the interest rate; (4) the value of the feed byproduct; and (5) the storage period for fodder beets.

Alcohol yield. The alcohol yield in the base case was assumed to be 21 gal of 185 proof alcohol per ton of fodder beets. However, preliminary trials at SDSU's fuel alcohol plant have indicated that lower and higher alcohol yields are possible in some cases. A 10% increase over the baseline alcohol yield of 21 gal would increase the yield to 23 gal/T of fodder beets. A 20% reduction from the baseline alcohol yield would decrease the alcohol yield to 17 gal/T of beets.

The impacts on costs of increasing and decreasing the alcohol yield to 23 and 17 gal/T of fodder beets, respectively, are shown in Table 6. Annual amortized capital and other fixed costs were assumed to remain constant, while operating costs were reduced for operations with an alcohol yield of 17 gal/T and increased for operations with an alcohol yield of 23 gal/T. This is attributed to the fact that less gasoline is required annually to denature the lower annual alcohol output and more gasoline is needed annually to denature the higher annual alcohol output. Also, certain other varible costs, including interest on operating capital, would be lower for a reduced alcohol yield and higher for an increased alcohol yield.

The annual production costs net of feed byproduct credit were estimated to be $1.87 in the baseline case, when alcohol yield is 21 gal/T of fodder beets. However, if the alcohol yield were to increase to 23 gal/T, total production costs would be $425,234 annually, or $1.74/gal of denatured alcohol **net** of the feed byproduct credit. This is a $.13 decrease in net per gallon cost from the baseline case. In turn, if the alcohol yield were to fall to 17 gal/T, total production costs would be $407,209 annually, or $2.21/gal of denatured alcohol net of the feed byproduct credit—a $0.34 increase in the per gallon net cost, compared to the baseline case.

Cost of fodder beets. Total production costs for fodder beets in the baseline case were shown in Table 2 to be $437/A, or $17.50/T when yields are assumed to be 25 T/A. Based on that, the cost of fodder beets per gallon of alcohol was estimated to be $.79 (Table 3), representing about 43% of the total annual operating costs per gallon of alcohol. A 20% change (higher and lower) in the cost per ton of fodder beets results in $21 and $14 per ton beets.

Land charges ($56/A) make up roughly 13% of the production costs shown in Table 2. Land values have been falling in South Dakota since early 1982. In fact, the $800/A land value on which the land charge in Table 2 was based may not have reflected the extent to which land values had already fallen by mid-1984. Since outright land sales are limited in the currently depressed market, it is difficult to state accurately how much land values have fallen by early 1986 in any given geographic area.

However, suppose for the sake of analysis that land values in east-central South Dakota have fallen all the way to $400/A. This would result in a land charge of $28/A (7% of $400/A), compared to $56/A in Table 2. Total costs of growing fodder beets would then be $409/A, or $16.36/T of fodder beets. This is 6% lower than if land had remained at $800/A.

The impacts on alcohol costs of varying the cost per ton of fodder beets are shown in Table 7. Annual amortized capital and other fixed costs were assumed to be constant. Operating costs were increased to $351,147 annually when the price of fodder beets was assumed to be $21/T, resulting in a cost of $2.03/gal of denatured alcohol net of the feed byproduct credit; this is a $0.16 increase in per gallon costs, compared to the baseline case. In turn, operating costs were

Table 6. Sensitivity of per gallon costs of 185 proof alcohol to changes in alcohol yield/T of fodder beets.

Alcohol yield/T of fodder beets (gal)	*Annual amortized capital and other fixed costs ($)*	*Annual operating costs ($)*	*Total production costs ($)*	*Annual denatured alcohol production (gal)*	*Total cost/gal of denatured alcohol ($)*	*Cost/gal of denatured alcohol net of feed byproduct credit ($)*
17	97,493	309,716	407,209	141,726	2.74	2.21
21*	97,493	322,387	419,880	175,074	2.40	1.87
23	97,493	328,530	426,023	191,747	2.27	1.74

*Denotes baseline case.

decreased to $292,628 annually when fodder beets were priced at $14/ton, resulting in a cost of $1.73/gal of denatured alcohol net of the feed byproduct credit; this is a $0.14 decrease from per gallon costs in the baseline case.

Table 7. Sensitivity of per gallon costs of 185 proof alcohol to changes in fodder beet cost/T.

Cost of fodder beets/T ($)	*Annual capital and other fixed costs ($)*	*Annual operating costs ($)*	*Total production costs ($)*	*Cost/gal of denatured alcohol net of feed byproduct credit ($)*
14	97,493	293,628	391,121	1.73
17.5*	97,493	322,387	419,880	1.87
21	97,493	351,147	448,640	2.03

*Denotes baseline case.

Interest rate. The interest rate determines (1) the amortization factor at which capital costs are amortized and (2) the charges for operating capital. In the baseline analysis, a 15% annual interest rate was applied. However, by varying the interest rate to 10%, 20%, and 30%, net costs per gallon of alcohol were changed to $1.78, $1.96, and $2.16, respectively. These results are shown in Table 8.

Table 8. Sensitivity of per gallon costs of 185 proof alcohol to changes in interest rates.

Interest rate (%)	*Annual capital and other fixed costs ($)*	*Annual operating costs ($)*	*Total production costs ($)*	*Cost/gal of denatured alcohol net of feed byproduct credit ($)*
10%	85,632	318,503	404,135	1.78
15%*	97,493	322,387	419,880	1.87
20%	110,214	326,272	436,486	1.96
30%	137,506	334,040	471,546	2.16

*Denotes baseline case.

Feed byproduct credit. The average economic value of feeding DDF to beef and dairy cattle was estimated to be $0.53/gal of alcohol (after deducting for costs of transportation) in the baseline case. However, the average economic value of DDF in beef rations was somewhat higher than its value in dairy rations. Results indicated that the average value of the feed byproduct credit (after transportation) would be $0.72 and $0.34 in beef and dairy rations, respectively.

The impacts of using these different feed byproduct credits are shown in Table 9. Net costs per gallon of alcohol range from $1.68 to $2.06 with the different byproduct credit assumptions.

Table 9. Sensitivity of the feed byproduct credit and net per gallon cost of alcohol to the type of ration in which DDF is fed.

Ration on which DDF value is based	*DDF value** ($)*	*DDF credit/gal of denatured alcohol*** ($)*	*Cost/gal of denatured alcohol net of feed byproduct credit ($)*
Dairy ration average	76.20/T	0.34	2.06
Beef and dairy ration average*	108.80/T	0.53	1.87
Beef ration average	141/T	0.72	1.68

*Denotes baseline case.
**Before deducting for transportation cost.
***After deducting for transportation cost.

Storage period. The storage period is perhaps the most critical aspect of processing sugar crops such as sweet sorghum, sugar cane, sugarbeets, and fodder beets into ethanol. In the baseline case, the storage life was assumed to be up to 12 months, to allow a continuous flow of raw material for the fuel alcohol plant. Generally, an 8-to 9-month storage life for properly insulated beets has been cited in the literature (Hayes). It must be noted that excessive extension of the alcohol production season is accompanied by a considerable reduction in the sugar yield. Thus, fodder beet storage problems require further intensive study to determine conditions under which the storage life might realistically be extended beyond 8 or 9 months.[6]

The sensitivity of per gallon costs of 185 proof alcohol to changes in the assumed storage period from 12 months (the baseline case) to 8 months is illustrated in Table 10. Annual capital and other fixed costs were assumed to remain constant. However, annual operating costs were decreased, due to the lower annual alcohol output (i.e., 124,497 gal) and to the use of smaller amounts of other variable inputs when beets are stored only 8 months and the processing period is reduced to that length of time. Operations requiring labor and other variable inputs were reduced to 32 weeks per year, compared to 45 weeks in the baseline case. A comparison of this case with the baseline case shows that a drop from 12 to 8 months in the

[6]Harvesting itself might extend over about a 1-month period. Thus, beets would perhaps only need to be stored for 11 months for an alcohol plant to be operated for 12 months of the year. Fresh beets could supply the plant during the 1-month harvesting period. Thus, storage of beets for 8 months would permit operation of a plant for 9 months. In our calculation, however, we have assumed that the alcohol plant operating period is equal to the storage period (either 8 months or 12 months). Modifying that assumption would have only a small effect on the per gallon of alcohol cost estimates shown in Table 10.

Table 10. Sensitivity of per gallon costs of 185 proof alcohol to changes in storage period.

Storage period (mo)	*Annual amortized capital and other fixed costs ($)*	*Annual operating costs ($)*	*Total production costs ($)*	*Annual denatured production (gal)*	*Total cost/ gal of denatured alcohol ($)*	*Cost/gal of denatured alcohol net of feed byproduct credit ($)*
8	97,493	229,254	326,747	124,497	2.63	2.10
12*	97,493	322,387	419,880	175,074	2.40	1.87

*Denotes baseline case.

storage and processing period results in an increase of about $.23 in the per gallon cost of alcohol.

Most optimistic case

The analyses presented in preceding sections indicate that fuel alcohol production from fodder beets in a small-scale plant is not likely to be economically feasible with recent prices of equipment and other inputs considered in this study. However, an additional sensitivity analysis was conducted with a **combination** of the most optimistic assumptions, including the following: (1) a high alcohol yield, of 23 gal/T; (2) a low interest rate, of 10%; and (3) low feedstock production costs, of $14/T.

Under the above set of assumptions, annual capital and other fixed costs were estimated to be $85,632, or $0.46/gal of alcohol, compared to $0.55 in the baseline case. Also, annual operating costs amounted to $296,321, or $1.54/gal of alcohol, compared to $1.84 in the baseline case. Total production costs came to $381,953 annually, or $2.00/gal of alcohol. From this amount, the credit for the feed byproduct ($0.53/gal) was subtracted. Total costs net of the feed byproduct credit came to $289,139 annually, or $1.47/gal of alcohol.

Even this "optimistic" (low) cost estimate exceeds the expected return on 185-proof alcohol—$.84 with the 1984 income tax credit and $.91 with the 1985 income tax credit in effect.

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ANNEX A

Explanation of capital and other fixed cost estimates

The major components, descriptions, and estimates of capital costs are listed in this annex under two categories: (1) capital costs and (2) other fixed costs. Data from SDSU Agricultural Experiment Station Bulletin 686 (Hoffman and Dobbs) were adapted whenever similar processing equipment was used. Costs from 1981 were adjusted to 1984 levels by using the Producer Price Index (PPI). The PPI data for the ''Machinery and Equipment'' commodity group were as follows:

Unadjusted PPI for mid-1984: 292.6
Unadjusted PPI for mid-1981: 263.3
Adjustment = 292.6 ÷ 263.3 = 1.1113, or 11.13% increase

Capital costs

Coal-fired steam boiler. The cost provided is for a boiler with 626,000 btu/hr output, using 10,000 btu/lb coal, and includes installation and freight. This system includes a hopper feeder, control cabinet for stoker and boiler control (110V), and electric starter for hopper and fresh air venting injection. The cost for this boiler is $25,461 in 1981 prices, or $28,295 in 1984 prices. The cost estimate was provided by Risager Plumbing and Heating, Inc., Aberdeen, SD.

Solid phase fermentor. This system is constructed entirely of stainless steel and consists of (1) an auger tube with cooling/heating shell,[7] (2) an auger flighting, (3) inlet and outlet ports, and (4) bearings. The capacity is about 3,180 cubic feet. The cost estimate ($50,000) was provided by Fabricators, Inc., Sioux City, IA.

Flume. Costs for the flume ($2,050) include (1) rollers, (2) bearings, (3) water pipe, (4) motor, and (5) steel material. The cost estimate was provided by Ralph Alcock, SDSU agricultural engineer.

Pre-chopper and automatic scale. Cost estimates ($5,000 for the pre-chopper and $3,500 for the automatic scale) were provided by Scale Center, Sioux Falls, SD.

Hammermill. The cost ($2,200) was provided by C&E Farm Equipment, Inc., Brookings, SD.

Conveyors. The cost ($4,550) was provided by Plastic Process Equipment Inc., Cleveland, OH.

Alcohol storage. The plant is capable of producing approximately 175,000 gal of denatured 185 proof alcohol per year. Storage capacity in this plant is for 10,000 gal. Cost was obtained from Bulletin 686. The adjusted 1984 price is $5,000 × 1.1113 = $5,556.

Heat exchanger. Cost was obtained from Bulletin 686. The adjusted 1984 price is $1,750 × 1.1113 = $1,945.

Feed byproduct storage. Total feed byproduct output is about 1,030 T/yr at a 5% moisture level. An open-ended cement feed bunker of 1,250 cubic feet (25 long × 10 wide × 5 high) is used for storage of DDF. This bunker would cost about $2,400 in 1984 prices.

Water softener. The cost for the two water softeners was assumed to be the same as in Bulletin 686. The adjusted (1984) price is $1,000 × 1.1113 = $1,111.

Building. The cost estimate came from Bulletin 686. The adjusted 1984 price is $26,000 × 1.1113 = $28,894.

Press and dryer. The capacity and degree of dehydration are based upon the assumption that the press is capable of pressing about 26 T/day of fermented pulp (88% moisture) to a 70-75% moisture product (DWF). Also, the dryer is capable of drying about 10 T/day of DWF to a 5% moisture level product (DDF). Cost estimates were provided by Davenport Machine and Foundry Co., Davenport, IA. Cost figures for the press ($37,000) and dryer ($56,000) represent only 75% of the cost estimates provided by that company. A 25% reduction was applied on the assumption that costs might go down if the equipment were produced and sold regularly.

Yeast tanks. Two yeast tanks each have a capacity of 106 gal and are equipped with a motor and agitation system. The tanks are operated on an alternating schedule to ensure continuous culture production of a pure yeast inoculum at a rate of 26 gal/hr. The cost estimate ($3,700) was provided by Fabricators, Inc., Sioux City, IA.

Distillation columns. Total alcohol output is the same as in Bulletin 686, or 166,320 gal of 185 proof non-denatured alcohol, annually. The adjusted 1984 price is $19,000 × 1.1113 = $21,115.

Temperature meters. The cost estimate was obtained from Bulletin 686. The adjusted 1984 price is $300 × 1.1113 = $333.

Pressure gauges. The cost estimate was obtained from Bulletin 686. The adjusted 1984 price is $50 × 1.1113 = $55.

Pumps and motors. The cost estimate was obtained from Bulletin 686. The adjusted 1984 price is $2,350 × 1.1113 = $2,611.

Pipes and accessories. The cost estimate was obtained from Bulletin 686. The adjusted 1984 price is $1,000 × 1.1113 = $1,111.

Flow meters. The cost estimate was obtained from Bulletin 686. The adjusted 1984 price is $150 × 1.1113 = $167.

Differential pressure cells. The cost estimate was obtained from Bulletin 686. The adjusted 1984 price is $250 × 1.1113 = $278.

Cooling tower. The cost estimate was obtained from Bulletin 686. The adjusted 1984 price is $3,900 × 1.1113 = $4,334.

Laboratory. The cost estimate was obtained from Bulletin 686. The adjusted 1984 price is $3,000 × 1.1113 = $3,334.

Skid-steer loader. The cost estimate was obtained from Bulletin 686. The adjusted 1984 price is $20,000 × 1.1113 = $22,226.

Beet storage. One cubic yard is assumed to store about 1,320 lb of fodder beets (Hayes). Approximately 7,920 T of fodder beets are required to produce 166,320 gal of non-denatured 185 proof

[7]Cooling is required to dissipate heat of fermentation during warm or moderate temperature months. In northern climate areas, heating may be required during cooler months to maintain a fermentation temperature of 28-32 C (83-90 F). Although the ethanol plant building is assumed to be insulated in our analysis, we have not explicitly accounted for any costs of heating the building.

alcohol per year. The total fodder beet tonnage would require about a 12,250 cubic yd storage facility (5 yd × 35 yd × 70 yd). The cost estimate ($24,073) was provided by Louis Lubinus, SDSU Extension agricultural engineer.

Plastic sheets. Storage pits should be covered with a thin plastic sheet about 1 millimeter thick. During the winter time, a layer of straw or hay should be added. This layer should be covered with an additional black plastic sheet, 15-20 millimeters thick, to prevent wind from blowing the straw off. However, for cost purposes, both plastic sheets are considered to have the same thickness (1 millimeter) in Table 3. The cost estimated ($400) was provided by Cope Plastics Inc., Fargo, ND.

Other Fixed Costs

Insurance. Four types of insurance should be carried: (1) general liability; (2) product liability; (3) workmen's compensation; and (4) fire and extended coverage. Bulletin 686 showed that insurance costs, on average, would comprise about 5% of the total capital investment.

Maintenance. Bulletin 686 showed that maintenance costs, on average, would comprise about 4% of the total capital investment.

Property taxes. Bulletin 686 showed that property taxes, on average, would comprise about 3% of the total capital investment.

ANNEX B

Explanation of operating cost estimates

This annex contains all technical data and sources of cost information for the variable inputs used in the fuel alcohol plant analyzed in this bulletin.

Fodder beets. The cost of fodder beets was estimated to be $17.50/T, based on a yield of 25 T/A (Table 2).

Sulfuric acid. The cost is $110/55-gal drum (i.e., $0.016/oz), including freight. The cost estimate was provided by Dakota Chemical Co., Sioux Falls, SD.

Ammonium hydroxide. The cost is $80/55-gal drum (i.e., $0.011/oz), including freight. The cost estimate was provided by Dakota Chemical Co., Sioux Falls, SD.

Yeast. In this process, purchased yeast is used only to inoculate the continuous flow yeast production tanks, which produce the inoculum for fodder beet pulp. Although the yeast inoculum was actually produced by SDSU microbiologists, the cost estimate was based on commercial prices and was obtained from Bulletin 686. The cost was not adjusted from 1981 to 1984 price levels. The recommended amount to be used is about 0.02 lb/gal of alcohol.

Electricity. The cost of electricity ($.057/kwh) is the weighted cost per kwh, given the declining block rate structure of an electric utility. The amount of electricity is based upon uses for the press, dryer, and other machines. Electrical rates for 1984 were provided by Sioux Valley Electric, Colman, SD.

Fuel. The fuel assumed to be used in the boiler for steam production is 10,000 btu/lb coal. The recommended amount to be used is about 1.95 lb/gal of non-denatured alcohol, and was provided by William R. Gibbons, graduate research assistant, Microbiology Department, SDSU. The cost estimate ($49/T) was provided by the Physical Plant at SDSU, and represents the average cost as of mid-1984.

Water. The amount of water is based on uses for washing fodder beets, cooling, clean-up, etc.. Water usage per gallon of alcohol was estimated by William R. Gibbons, SDSU Microbiology graduate research assistant. The cost of water is based on 1984 rates provided by the Big Sioux Rural Water System, Brookings, SD.

Labor. Three types of labor are required to operate the plant: (1) a manager; (2) an engineer; and (3) four technicians. The overall manager works 8 hr/day, 6 days/wk for 45 wks/yr, at an hourly wage rate of $11/hr. The same total hours also apply to the plant engineer, but with a wage rate of $10/hr. Each technician works 8 hr/day, 7 days/wk, for 45 wk/yr, with a wage rate of $6/hr. There will need to be someone on duty to monitor operations 24 hr/day; therefore, technicians have to work on three shifts.

Total annual labor costs are calculated as follows:

Manager: ($11/hr) (8 hr/day) (6 days/wk) (45 wk/yr) = $ 23,760
Engineer: ($10/hr) (8 hr/day) (6 days/wk) (45 wk/yr) = $ 21,600
4 tech's: ($6/hr) (32 hr/day) (7 days/wk) (45 wk/yr) = $ 60,480
Total labor costs per year = $105,840

Laboratory tests. The cost estimate was obtained from Bulletin 686. The adjusted 1984 cost is $2,475.

Denaturant. The Bureau of Alcohol, Tobacco, and Firearms (BATF) regulations require addition of a denaturant—often gasoline—to alcohol to make it unfit for human consumption. The cost of gasoline, as of mid-1984, was provided by Amoco Oil Co., Brookings, SD.

Interest on operating capital. The interest charge is assumed to be 15% per year on total operating costs, for 3 months.

ANNEX C

Explanation of alcohol production estimates

The amount of alcohol produced annually depends on many factors. These factors are explained in this annex.

Fermentation capacity. It is assumed that the fermentor is continuously operated at 75% of maximum capacity. Fermentation takes about 24 hr, producing fermented beet pulp with 8% (v/v) ethanol. Total fermentor capacity is about 64,000 lb, or 32 T of fermented fodder beet pulp. Therefore, fodder beet pulp must be dropped into the inlet port of the fermentor at the rate of 1.05 T/hr. This means that a total of 7,920 T of beets are needed in the processing plant in order to produce 166,320 gal of 185 proof non-denatured alcohol per year, assuming a fermentation yield of 21 gal of alcohol/T of fodder beets.

Alcohol content of beer. The continuous-solid phase fermentor is capable of producing fermented beet pulp with an average of 8% (v/v) ethanol content. It is assumed that liquid from the press and vapors from the dryer (i.e., beer) will also contain 8% (v/v) ethanol.

Length of time for production process. The production process includes 15 hr for loading, cleaning, fluming, and pulping the beets; 24 hr for fermentation; and 6 hr for pressing, drying, and distillation.

Days of operation. The pilot plant is assumed to operate 24 hr/day, 7 days/wk, for 45 wk/yr (if storage life is 12 months/yr); otherwise, the plant would operate 24 hr/day, 7 day/wk, for 32 wk/yr (when storage life is 8 months).

Annual output of 185 proof alcohol. The distillation system is assumed to operate at the rate of 22 gal of 185 proof alcohol per hour for 45 wk/yr (when storage life is 12 months per year). Therefore, total annual 185 proof alcohol output would be: (22 gal/hr) (24 hr/day) (7 day/wk) (45 wk/yr) = 166,320 gal of non-denatured 185 proof alcohol.

When storage life is 8 months (32-wk processing period), total annual output would be: (22 gal/hr) (24 hr/day) (7 day/wk) (32 wk/yr) = 118,272 gal of non-denatured 185 proof alcohol.

Denaturant. The denaturing substance is gasoline. Five gallons of gasoline are added to each 95 gal of non-denatured alcohol. The total number of gallons of gasoline required annually is calculated as follows:

1. 12-month storage period
   166,320 ÷ 0.95 = 175,074 gal of denatured alcohol
   175,074 – 166,320 = 8,754 gal of gasoline

2. 8-month storage period
   118,272 ÷ 0.95 = 124,497 gal of denatured alcohol
   124,497 – 118,272 = 6,225 gal of gasoline

Total annual denatured 185 proof alcohol output. The total alcohol output is equal to total output of 185 proof non-denatured alcohol plus the gallons of gasoline added annually as denaturant, or 166,320 + 8,754 = 175,074 gal of denatured 185 proof alcohol (12-month storage period) and 118,272 + 6,225 = 124,497 gal of denatured 185 proof alcohol (8-month storage period).

ANNEX D

Explanation of feed byproduct quantity estimates

Experimental research data at SDSU's fuel alcohol plant showed that for every ton of fodder beets used in the production of 185 proof alcohol, about 260 lb of 5% moisture Distillers Dried Feed (DDF) could be produced. The annual production output of DDF is calculated as follows:

1. DDF yield per ton of fodder beets was estimated based upon laboratory trials in SDSU's fuel alcohol plant.
   Average DDF yield (100% DM) = 124 g/kg fodder beets
   Average DDF yield (95% DM) = 130 g/kg fodder beets, or 260 lb (95% DM)/T of fodder beets
2. annual output of 185 proof non-denatured alcohol is 166,320 gal
3. yield per ton of fodder beets is 21 gal
4. number of tons of fodder beets required for production is 166,320 ÷ 21 = 7,920 T
5. DDF annual output is:
   ((7,920 T of beets) (260 lb/T of beets)) ÷ (2,000 lb/T) = about 1,030 T of DDF per year.

ANNEX E
Total fixed and operating costs associated with distillers dried feed delivery (1,030 T of DDF)

(A) **Fixed costs**

Item	*Capital cost ($)*	*Useful life (yr)*	*Amortized costs (15%)*	*Cost/gal of alcohol ($)*
1-ton truck	20,000	10	3,995	0.023
Vehicle license and insurance	1,067*	1	1,067	0.006
Tires	1,000*	5	298	0.002
Total fixed costs (A)	22,067		5,350	0.031

(B) **Operating costs**

Item	*Cost/unit ($)*	*Units/yr*	*Annual costs ($)*	*Cost/gal of alcohol ($)*
Gasoline	$1.19/gal	1,113[1]	1,324.47	0.008*
Oil, filter, and grease	$25/change	3	75.00	0.000**
Labor	$6/hr	1,460[2]	8,760.00	0.049
Antifreeze	$20/job	1	20.00	0.000**
Tune-up	$225/job*	1	225.00	0.001
Weigh payments	$4/weigh	912.5 weighs[3]	3,650.00	0.021
Total operating costs (B)			14,054.47	0.079
Total fixed and operating costs	(A+B)		19,404.47	0.11

*Costs marked by an asterisk were derived from Dobbs and Hoffman; the 1981 data in that publication were adjusted to 1984 price levels using the Producer Price Index (PPI).

**Annual cost per gal is so small that it rounds to zero at three decimal places.

[1]12,247 miles/yr ÷ 11 miles/gal = 1,113 gal/yr.

[2]4 hr/day x 365 days/yr = 1,460 hr/yr.

[3]An average 2.5 weighs/day for 365 days/yr = 912.5 weighs/yr.

ANNEX F
Fixed and operating costs for fuel alcohol delivery (adjusted to 1984 price levels)

(A) **Fixed costs**

Item	*Capital cost ($)*	*Useful life (yr)*	*Amortized costs (15%)*	*25% of annual costs ($)*	*Cost/gal of alcohol ($)*
Truck	27,783	10	5,536	1,384	0.008
Vehicle license and insurance	2,556*	1	2,556	639	0.004
Tires	1,222*	5	365	91	0.001
Total fixed costs (A)	31,561		8,457	2,114	0.013

(B) **Operating costs**

Item	*Cost/unit ($)*	*Units/yr*	*Annual costs ($)*	*Cost/gal of alcohol ($)*
Gasoline	$1.19/gal	219	260.61	0.001
Oil, filter, and grease	$25/change	2	50.00	0.000**
Labor	$6/hr	396	2,376.00	0.014
Antifreeze	$20/change	0.25	5.00	0.000**
Tune-up	$225/job*	0.25	56.00	0.000**
Total operating costs (B)			2,747.61	0.015
Total annual costs	(A+B)		4,861.61	0.028 (rounded to $0.03)

*Costs marked by an asterisk were derived from Dobbs and Hoffman; the 1981 data in that publication were adjusted to 1984 price levels using the Producer Price Index (PPI).

**Annual cost per gal is so small that it rounds to zero at three decimal places.

ANNEX G
Metric measurement conversions

Contained here are certain conversions of English to metric measurement units. These conversions will be of use to individuals wishing to determine and state inputs, outputs, or costs found in this report in metric units.

Symbol	*When you know:*	*Multiply by:*	*To find:*	*Symbol:*
Mass (wgt)				
oz	ounces	28.0	grams	g
lb	pounds	0.45	kilograms	kg
T	short tons (2,000 lb)	0.9	tonnes	t
	long tons (2,240 lb)	1.01	tonnes	t
g	grams	0.035	ounce	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.10	short tons	
t	tonnes (1,000 kg)	0.98	long tons	
Volume				
tsp	teaspoons	5.0	milliliters	ml
tbsp	tablespoons	15.0	milliliters	ml
fl oz	fluid ounces	30.0	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons (U.S.)	3.8	liters	l
gal	gallons (Imp)	4.5	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons (U.S.)	gal (U.S.)
l	liters	0.22	gallons (Imp)	gal (Imp)
m^3	cubic meters	35.0	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3

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