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Framework for Examining the Economic Feasibility of Small Scale Alcohol Plants

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FRAMEWORK FOR EXAMINING THE
ECONOMIC FEASIBILITY OF SMALL SCALE
ALCOHOL PLANTS

by

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***With minor corrections in October 1981.

Preface

This Staff Paper has been prepared primarily to share with other researchers and extension workers a practical method of economic analysis and preliminary data for examining the feasibility of small scale alcohol plants. Research on which this paper is based is currently in mid-stream. We therefore invite comments on the methods, assumptions, and data contained herein. By sharing our approach and findings at this preliminary stage with other economists and biological and physical scientists, hopefully, our fuel alcohol research and that of others can be strengthened. Please address reactions and suggestions regarding the contents of this Staff Paper to any of the three authors.

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FRAMEWORK FOR EXAMINING THE ECONOMIC FEASIBILITY OF SMALL-SCALE ALCOHOL PLANTS

by

Thomas L. Dobbs, Randy Hoffman, and Ardelle Lundeen

Introduction

The feasibility of producing fuel alcohol from grain has received much attention from the Midwest and Plains States over the last few years. There has been interest in plants ranging from quite small, "on-farm" stills to very large, fuel-feed complexes costing many millions of dollars. As a result of this interest, several studies of the economic feasibility of large-scale fuel alcohol plants were conducted and published in the late 1970's. More recently, a few studies of the economics of smaller-scale plants have been initiated, and some of the results are now beginning to appear in print (Hutchinson and Dobbs; Atwood and Fischer).

Except for extension oriented materials (e.g., Dobbs; Doering), however, there has as yet been little detailed analysis of the set of interrelated procurement, production, marketing, and financial organization factors which influence the economic feasibility of small-scale plants. The purpose of this Staff Paper is to specify the methodological components required for such an analysis. The methodology will be illustrated with preliminary data and analysis from research underway with South Dakota State University's pilot fuel alcohol plant. Components of plant feasibility analysis which receive consideration are:

1. access to and cost of the feedstock input;

2. plant capital and operating costs;

3. utilization, transportation, and marketing of the plant's fuel and animal feed products; and

4. organizational and financial considerations for a small-scale plant.

Much of the analysis focuses on the importance of spatial considerations in alcohol plant feasibility. Economies of plant scale and transportation costs are considered. The framework presented in this paper therefore incorporates the important matter of plant size and location. It is incorporated with the kind of cost-benefit approach that is likely to be adaptable to general feasibility studies. More complicated mathematical programming approaches which are usually only practical in research settings--at least for small-scale plant analyses--are not treated here.

The following section contains an economic description of the pilot plant used as a case example in this paper. Evidence on costs associated with alternative sized plants are then reviewed in the third section of the paper. Spatial considerations are brought into the fourth section. The final section brings the methodological components together to address the central questions of: (a) economic and financial feasibility and (b) territory to be served by a small-scale plant.

Profile of Case Plant Example

The description of the case plant presented in this analysis is based upon the physical structure of the alcohol fuel plant currently operating on the South Dakota State University (SDSU) campus. The SDSU facility is currently limited to a theoretical annual output of approximately 45,000 gallons of 190 proof alcohol; fermentation capacity is the constraining factor. The distillation capacity of the SDSU plant, however, is estimated to be in the 150,000 to 200,000-gallon range.

The analysis in this paper deals mainly with a 45,000-gallon plant. Very preliminary capital and operating costs for both a 45,000-gallon plant and a plant in the 150,000 to 200,000-gallon range are presented. However, most of the subsequent feasibility analysis in the paper is with respect to a plant producing slightly less than 45,000 gallons of fuel alcohol per year.

45,000-gallon Plant

Capacity.--The cost analysis presented here is based upon the assumption that average variable costs are constant up to the point at which some capacity constraint is reached. Average fixed costs of course decline up to that point.

In order to calculate the capacity of the current SDSU pilot plant, several assumptions are here made concerning the following:

(1) Fermentation: Fermentation capacity for the plant is based upon the fermentation tanks presently installed. There are currently two 1,500-gallon cooking-fermentation tanks[1/] and one 1,300 gallon tank, for a total of 4,300 gallons of cooking-fermentation capacity. However, it is assumed that the fermentation tanks will normally be only 95% filled, lowering the fermentation capacity to 4,085 gallons. The distillation columns are capable of distilling a larger volume of alcohol than can currently be fermented. Therefore, the distillation columns will be idle for periods of time--resulting in a continuous cook-fermentation process and a batch-type distillation process.

[1/] Both cooking and fermentation are currently done in these tanks.

(2) Days of operation: The plant is assumed to operate 24 hours a day for 45 weeks of the year. Seven weeks are allowed for down-time due to maintenance and repair, vacation time for personnel, etc.

(3) Alcohol content and recovery: Although experimentation concerning optimum alcohol content is still ongoing, past work has indicated that a 10% alcohol level in the beer before distillation may be a desirable goal. That is the alcohol content assumed in this analysis. It is also assumed that 92% of the alcohol produced during fermentation can be recovered during distillation.

(4) Length of time for the production process: The production of alcohol is assumed to be done in a batch process, as noted earlier. Each batch of 4,085 gallons of mash is assumed to require 68 hours to complete the production process; this includes 48 hours for fermentation, 12 hours for loading and cooking, and 8 hours for distillation. Production of alcohol within these time constraints would allow for approximately 2.5 batches to be completed per week of operation.

Given these assumptions, the annual output of the SDSU pilot plant is estimated to be 44,394 gallons of 190 proof alcohol, slightly less than 45,000 gallons. Per gallon costs to follow are based on this level of annual output.

Feed byproduct output.--The animal feed produced in conjunction with the alcohol is considered to be a potentially good livestock feed because of its high protein content. It can be an important source of income from operation of an alcohol plant.

The amount of feed byproduct produced annually by the baseline case plant in this analysis is directly related to the annual output of alcohol. For every bushel of corn that goes into the production of alcohol, approximately 25 gallons of 92% moisture whole stillage is extracted. The stillage is converted to 70% moisture distillers wet grain (DWG) by the use of centrifugal force. This is the feed byproduct assumed sold by the case plant.

Producing the 44,394 gallons of alcohol (assumed as the annual production of the SDSU pilot plant) would require approximately 18,510 bushels of corn which would allow for the production of about 494 tons of DWG annually.

Capital and other fixed costs.--An alcohol plant producing around 45,000 gallons per year requires a sizeable investment in capital equipment. The capital and other fixed items that would be needed to duplicate the current SDSU pilot plant on a commercial basis and their costs are shown in Table 1. Annual costs of each capital item were calculated by amortizing the purchase price of the item over its useful economic life with a 15%-interest rate. The annual cost of each item was then divided by the annual alcohol output of the plant, yielding the annual cost per gallon estimates shown in column 5 of the table.

Of the seventeen items listed in Table 1 which are unlikely to already be available to a group of small plant investors, the three most

Table 1. Capital and other fixed costs: 44,394-gallon plant.

Item	Capital cost	Useful life (years)	Annual amortized cost (15% interest)	Cost per gallon
A. Items not likely to be already available				
Coal-fired boiler	$ 26,450	15	$ 4,522.95	$ .102
Fermentation tanks (3)	11,750	10	2,338.25	.053
Grain handling system	12,800	10	2,547.20	.057
Alcohol storage	4,050	10	805.95	.018
Auger	500	10	99.50	.002
Heat exchanger	1,750	10	348.25	.008
Feed byproduct storage	1,200	20	190.80	.004
Water softeners (2)	1,000	10	199.00	.004
Building	16,000	20	2,544.00	.057
Distillation columns	19,000	10	3,781.00	.085
Temperature meter	300	10	59.70	.001
Pressure gauges (2)	50	10	9.95	.000
Pumps & motors	2,350	10	467.65	.011
Pipes & accessories	850	5	253.30	.006
Centrifuge	32,000	15	5,472.00	.123
Flow meters (2)	150	10	29.85	.001
Differential pressure cell	250	10	49.75	.001
Subtotals =	$130,450		$23,719.10	$ .534
B. Items possibly already available among members of a cooperative group				
43 ft. auger-vertical	$ 2,400	10	$ 477.60	$ .011
Skid-steer loader (or tractor loader of some kind)	20,000	10	3,980.00	.090
Steel grain bin	4,100	20	651.90	.015
Subtotals =	$ 26,500		$ 5,190.50	$ .116
C. Other fixed costs			Annual cost	
Insurance			$ 2,000	$ .045
Maintenance			3,900	.088
Property taxes			4,150	.093
Subtotals =			$10,050	$ .226
Totals of A, B, and C =			$38,959.60	$ .876

costly, on an annual per gallon of output basis, are (1) the centrifuge, at $.12/gallon; (2) the boiler, at $.10/gallon; and (3) the distillation columns, at almost $.09/gallon. Those items account for approximately $.31 of the total capital and other fixed costs of $.88 per gallon of alcohol output.

Another three items account for an additional $.17 per gallon of alcohol produced. These are (1) the grain-handling system, at $.06/ gallon; (2) the building, at $.06/gallon; and (3) the fermentation tanks, at $.05/gallon. Thus the purchase of six of the capital items listed in Table 1 requires $.48 of the total $.88 per gallon cost of alcohol attributed to capital and other fixed items.

The SDSU alcohol plant receives its steam power through the campus boiler system. Of course, an independent commerical firm would normally need to provide its own boiler. The decision as to what type of boiler to purchase is dependent upon at least three factors: (a) the capital cost of different boilers; (b) the costs of operation of boilers run by different fuel sources; and (c) the total amount of steam needed to operate the alcohol plant.

Approximately 626,000 BTU's of output per hour are required of the boiler unit providing steam for cooking and distillation of alcohol in the baseline case plant. Four types of boiler that could provide such output were considered: (1) a coal-fired boiler; (2) a propane-fired boiler; (3) a fuel-oil fired boiler; and (4) an electric boiler.

Table 2 contains the purchase cost and annual capital cost per gallon of alcohol output for each of the four boiler types. The coal-fired boiler has the highest capital cost per gallon, while the fuel oil-powered boiler shows the lowest. However, the coal-fired boiler proves to be the most economical choice, due to its lower annual operating costs per gallon of alcohol (shown in a later table).

Small scale fuel alcohol production may involve a farm or a rural cooperative setting. In such a setting, it is possible that some capital items needed for alcohol production could be made available by cooperative farm members at little or no cash cost. Some such items and their cost per gallon are shown in Part B of Table 1.

If the vertical auger, the skid-steer loader, and the grain storage cannot be provided by cooperative members, then the purchase of those items would add approximately $.12 to each gallon of alcohol produced. The skid-steer loader, used for handling the feed byproduct, accounts for $.09 of that additional $.12/ gallon.

There are certain additional fixed costs associated with the existence of an alcohol plant. These include insurance, maintenance, and property taxes--shown in Part C of Table 1.

Inclusion of these other fixed costs adds another $10,050 to the annual cost of alcohol production. This amounts to an additional cost of $.23 for each gallon of alcohol produced.

Table 2. Capital costs for four types of boilers

Item	Capital cost	Useful life (years)	Annual amortized cost (15% interest)	Annual Capital cost per gallon
Coal-fired boiler	$ 26,450	15	$ 4,522.95	.102
Propane-fired boiler	8,050	15	1,376.55	.031
Fuel oil-fired boiler	7,150	15	1,222.65	.028
Electrical boiler	16,150	15	2,761.65	.062
Boiler fuel tank[1/]	1,370	10	272.63	.006

[1/] Fuel storage tank will be needed for propane and fuel oil burners.

Total capital and other fixed costs shown in Table 1 come to $.88/gallon for a plant producing a little under 45,000 gallons of fuel per year.

Operating costs.--Preliminary operating cost data are available from previous operating experience of the SDSU pilot alcohol plant (see Hutchinson and Dobbs). Some of the preliminary data have been updated for purposes of this paper, but much of the updating awaits completion of research operations now underway with the plant. However, the method of analysis and general notions of operating costs can be illustrated with such preliminary estimates as are currently available.

Operating costs per gallon shown in Table 3 total $2.60, three times the level of capital and other fixed costs (Table 1). Two variable inputs account for $2.13 of that total. They are corn, at $1.25/gallon, and labor, at $.88/gallon. Propionic acid adds $.10/gallon and boiler fuel contributes another $.09/gallon (assuming use of a coal-fired boiler with an energy output of 10,000 BTU's per pound of coal). The only other variable input with any large cost is gasoline, which is used as a denaturant; it adds approximately $.06/gallon to the cost of alcohol produced in the base case plant.

Shown in Table 4 are the fuel costs for the four types of boilers listed previously in Table 2. As is evidenced in the last column of Table 4, the annual operating costs of a boiler fueled by coal are far lower than operating costs for any of the other boiler types. The lower annual fuel cost of the coal-fired boiler more than offsets the higher annual capital cost of the coal-fired boiler, in relationship to the costs of other boilers. Hence, the coal-fired boiler appears to be the most economical source of energy for the plant, assuming reasonable access to coal.

Total costs.--The total annual costs of producing each gallon of alcohol and the accompanying feed byproduct, using the existing SDSU pilot plant as the baseline case, can be calculated by adding the totals at the bottoms of Tables 1 and 3. These figures do not include any costs of distributing the alcohol and feed byproduct. However, they do include certain capital items that may be available in a farm cooperative setting (listed in Part B of Table 1). The total per gallon costs are: $.88 (from Table 1) plus $2.60 (from Table 3) = $3.48. This figure does not include a credit for feed byproduct sales, which would need to be figured in to arrive at a net cost for the 190 proof alcohol.

165,000-gallon Plant

The baseline case plant discussed so far in this analysis was assumed to produce approximately 45,000 gallons of fuel alcohol annually. However, with the same basic plant structure, a considerably larger amount of alcohol could be produced with some additions to the capital equipment. The main additions would be more and larger fermentation tanks--to fully utilize the distillation columns.

Table 3. Operating costs: 44,394-gallon plant

Item	Costs per unit	Units per week	Total cost per week	Annual cost (45 weeks)	Cost per gallon
Corn	$3.00/bu	411.4 bu	$ 1,234.20	$55,539.00	$1.251
Diazyme L-100	2.92/liter	15.65 liters	45.70	2,056.41	.046
Taka-therm	1.60/lb	12.68 lbs	20.29	912.96	.021
Sulfuric acid	1.17/gal	7.55 gal	8.83	397.35	.009
Yeast	.90/lb	10.65 lbs	9.59	431.55	.010
Electricity[1/]	.034/kwh (ave)	652.4 kwh	22.46	1,010.70	.023
Fuel (coal at 10,000 BTU/lb)	47.00/ton	1.97 ton	92.59	4,166.55	.094
Water[2/]	.56/1,000 gal (ave)	11,696 gal	9.14	411.30	.009
Water softener salt	4.25/80 lbs	9.23 lbs	.49	22.05	.000
Denaturant (gasoline)	1.30/gal	47 gal	61.10	2,749.50	.062
Labor	6.20/hr (ave)	140 hr	868.00	39,060.00	.880
Propionic acid	.90/lb	95.1 lbs	85.55	4,448.34[3/]	.100
Interest on operating capital (at 15%/yr for 3 mo/yr)			92.67	4,170.21	.094
Totals =			$ 2,550.61	$115,375.88	$2.599

1/ Electricity price is the average cost per kwh, given the block declining rate structure of an electric utility on a monthly basis and the estimated monthly electrical use.

2/ Water price is the average cost per 1,000 gallons, given the block declining rate structure of a water utility on a monthly basis and the estimated monthly water use.

3/ Annual cost of propionic acid is calculated on a 52-week basis.

Table 4. Fuel costs for four types of boilers

Item	Cost per unit	Units per week	Total cost per week	Annual cost (45 wks)	Cost per gallon
Fuel by coal (10,000 BTU/lb)	$47/ton	1.97 tons	$ 92.59	$ 4,166.55	$.094
Fuel by electricity[1/]	$ .028/kwh	8,081.4 kwh	$226.21	$10.179.45	$.229
Fuel by fuel oil, No. 2	$1.20/gal	281.4 gal	$337.68	$15,195.60	$.342
Fuel by propane gas	$ .62/gal	376.3 gal	$233.31	$10,498.95	$.236

[1/] Electricity price is based on the lowest rate charge of a declining block rate structure; it is assumed that other electrical usage exceeds the minimum usage levels of the rate schedule. The weekly cost is the average weekly cost for a full month of operation.

An increase in annual alcohol production allows for an increase in production of distillers wet grain (DWG) also. Thus, there is potential for increased revenues to the alcohol plant from the sale of these products. The increase in production of alcohol and DWG will affect the per unit fixed cost of alcohol and, quite probably, the per unit variable cost of alcohol. Increased alcohol and DWG production will definitely affect transportation and marketing considerations in the plant feasibility analysis.

Although the larger size plant is not examined in any detail in this paper, some of the preliminary cost changes are presented below.

Capacity.--A so-called expanded plant would be limited in production only by the capacity of the distillation columns. The practical distillation capacity of the columns used in the SDSU pilot plant is approximately 22 gallons of 190 proof alcohol per hour. The following assumptions are made in calculating the potential annual alcohol output of an "expanded" plant:

(1) Fermentation: At present, there are three fermentation tanks at the SDSU plant, with a total capacity of 4,300 gallons. The expanded plant requires four fermentation tanks, each holding 5,000 gallons, to keep the distillation columns running continuously at the rate of 22 gallons of alcohol per hour.

(2) Days of operation: The expanded plant is assumed to operate 24 hour a day for 45 weeks of the year. Seven weeks are allowed for down-time due to maintenance and repair, vacation time for personnel, etc.

Given the above assumptions, the maximum annual alcohol production in the "expanded" plant is 166,320 gallons.

Feed byproduct output.--As with the 45,000-gallon capacity alcohol plant, the amount of distillers wet grain produced in the "expanded" plant is directly related to the volume of corn used to produce alcohol. Annual production of 166,320 gallons of fuel alcohol in the expanded plant would require 69,350 bushels of corn input. The resulting production of DWG from this amount of corn would be about 1,851 tons per year.

Capital and other fixed costs.--Given the alcohol output of the expanded plant, average fixed cost per gallon of alcohol is expected to decline. However, along with expanded alcohol output comes some expansion or change in capital equipment and other fixed costs. Table 5 contains a list of capital and other fixed costs for the plant capable of producing around 165,000 gallons annually. Cost items that differ in level from the 45,000-gallon plant are marked by an asterisk.

It is clear from data in Table 5 that the increase in capital and other fixed costs associated with an expansion of the SDSU alcohol plant are small in comparison to the potential increase in production. Total

Table 5. Capital and other fixed costs: 166,320-gallon plant.

Item	Capital cost	Useful life (years)	Annual amortized cost (15% interest)	Cost per gallon
A. Items not likely to be already available				
Coal-fired boiler	$ 26,450	15	$ 4,522.95	$ .027
*Fermentation tanks (4)	21,800	10	4,338.20	.026
Grain handling system	12,800	10	2,547.20	.015
*Alcohol storage	5,100	10	1,014.90	.006
Auger	500	10	99.50	.001
Heat exchanger	1,750	10	348.25	.002
Feed byproduct storage	1,200	20	190.80	.001
Water softeners (2)	1,000	10	199.00	.001
*Building	26,000	20	4,134.00	.025
Distillation columns	19,000	10	3,781.00	.023
Temperature meter	300	10	59.70	.000
Pressure gauges (2)	50	10	9.95	.000
Pumps & motors	2,350	10	467.65	.003
*Pipes & accessories	1,100	5	327.80	.002
Centrifuge	32,000	15	5,472.00	.033
Flow meters (2)	150	10	29.85	.000
Differential pressure cell	250	10	49.75	.000
Subtotals =	$151,800		$27,592.50	$ .166
B. Items possibly already available among members of a cooperative group				
43 ft. auger-vertical	$ 2,400	10	$ 477.60	$ .003
Skid-steer loader (or tractor loader of some kind)	20,000	10	3,980.00	.024
Steel grain bin	4,100	20	651.90	.004
Subtotals =	$ 26,500		$ 5,190.50	$ .031
			Annual cost	
C. Other fixed costs				
*Insurance			$ 4,000	$ .024
*Maintenance			4,550	.027
*Property taxes			4,850	.029
Subtotals =			$13,400	$ .080
Totals of A, B, and C =			$46,183.00	$ .277

*Items that differ in level of costs from 44,394-gallon plant.

annual fixed costs would increase by around $7,200, whereas total annual alcohol production could increase from 44,394 gallons to 166,320 gallons. The average cost per gallon of of alcohol might therefore be reduced from $.88 in the "baseline" (current) plant to around $.28 in an "expanded" plant.

Operating costs.--Data on operating costs available at the time of analysis for this paper were based on very preliminary experiments with small production batches. To assume that there is a linear relationship between all variable inputs and output in a range of 4,500 gallons per year (Hutchinson and Dobbs) to around 165,000 gallons per year of alcohol production is probably not realistic.

At least three variable input items are likely to decrease in terms of cost per gallon of alcohol output. Water and electricity are two of these, because of their frequently declining block rate charge structures.[2/] Cost per gallon of alcohol for a third input, labor, is expected to decrease substantially.

In the cost analysis of the 45,000-gallon plant, three of the important variable cost items were corn, labor, and propionic acid. It has already been stated that per gallon labor costs would be expected to drop substantially as we moved to an "expanded" (165,000-gallon, or so) plant. Propionic acid is added to distillers wet grain in a constant ratio; hence, the per gallon cost of that item is not expected to change. The volume of corn needed to produce each gallon of alcohol is also not expected to be much different in an expanded plant than in the baseline plant.

If the operating costs per gallon of alcohol for these three variable inputs behave in the manner expected, then even some increase in cost per gallon could occur for other variable inputs and the net result would still probably be lower total operating costs per gallon for an expanded plant.

Although better operating cost data are needed, the conclusion can be drawn from our preliminary analysis that operating costs per gallon of alcohol in an expanded plant could easily be $.40 to $.60 less than per gallon operating costs in the baseline (45,000-gallon capacity) alcohol plant. This would place total operating costs for an expanded plant at around $2.10 per gallon of alcohol.

Total costs.--These very preliminary calculations indicate that total per gallon costs in an "expanded" plant, of around 165,000 gallons per year, might be approximately $2.38. This consists of $.28 in capital and other fixed costs (Table 5) and approximately $2.10 in operating costs. This is $1.10 per gallon less than the preliminary estimate presented earlier for the 45,000-gallon per year plant.

2/ However, an unknown factor for water, in particular, is that the ratio of volume of water input to volume of alcohol output could vary significantly from smaller capacity to larger capacity production processes.

As was the case with the 45,000-gallon plant, this cost estimate does not include any alcohol and feed byproduct transportation and marketing costs, nor does it include a credit for the sale or use value of the feed byproduct.

Cost Summary for Case Plant

Total per gallon costs for alcohol produced in the case plant, adjusted for feed byproduct credits of $.41/gallon of alcohol[3/] are estimated to be approximately:

(1) $3.07, if the plant were operated at the "baseline" capacity of nearly 45,000 gallons per year; and

(2) $1.97, if the plant were operated at an "expanded" capacity of slightly more than 165,000 gallons per year.

Costs Associated with Alternative-Sized Small Scale Plants

Physical dimensions and cost components of the SDSU pilot alcohol plant were described in the previous section. Preliminary research at SDSU thus far indicates that costs per gallon of 190 proof fuel alcohol--net of feed byproduct credits--may be about $4 if operated at 9,000 to 10,000 gallons per year, $3 if operated at 45,000 gallons per year, and $2 if operated at 165,000 gallons per year (costs in 1981 dollars). There are clearly some economies of scale involved, due in part to greater utilization of various components of the plant as annual output goes up. While some additional capital investments are required to make successive, large increases in annual output with alcohol plants similar to that at SDSU, some components require little or no change up to certain points. For example, the same size of distillation column could be used for annual output up to around 165,000 gallons.

Several other studies shed additional light on probable economies of scale associated with fuel alcohol production. These are summarized in Table 6. The findings are expressed graphically in Figure 1. Data from Table 6--up to 400,000 gallons of annual output--are plotted in Figure 1.

It is clear from the data shown that economies of scale exist in going from "farm scale" levels of production (around 10,000 gallons per year) to "community scale" levels (100,000 to 400,000 gallons). This is due in large part to the fact mentioned above that capital equipment can be more fully used as one moves up to 100,000 or more gallons per year. There are also energy, labor, and other operating efficiencies associated with the continuous batch operations that cannot be fully captured in low-volume, discontinuous batch operations.

[3/] This figure is based upon an estimate contained in Hutchinson and Dobbs, p. 6; the earlier estimate has been adjusted here for inflation that has taken place in the interim.

Table 6. Fuel alcohol production costs at alternative levels of annual output

Cost estimate source	Assumed annual output (190 proof equivalent)[1/]	Costs per gallon (1981 dollars; 190 proof equivalent)[2/]
	-------gallons-------	-------------dollars------------
#1. S. Dak. State Univ.[3/]	9,088	3.97
#2. S. Dak. State Univ.[4/]	44,394	3.07
#3. S. Dak. State Univ.[4/]	166,320	1.97
#4. Univ. of Nebraska[5/]	12,630	3.37
#5. Univ. of Nebraska[5/]	42,100	2.51
#6. Solar Energy Research Institute[6/]	400,000	1.30
#7. U.S. Department of Agriculture[7/]	60,000	1.49
#8. U.S. Department of Agriculture[7/]	360,000	1.25
#9. U.S. Department of Agriculture[7/]	1,052,600	1.28
#10. E.S.C.S., U.S.D.A.[8/]	10,526,300	1.58
#11. E.S.C.S., U.S.D.A.[8/]	42,105,300	1.30

(continue next page for footnotes)

Continuation of Table 6, footnotes

1/ Some studies presented output in approximately 190 proof terms, while others stated annual output in 200 proof (anhydrous) terms. Adjustments to 190 proof equivalents were made, where necessary, using relative BTU content values.

2/ Cost estimates from various studies were adjusted for inflation to 1981 levels by using the Producer Price Index for Processed Foods and Feeds. These are net of byproduct credits.

3/ Source: Hutchinson and Dobbs, p. 15.

4/ Source: Preliminary data from research currently underway at South Dakota State University by economists Randy Hoffman and Thomas Dobbs in cooperation with researchers in the Agricultural Engineering and Microbiology Departments.

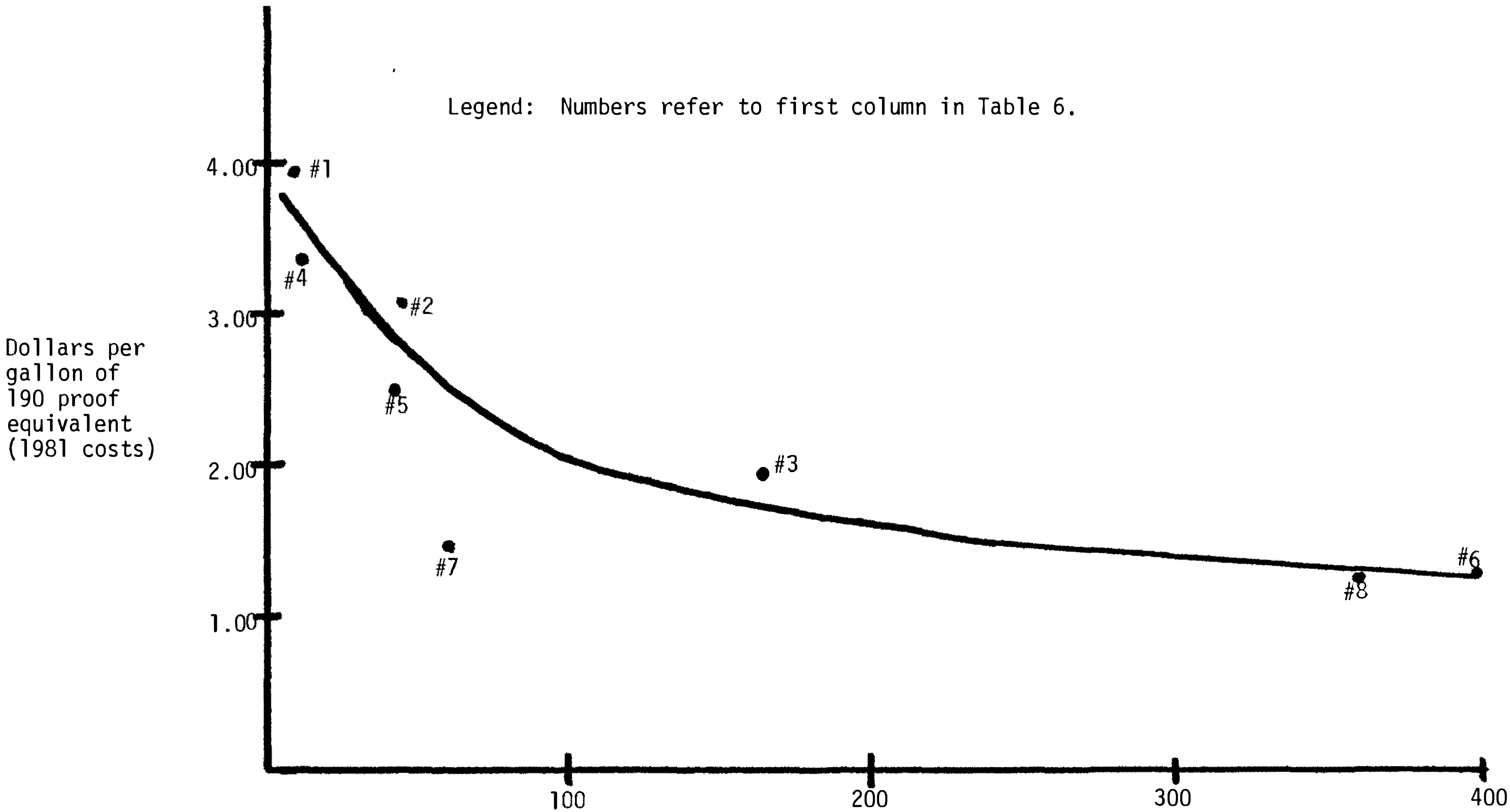
5/ Source: Atwood and Fischer, p. 26.

6/ Source: Jantzen and McKinnon, p. 7.

7/ Source: U.S. Department of Agriculture, pp. VIII-11 and VIII-12.

8/ Source: Meekhof, Gill, and Tyner, p. 15.

Figure 1. Fuel alcohol production costs at alternative levels of annual output



Annual fuel alcohol output (1,000 gallons of 190 proof equivalent)

Source: Table 6 of this paper.

Data presented here are more ambiguous about economies of scale as one moves from "community scale" into medium scale (e.g., 1 million to 10 million gallons of annual production) and large scale (substantially more than 10 million gallons) operations. In part, certain economies have probably been masked by the way in which some of the cost conversions were made and presented in Table 6. For one thing, cost estimates #9, #10, and #11 were stated in 200 proof terms in the sources from which they were taken. Our conversions to costs in 190 proof terms were done strictly on a percentage basis; i.e., it was assumed that 190 proof alcohol in those plants would cost 95% as much (per gallon) to produce as would 200 proof alcohol. In reality, going from 190 to 200 proof is a very expensive part of the overall process, and it is currently a relatively more costly process in small than in large alcohol plants.

Secondly, costs published for medium to large scale operations (such as for #10 and #11 in Table 6) are generally based upon the assumption that the feed byproduct is dried. The resulting byproduct is a much easier to handle and more marketable commodity than the whole stillage or distillers wet grain products likely to be produced in most small scale plants. Therefore, the byproduct credits accounted for in cost estimates shown in Table 6 are more likely to be fully realized in the medium and large scale than in the small scale operations.

For both of the above reasons, cost estimates may be somewhat overstated for the larger scale alcohol production operations--relative to the smaller scale operations. Our focus in this paper is primarily on the smaller scale operations of less than a quarter of a million gallons annual output, in which it is here assumed that 190 proof alcohol is produced. We will therefore avoid a detailed, direct comparison of small, community scale operations with the very large operations involving several or many million dollar investments.

Location and Marketing Analysis

One of the often stated arguments supporting the economic feasibility of fuel alcohol plants in midwestern States is the availability of corn, as the major input, and farming operations to utilize the fuel alcohol and the feed byproduct. However, little work has been done to examine the kind of locational structure which would be needed to supply inputs and utilize the output of smaller scale fuel alcohol plants. The location of a plant could have important implications for transportation costs for inputs and outputs.

This section of the paper considers three main factors in location analysis of alcohol fuel plants similar in design and capacity to SDSU's pilot plant: (1) number of farms required to supply corn to produce approximately 45,000 gallons of alcohol annually; (2) number of farms required to use alcohol annually produced; and (3) number of beef or dairy farms required to consume the annual volume of feed byproduct produced from the plant.

For each factor, the method to calculate number of farms is described and the procedure is then applied to a case study plant to estimate transportation costs for inputs and outputs. The hypothetical location of the case study plant is central Moody County, located in southeastern South Dakota. Moody County was chosen for the plant location because corn is the major crop produced in the county and because both beef and dairy farms to utilize the feed byproduct are common there. Corn is probably the most economically feasible crop at present in South Dakota from which to manufacture alcohol. Locating the plant in an area where corn is abundant eliminates large corn transportation costs.

The average size of all farms in Moody County is 382 acres, of which 322 are cropland. Moody County has 782 farms of all types, including 112 dairy farms, 237 beef fattening farms, and 673 corn producing farms (Preliminary Agricultural Census, 1978).

Corn Supply Area

Estimation method.--Needed corn supply area can be expressed as the number of farms required to produce a sufficient volume of corn to supply annual needs of the alcohol plant. An alcohol plant similar to the "baseline" case plant (nearly 45,000 gallons capacity) would require approximately 18,520 bushels of corn annually. The number of farms needed to produce this volume of corn for any given area can be determined with the following equation:

$$\frac{\text{18,520 bushels of corn}}{\text{Bu/acre ave. yield in county}} \div \begin{matrix}\text{Average acres of corn} \\ \text{per farm in county}\end{matrix} = \begin{matrix}\text{Number of farms required} \\ \text{to supply needed corn}\end{matrix}$$

Application to Moody County.--Data from the South Dakota Crop and Livestock Reporting Service indicate that the average corn yield in Moody County from 1977 through 1979 was 83.2 bushels per acre. The average farm had 141 acres of corn. Applying these figures to the above formula indicates that about 223 acres of corn would satisfy the annual needs of the fuel alcohol plant. This is the corn acreage of less than two farms in Moody County.

Corn purchases are likely to be on a local basis and the minor costs associated with transporting the corn from the farms to the alcohol plant site will likely not differ significantly from those associated with transporting the corn to a local grain elevator. Therefore, it is assumed that the local per bushel purchase price of corn will include all transportation costs.

Fuel Alcohol Utilization Area

The SDSU pilot plant used as the model in this analysis is capable of producing alcohol of only 190-192 proof (this is currently true of most small plants), which cannot be mixed with gasoline to be used as gasohol. It must be injected in engines via modified equipment, rather than mixed directly with gasoline or diesel fuel in the tanks. This limits marketing possibilities for the hydrous alcohol from small plants. Hence, a farmers' cooperative, in which the members are the main users of the alcohol, may be the most feasible type of organization to own and operate the alcohol plant.

Estimation method.--It is assumed that the fuel alcohol will need to be delivered to consuming farms, since it is unlikely that the farmers will have the desire or the means to transport fuel from the plant site themselves. Two factors need to be considered when calculating the routing schedule: (1) the rate of consumption of the fuel alcohol by each farm; and (2) the spatial distribution of the consuming farms.

To estimate the number of farms needed to utilize the alcohol production of the "baseline" plant, the average number of gallons of liquid fuel used per acre in South Dakota annually is multiplied by the average number of acres of cropland per farm in the county being examined. This gives liquid fuel usage per farm. The number of gallons of ethanol needed to replace the existing liquid fuels is then estimated for 100%, 75%, 50%, and 25% replacement of liquid fuels on each farm. The capacity of the plant--nearly 45,000 gallons--is divided by these gallonage results to estimate the number of farms required to utilize the production of the alcohol plant at various fuel replacement rates.

Although the annual consumption of fuel alcohol by each farm (under various assumptions about conventional fuel replacement rates) can be calculated, the results do not take into account seasonal peaks and lows in fuel consumption that may affect delivery scheduling. Attempting to find an optimal solution to delivery routes, given seasonal peaks and storage capabilities at the plant and on the farms, could be a major analytical task in itself and may not be worth the effort, given the small impact operating costs of alcohol delivery have on total costs of alcohol production and marketing. Therefore, this analysis assumes an even distribution of delivery dates to each farm throughout the year, implying that the farmers themselves are responsible for most of the alcohol storage.

After the number of farms needed to utilize the fuel alcohol has been determined, the location of farm sites in the county in relation to the plant site must be determined or assumed. Fuel delivery mileage can then be estimated. It is assumed in this study that farms are evenly distributed geographically throughout the county. Total square miles in the county are divided by number of farms in the county to determine farms per square mile.

In this paper, farms utilizing the fuel alcohol are assumed to be those located closest to the plant. Hence, fuel delivery costs are based on the lowest possible mileage.

The total cost of alcohol delivery is found by adding the variable cost of traveling the delivery route to the fixed cost associated with owning a delivery truck. The total delivery cost is divided by the number of gallons of alcohol produced in order to put the transportation cost on a per gallon basis.

Application to Moody County.--Table 7 contains an estimate of the amount of fuel now used on the average Moody County farm and the amount of ethanol needed to replace that fuel. If, for example, 100% of all liquid fuel needs were to be replaced on the average farm, it would require the use of 7,813 gallons of ethanol.

Drawing on the data in Table 7, the number of farms required to utilize the 44,394 gallons of ethanol fuel was determined. The results are as follows: (1) six farms, if 100% of the conventional liquid fuel is replaced by ethanol; (2) eight farms, if 75% of the conventional fuel is replaced; (3) twelve farms, if 50% of the conventional fuel is replaced; and (4) twenty-three farms, if 25% of the conventional fuel is replaced.

In the remaining analysis, it is assumed that farmers substitute ethanol for 50% of their conventional fuel. Hence, the baseline case alcohol plant is assumed to supply fuel for twelve farms in Moody County.

The schedule for delivering the alcohol was arrived at by using the following assumptions:

(1) A bulk gas truck with a tank capacity of 2,500 gallons is used to deliver the alcohol.

(2) The route to all twelve farms takes 2 days--

   (a) 400 gallons of alcohol are delivered to each of six farms on the first day; and

   (b) 400 gallons of alcohol are delivered to each of six farms on the second day.

(3) The 2-day route is repeated about every 5 weeks or approximately 10 times a year. This supplies each farmer's annual needs and accounts for the total alcohol output of the plant.

(4) Special deliveries of less than 400 gallons to individual farms between regular deliveries will require the equivalent mileage of two extra, full route trips during the course of the year.

Moody County has an average of three farms on every two square miles of land. Depicted in Figure 2 are the locations of those farms around the alcohol plant; it is assumed that the farms are evenly distributed, geographically, throughout the County. As is evident from

Table 7. Potential annual fuel alcohol use on an average Moody County, South Dakota farm, having 322 acres of crop and hay land

Fuel	Gal/acre*	Total annual fuel usage	Volumetric value relative to ethanol	Gallons of ethanol for replacement of existing fuel — Replacement percentage 100%	75%	50%	25%
Gasoline	8.5	2,737	1.5	4,106	3,080	2,053	1,027
Diesel	5.8	1,864	1.8	3,362	2,522	1,681	841
LPG	1.0	322	1.07	345	259	173	86
Totals =				7,813	5,861	3,907	1,954

*This is average gallons per acre of planted cropland and hayland in all of South Dakota.

Source of information on fuel use per acre and volumetric values: Dobbs, p. 4.

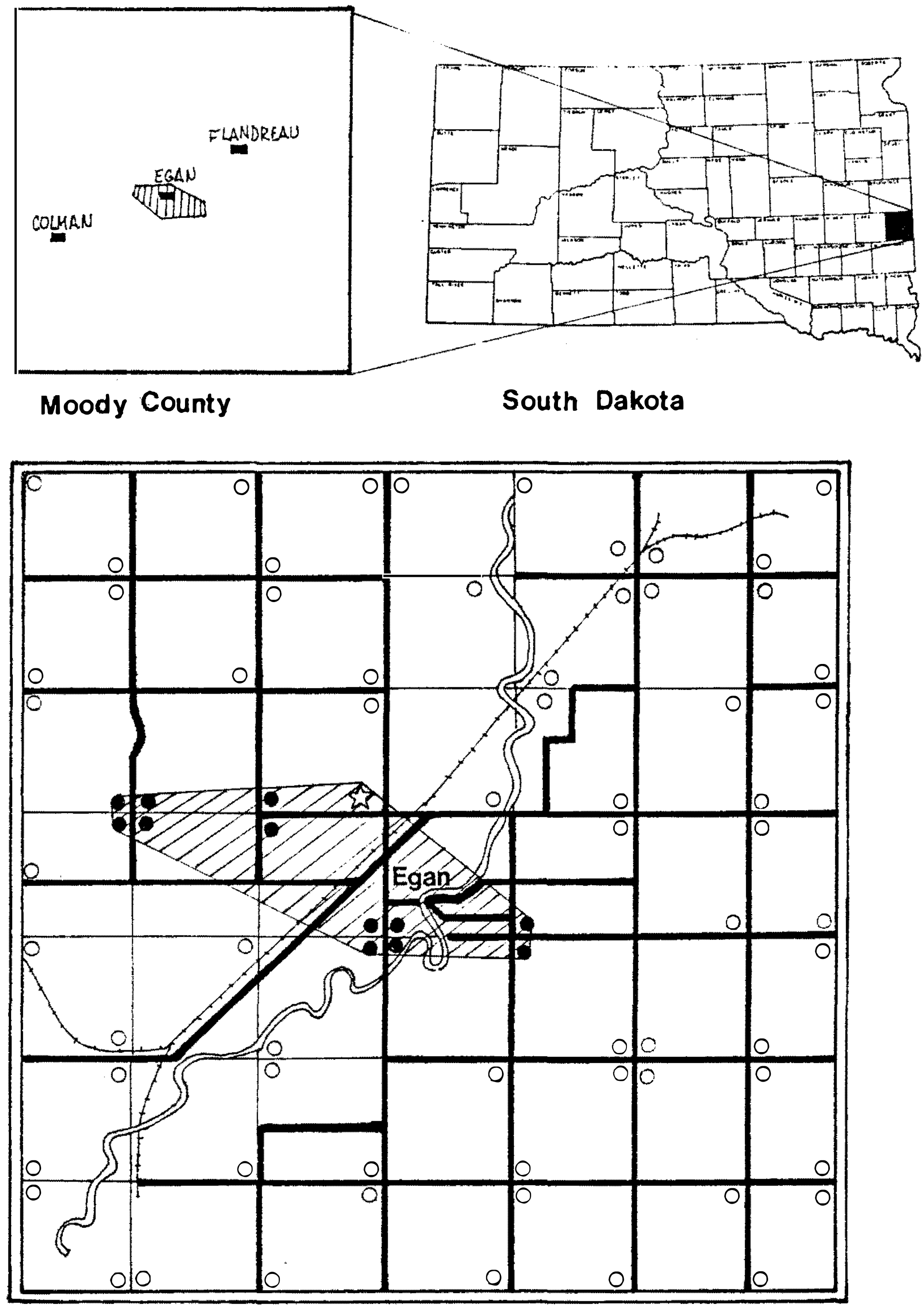


Figure 2: Assumed geographic distribution of farms in Moody County, for purposes of potential fuel alcohol consumption.

☆ Alcohol Plant Site

○ Potential Alcohol Consuming Farm Sites

● Farm Sites Selected to Consume Alcohol, Assuming Least Mileage Delivery Route

▨ Area Covered by Delivery Route

the map, the minimum mileage that can be driven to reach the nearest twelve farms on a two-day route would be 8 miles. If this route were taken twelve times a year, the total annual mileage for delivery of alcohol would be 96 miles. An additional 54 miles is assumed necessary for miscellaneous travel, bringing the total alcohol delivery mileage per year to 150 miles.

Costs of delivering the alcohol include the fixed costs of purchasing a bulk gas delivery truck and the costs of operating the truck. Because of the small delivery route and the few days per year in which the alcohol plant can actually utilize the gas truck, it is assumed that the truck can be rented to some other user for 3/4 of the year, or conversely, that the alcohol plant rents the truck for 1/4 of the year. In either case, only 1/4 of the annual fixed costs of owning the delivery truck are assigned to the alcohol plant.

Table 8 contains data on fixed and operating costs associated with the alcohol delivery truck. Fixed costs of the truck allocated to the alcohol plant add $.043 to the cost of each gallon of output, and operating costs of delivering the fuel to twelve farm customers add another $.022/gallon. Labor accounts for much of the delivery operating cost. Fixed and operating delivery costs combined add $.065/gallon to the cost of alcohol fuel under these assumptions.

Feed Byproduct Utilization Area

Because of the high protein content of the distillers wet grain (DWG) produced as a byproduct of the fuel alcohol, many fuel alcohol proponents have suggested substituting the DWG for soybean meal in livestock rations. Considering the price of soybean meal, the sale of DWG for livestock rations could prove to be a valuable source of income for an alcohol plant if the DWG has most of the nutritional charactertistics of soybean meal and if the DWG can be handled and stored inexpensively.

Most animal scientists agree that DWG will prove to be most useful in the feeding of ruminants. Ruminants are better able to digest the type of protein found in DWG than are non-ruminants (Kuhl, Voelker, Schoper). For this reason, only dairy farms and beef fattening farms are considered as feeders of DWG in this paper.

Estimation method.--The DWG produced at the alcohol plant must either be delivered to or picked up by the farmers. In both cases, a cost is incurred which must be considered when analyzing the economic substitutability of DWG for soybean meal.

If it is the intent of the plant management to deliver the DWG, three important factors need to be considered: (1) the length of time that the DWG can be stored; (2) the number of farms required to consume the annual byproduct output of the plant; and (3) the spatial distribution of the beef and/or dairy farms that will be feeding the DWG.

Table 8. Fixed and operating costs associated with delivery truck for the alcohol fuel (44,394 gallons delivered)

A. Fixed costs

Item	Full capital cost	Useful life (years)	Full amortized cost (15% interest)	¼ of annual amortized cost	Cost per gallon delivered
Bulk gas truck	$25,000	10	$4,975	$1,244	$.028
Vehicle license & insurance	2,294	1	2,294	573	.013
Tires	1,116	5	333	83	.002
Subtotals	$28,410		$7,602	$1,900	$.043

B. Operating costs

Item	Cost per unit	Units per year	Annual cost	Cost per gallon delivered
Gasoline	$ 1.30/gal	30 gal[1/]	$ 39.00	$.001
Oil, filter, grease	$17.25/change	2 changes	34.50	.001
Labor	$ 4.30/hr	192 hours	825.60	.019
Anti-freeze	$15/change	1/4 change	3.75	--
Tune-ups	$200/job	1/4 job	50.00	.001
Subtotals	=		$952.85	$.022
TOTALS OF A AND B =			$2,852.85	$.065

[1/] 150 miles/year ÷ 5 miles/gallon = 30 gallons/year.

The length of time that 70% moisture DWG can be stored without significant spoilage is still an unanswered question. Different storage techniques have been tested, but reports of their effectiveness have been mixed. Furthermore, little analysis has been done in determining capital costs of different storage techniques or labor costs associated with the time and inconvenience caused by some storage methods.

The addition of propionic-acetate acid to feed rations containing DWG is the method being used in dairy feeding trials at SDSU to increase storability time of the DWG. This method is the one assumed to be used in this analysis. It appears to allow for the safe storage of DWG for approximately 7 days before additional labor intensive storage methods need to be applied to prevent spoilage.

Before one can determine the number of livestock farms required to consume the feed byproduct of an alcohol plant, data are needed concerning the average number of animals per farm in the study area and the recommended daily consumption of DWG for the types of animals to be fed. The number of animals required to consume the annual byproduct output of the plant is calculated by dividing that output by the annual consumption per animal. The resulting number of cattle is divided by the average number of cattle per farm in the area to determine the number of farms needed to consume the byproduct.

Some spatial distribution of the potential byproduct consuming livestock farms around the alcohol plant must be assumed in order to calculate delivery mileage. To determine the spatial distribution of farms within a particular county, the total number of each type of cattle farm is divided by the number of square miles in the county, yielding the average number of cattle and dairy farms per square mile in the county. The placement of each farm within the square mile segments is done by a random number process. For instance, if there were an average of one livestock farm for each five square mile segment in a county, the section in which the farm is located is chosen by random number. In this paper, livestock farms are assumed to be located in either the northwest or southeast corner of each of the randomly selected sections.

Once the livestock farm sites have been randomly placed in the sections surrounding the alcohol plant, a delivery route to the required number of farms located closest to the plant is delineated and mileage is calculated. The fixed costs of a truck and associated equipment and the variable costs of covering the delivery route are estimated and divided by the annual alcohol output to ascertain the cost of delivering the byproduct per gallon of alcohol produced.

Application to Moody County.--The DWG produced at the SDSU pilot plant has a moisture content of approximately 70%. Recommendations for feeding DWG with this moisture level on a daily basis call for a safe feeding level of 9 pounds per animal in most beef rations and 35 pounds per animal in dairy cow rations. The "baseline" case plant described earlier in this paper could yield an annual alcohol output of 44,394 gallons. At this level of alcohol production, 988,533 pounds of

DWG would also be produced. This is an average of approximately 19,010 pounds of DWG per week over a 52-week year. The numbers of beef or dairy animals required to consume this weekly DWG output are:

$$(1)\quad \frac{\text{19,010 pounds DWG produced weekly}}{\text{(9 lbs of DWG per beef animal daily) (7 days/week)}} = \text{302 fattening beef cattle}$$

or

$$(2)\quad \frac{\text{19,010 pounds DWG produced weekly}}{\text{(35 lbs of DWG per dairy cow daily) (7 days/week)}} = \text{78 dairy cows}$$

Data from the 1978 Preliminary Agricultural Census indicate that the average beef fattening farm in Moody County contains 81 cattle and that the average dairy farm in Moody County has 28 dairy cows. Thus, a minimum of four beef fattening farms or three dairy farms would be required to consume all of the DWG produced annually by the case alcohol plant.

Because of the assumed 7-day storage restriction for DWG, the feed byproduct would have to be delivered to each participating farm on a weekly basis. The schedule for delivering the DWG was arrived at by using the following assumptions:

(1) A 1-ton truck is used to deliver the DWG.

(2) It takes 1 day per week to deliver the DWG to either four beef fattening farms or three dairy farms.

(3) The truck must be weighed before each delivery and after each delivery to determine the amount of DWG delivered. Therefore, it would be necessary to travel to each farm, unload, and travel back to the alcohol plant for weighing and reloading before delivering to the next farm.

As is the case with alcohol delivery, the total mileage involved in delivering the DWG is dependent on the spatial distribution of the beef and dairy farms in Moody County. There are about two dairy farms for every 10 square miles. The map in Figure 3 shows the distribution of dairy farms in Moody County, arrived at through the method described in the previous section.

A spatial distribution pattern for beef fattening farms in Moody County was arrived at in the same fashion. There are about four beef fattening farms for every 9 square miles in Moody County. The map in Figure 4 shows the distribution of beef fattening farms in Moody county, given the previously stated assumptions.

Given the distribution of dairy farms shown in Figure 3, the minimum weekly round trip mileage required to deliver to the three dairy farms nearest the alcohol plant is 16 miles. The map in Figure 4 indicates that the minimum weekly mileage needed to deliver DWG to the

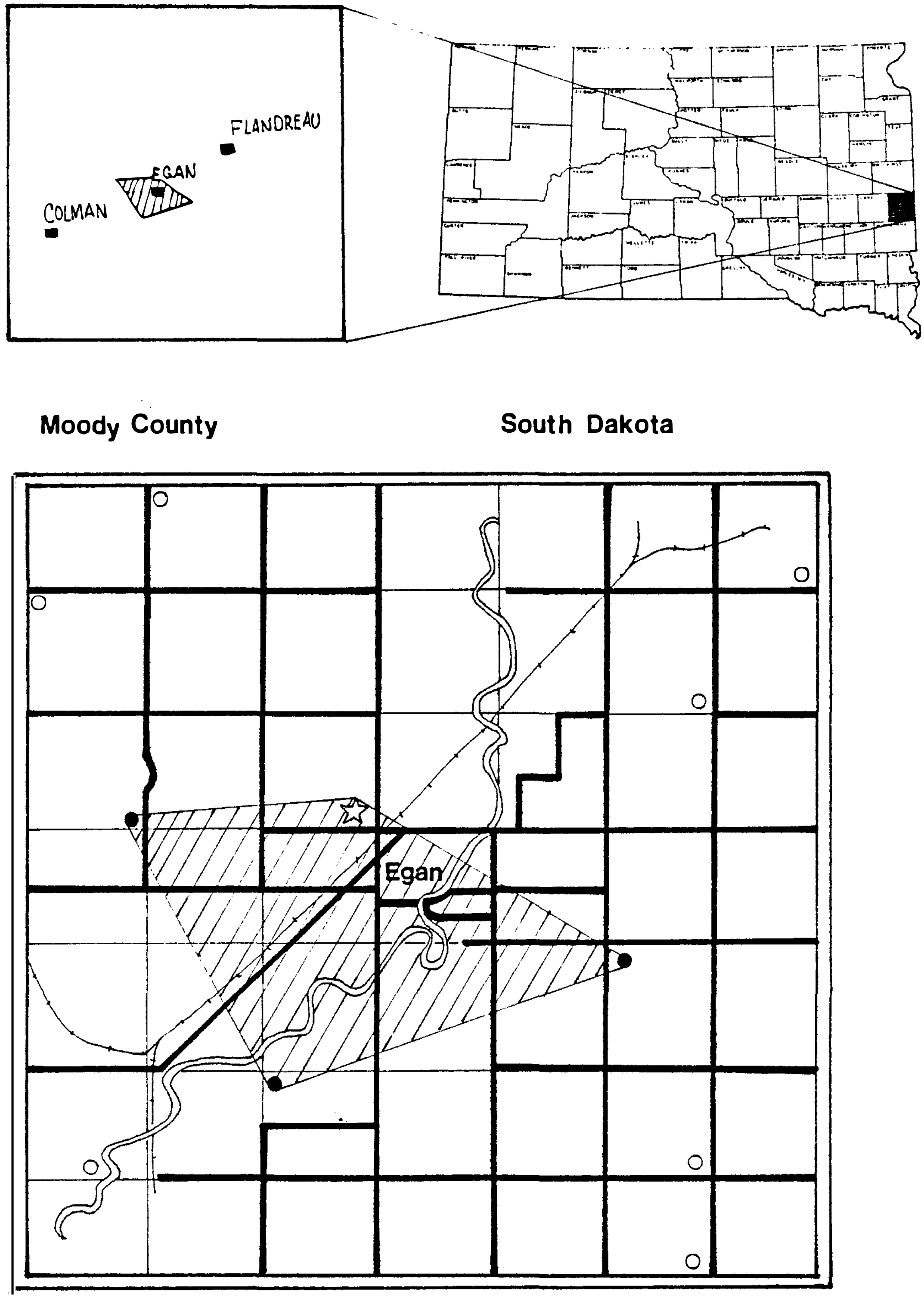


Figure 3: Assumed geographic distribution of dairy farms in Moody County, for purposes of feed byproduct consumption.

☆ Alcohol Plant Site

○ Dairy Farm Sites which are Potential DWG Users

● Dairy Farm Sites Selected to Consume DWG, Assuming Least Mileage Delivery Route

▨ Area Covered by Delivery Route

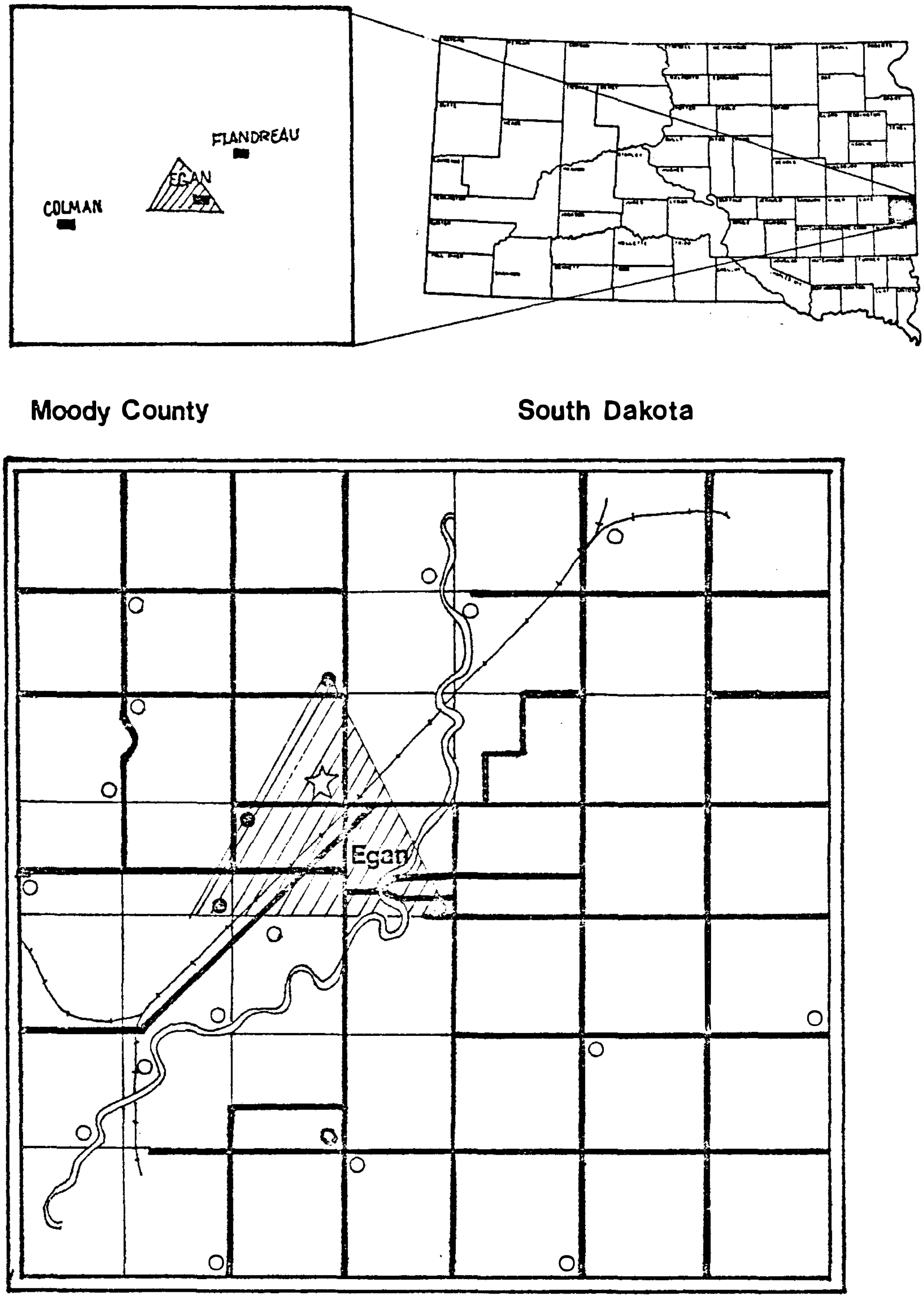


Figure 4: Assumed geographic distribution of beef fattening farms in Moody County, for purposes of feed byproduct consumption.

☆ Alcohol Plant Site

○ Beef Fattening Farms which are Potential DWG Users.

● Beef Fattening Farms Selected to Consume DWG, Assuming Least Mileage Delivery Route

▨ Area Covered By Delivery Route

four beef fattening farms nearest the alcohol plant would be 12 miles. Because of the lower mileage requirements, it is assumed here that the alcohol plant's DWG will be delivered to beef fattening farms. The deliveries require 624 direct miles of travel annually, rounded upward to 700 miles annually to account for miscellaneous travel.

The costs of delivering the DWG to the four beef fattening farms are divided into fixed and operating costs, shown in Table 9. The fixed costs consist of a one ton delivery truck, compensation plates, insurance, and tires. As with the alcohol delivery truck, the feed byproduct delivery truck will not be fully utilized by the baseline case alcohol plant during the course of a year. Therefore, it is assumed that the truck is rented by some other user for 2/3 of the year, and that only 1/3 of the fixed costs associated with owning the truck are assigned to the alcohol plant. With this assumption, the fixed cost of delivering the DWG comes to $.03/gallon of fuel alcohol produced.

When total operating costs of $.064/gallon of alcohol are added, the total cost of delivering the feed byproduct comes to $.094/gallon. Much of the operating cost component is for the labor cost of loading, unloading, and driving the truck for 8 hours each week.

Summary of Location Analysis for 45,000-gallon Plant

The location analysis reported in this paper is structured to fit the assumptions of the baseline case alcohol plant in terms of corn input and alcohol and feed byproduct output capacity. The organizational setting of the plant is assumed to be a farmers' cooperative located in central Moody County in South Dakota.

The amount of corn needed for the case study plant could be supplied by two average size farms in Moody County. Because of nearness to local elevator facilities, transportation costs are subsumed into the local price of corn.

To dispose of the total alcohol output of the plant, twelve farms would be required to replace 50% of their liquid fuel needs with alcohol. Four beef fattening farms or three dairy farms would be required to use the feed byproduct, in order to dispose of the total byproduct output. Because it would result in lower delivery costs, the analysis of this paper assumed the byproduct is sold to beef fattening farms.

Costs of delivering 44,394 gallons of alcohol and 988,533 pounds of distillers wet grain (DWG) are figured on a minimum basis. In other words, it is assumed that the farmers located nearest the alcohol plant can be persuaded to participate in the cooperative or to buy the plant's products. Given the conditions stated in the baseline case alcohol plant scenario, delivery of both the fuel alcohol and the DWG will add $.159 to the total production cost of each gallon of fuel alcohol.

Table 9. Fixed and operating costs associated with delivery truck for the feed byproduct (44,394-gallon fuel/year alcohol plant, with 988,533 pounds/year of byproduct)

A. Fixed costs

Item	Full capital cost	Useful life (years)	Full amortized cost (15% interest)	1/3 of annual amortized cost	Cost per gallon of alcohol produced
One-ton truck	$14,000	10	$2,786	$ 929	$.021
Vehicle license & insurance	960	1	960	320	.007
Tires	900	5	268	89	.002
Subtotals	$15,860		$4,014	$1,338	$.030

B. Operating costs

Item	Cost per unit	Units per year	Annual cost	Cost per gallon of alcohol produced
Gasoline	$ 1.30/gal	64 gal[1]	$ 83.20	$.002
Oil, filter, grease	$14.75/change	2 changes	29.50	.001
Labor	$ 4.30/hr	416 hours	1,788.80	.040
Anti-freeze	$15/change	1/3 change	5.00	--
Tune-ups	$200/job	1/3 job	66.67	.002
Weigh payments[2]	$2/weigh	416 weighs	850.00 (rounded up)	.019
Subtotals =			$2,823.17	$.064
TOTALS OF A AND B =			$4,161.17	$.094

[1] 700 miles/year ÷ 11 miles/gallon = 64 gallons/year.

[2] To weigh the farm truck carrying the feed byproduct, it is assumed that the alcohol firm could use the local grain elevator scale. Eight weighs/week (four filled and four empty) at $2/weigh, comes to nearly $850/year.

Transportation costs for a small scale alcohol plant represent a relatively minor item in the total cost of producing each gallon of fuel alcohol. However to minimize costs, it appears that the proximity of customers for the fuel alcohol and the feed byproduct is more important than proximity to the supply of corn input, given the plant is located in a corn-producing area. Producers who haul their corn to the local elevator could probably haul it to the local alcohol plant without extra transportation costs.

Extension of Location Analysis to 165,000-gallon Plant

An increase in the volume of alcohol and DWG associated with expanding the size of the alcohol plant would require a greater effort in coordinating the delivery of those products to farm customers. Because of the very preliminary nature of our "expanded" plant analysis at this time, a detailed sketch of possible delivery scenarios--such as was presented for the 45,000-gallon capacity plant--is not drawn in this paper. Instead, only some basic estimates of farm customer numbers are made, on which general approximations of delivery schedules, mileages, and transportation costs could be based.

The locational setting for an "expanded" alcohol plant is also assumed to be central Moody County of South Dakota. The corn required to produce 166,320 gallons of alcohol in an expanded plant is about 69,350 bushels. This would be equivalent to the corn produced on 834 acres (or on about six Moody County farms).

It is assumed that the expanded plant would be capable of producing only 190-192 proof alcohol. Thus, as with the 45,000-gallon plant, alcohol is presumed to be used as a replacement for liquid fuels currently being utilized on local farms.

If each farmer participating in or buying from the alcohol cooperative is able to replace 50% of his conventional liquid fuels with alcohol, then forty-three farms would be needed to consume the alcohol output of the expanded plant. This compares with twelve farms for the baseline (45,000) plant.

The number of dairy or beef farms needed to consume the annual output of DWG produced by the expanded plant also increases proportionately. With the expanded plant producing around 71,220 pounds of DWG each week of the year, it would require either 291 dairy cows or 1,131 fattening beef cattle to consume the total feed byproduct output of the plant. Given the average size of livestock farms in Moody County, this means that the alcohol plant would need to have DWG delivered to either eleven dairy farms or fourteen beef fattening farms. Only three dairy farms or four beef fattening farms are required in the case of the 45,000-gallon plant.

Although costs of delivering the alcohol and DWG produced in the expanded plant are not examined in this paper, it is obvious that those costs will increase, in total, over the delivery costs presented for the 45,000-gallon alcohol plant. However, delivery costs on a per gallon of alcohol basis may well decrease. The per gallon costs for fixed items such as the delivery truck are likely to be less for the expanded plant, whereas the variable delivery costs may not differ significantly from those shown for the baseline plant.

Putting It All Together

Territory to be Served by a Small Scale Plant

A procedure for examining the economic feasibilty of small scale fuel alcohol plants has been presented in this paper, with plants patterned after the SDSU pilot plant used as "cases" to illustrate the method and to indicate preliminary cost findings. Preliminary data from research at SDSU and findings from studies elsewhere revealed that per unit costs--at least for small or community scale plants--are likely to decline with increases in levels of output. Balanced against these economies of scale in production is the fact that transportation costs can be kept down when plants are located close to corn supplies and to farm customers of the fuel and feed byproduct. Delivery costs for the fuel and feed byproduct are small in relation to production costs.

Hence, it makes economic sense for so-called community scale plants to be as large as available technology, capital, and management (including marketing) capacity permit. In the case of a plant utilizing a distillation unit like that at SDSU, production of at least 150,000 gallons of alcohol per year should be the goal. With larger distillation units and greater fermentation capacity, community scale plants might well be striving for an annual output of 500,000 or 1,000,000 gallons. However, the larger the plant, the more critical it becomes--from a fuel marketing standpoint--to achieve production of anhydrous alcohol.

A plant patterned after that at SDSU could produce around 165,000 gallons of 190 proof alcohol per year if sufficient fermentation capacity were to accompany the distillation unit. Corn feedstock requirements of such a plant could be met by as few as six farms in a typical southeastern South Dakota county. The product marketing territory would need to be larger than that, however.

If the distillers wet grain (DWG) were utilized by beef animals, it would require about fourteen beef fattening farms to consume this byproduct. This is equivalent to about 6% of the beef fattening farms in the county used for case study analysis in this paper. If beef fattening farms closest to the plant utilized all of the byproduct, the feed byproduct marketing territory would be an area of about 32 square miles. If only every third beef farm reaching out from the plant site relied on DWG from the plant, the marketing territory would encompass a little less than 100 square miles.

Marketing of 190 proof alcohol from a community scale plant is likely to require as large a territory as is required for disposing of the feed byproduct. If farmers were willing and able to substitute fuel alcohol for 50% of their conventional fuel needs--a very optimistic assumption at the present time--it would require forty-three farms in the case study county to utilize the fuel from an approximatley 165,000-gallon/year plant. Assuming these farmers are the ones closest to the plant, this would constitute a fuel marketing territory of 29 square miles. If, instead, every third farm utilized alcohol fuel to replace 50% of its conventional liquid fuel requirements, the marketing territory would be nearly 90 square miles. Even this latter assumption may be optimistic for the near future, given limitations, costs, and inconveniences in converting existing farm vehicles and motorized equipment to utilize hydrous alcohol. Hence, a community scale alcohol operation is likely to require at least as large a marketing territory for its fuel as for its feed byproduct at the present time.

Organizational and Financial Considerations

A cooperative setting has often been referred to in this paper, but organizational and financial considerations have not been elaborated. The kind of community scale plant (of either the 45,000-gallon or the 165,000-gallon size) discussed in this paper could be organized financially and managerially in a number of ways. Sole proprietorships, corporations, and cooperatives are all possibilities. Each has advantages and disadvantages.

A possible key advantage of the cooperative approach for a community scale plant, however, is the commitment of members to utilize the 190 proof fuel and the DWG byproduct. Marketing 190 proof alcohol is likely to present very serious problems for small plants unless cooperative members or other kinds of customers have some kind of binding commitment to accept the fuel. Also, because of storage time limitations on the semi-wet feed byproduct, a reasonably dependable set of customers in the general vicinity of the plant is important. Cooperative members who have a financial stake in the alcohol plant itself are more likely to provide such dependability than are other potential customers.

One aspect of fuel alcohol economic research currently underway at SDSU focuses on the feasibilty of cooperative organization for management and finance of community scale alcohol plants. Financing possibilities, returns on members' investments, marketing agreements, and dividend policies are among the considerations included in that cooperative analysis. It is an attempt to determine not only if a small alcohol plant patterned after the SDSU pilot plant could be economically feasible, but whether the cooperative method of organizing and financing such an operation appears practical.

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