Economic Report ER78-10

Economics of Gasohol

by
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Department of
Agricultural and Applied Economics

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SUMMARY

This report analyzes the feasibility of producing ethyl alcohol from grain and blending it with gasoline to form gasohol for use as a motor fuel. Each bushel of corn is assumed to produce 2.7 gallons of 200^{o} proof ethyl alcohol and 18.36 pounds of distillers' dried grains and solubles (DDGS) used for livestock feed. A bushel of wheat produces 2.6 gallons of 200^{o} proof ethyl alcohol and 16.9 pounds of DDGS. The report evaluates the energy balance of alcohol and tion, reviews the literature on characteristics of gasohol as a motor fuel and evaluates the economic feasibility of alcohol production. The report also analyzes the effect of a subsidy program on the economic feasibility of gasohol and its likely impact on farm income levels.

The analysis in this report shows that for every BTU of fossil fuel energy that goes into making alcohol from corn between .43 and .636 BTU's are obtained, the ratio depending on the method of computation. The methods underlying the two ratios are summarized below:

Energy Output-Input Ratios for a Gallon
of Alcohol Produced from Corn

Method 1

Input	BTU's
Direct energy required to produce the corn - - - - - - - - -	39,780
Direct energy used to convert the corn into alcohol - - - -	174,660
Total	214,440
Output	
Energy content of alcohol - - - - - - - - - - - - - - - - - -	84,400
Energy content of distillers' dried grain and solubles - - -	52,000
Total	136,400

Ratio: $\frac{136,400}{214,440} = .636$

Method 2

Input	BTU's
Energy required to produce the portion of the corn transformed into alcohol (portion of corn transformed into distillers' dried grain and solubles omitted) - - - - - - - - - - - - - - - -	22,277
Energy used to convert the corn into alcohol - - - - - - - - - - -	174,660
Total	196,937
Output	
Energy content of alcohol -	84,400
(Energy content of distillers' dried grain and solubles omitted)	

Ratio: $\frac{84,400}{196,937} = .43$

While the proper method of allocating the BTU's used to produce ethyl alcohol between the alcohol and DDGS can be debated, the important point is that more BTU's are required to produce the alcohol than the alcohol contains.

Gasohol, as a fuel, presents some minor problems. It has a lower BTU content than gasoline; therefore, miles per gallon with gasohol will be no greater than for gasoline. Mixing alcohol with gasoline has been suggested as an effective way to increase octane number, but the increase in octane number, in road tests, is practically nil for premium gas. Some minor problems exist with vapor lock but can be corrected by changing the gasoline mix. There is also a problem of separation into component parts if water is present in quantities greater than one percent. This can be remedied with a more water-free distribution system. Every correction or alteration required to facilitate the use of gasohol adds extra costs which must be justified by the properties of gasohol.

The cost of producing ethanol was estimated for alternative sizes of production facilities. Economies of size exist because of both decreasing investment costs and lower operating costs per gallon of capacity as plant size is increased. The costs were examined in detail for two plant sizes, 17 million and 34 million gallons of annual capacity. It was estimated that the initial investment would total $24,275,000 for a plant producing 17 million gallons annually. The investment for the 34 million gallon plant is $37,990,000. The annual ownership costs (for depreciation, interest, insurance and real estate taxes) are $.186 per gallon for the 17 million gallon plant and $.145 per gallon for the larger plant. The operating costs for the two sizes of plant were broken down into the cost of the corn, cost of electricity, cost of fuel oil and other operating costs. A credit was allowed for the value of the DDGS produced as a by-product of the operation. The cost of gasohol is calculated assuming .1 gallon of alcohol is combined with .9 gallon of gasoline.

The analysis for the 34 million gallon plant with current electricity and fuel oil prices, and the current wholesale price of gasoline ($.43 per gallon) is summarized graphically in Figure i. The graph indicates that for any price of DDGS, the cost of producing gasohol (and hence minimum price of gasohol) increases as the corn price increases. The graph also indicates that the price of DDGS is an important determinant of the cost of gasohol production. While DDGS historically has been priced as a high protein feed, the production of large quantities of DDGS from a regional or national gasohol program would significantly increase the supply of protein feed causing the price of DDGS to drop. The analysis in this report indicates that DDGS has feeding value as a source of energy approximately equal to corn. Thus, it is reasonable to expect the price of DDGS to be approximately equal to the price of corn on a pound for pound basis if large quantities of DDGS are produced.

The data in Figure i indicate the breakeven price of gasohol is well above the price of gasoline at the current time even for the largest and lowest-cost plant analyzed. For example, the figure indicates that with a corn price of $2.50 per bushel (approximately $.045 per pound), a DDGS price of $100 per ton, or $.045 per pound, and a wholesale price of regular gasoline of $.43 per gallon (the wholesale price in Minneapolis during the Fall of 1978), the cost of gasohol is $.519 per gallon, or $.089 per gallon higher than the cost of gasoline. The graph indicates that the difference between the break-even price of gasohol and the price of gasoline narrows as grain prices decline. However, the analysis indicates that even if the price of corn is reduced to zero, the value of DDGS would have to equal $90 per ton for the cost of gasohol composed of 90% gasoline and 10% alcohol to have a cost per gallon as low as gasoline.

It is sometimes argued that gasohol will become more feasible as the price of gasoline increases. However, as the cost of gasoline increases the cost of other forms of energy and other inputs used to produce ethyl alcohol also increase. The analysis in Figure ii is based on a doubling of wholesale gasoline prices from $.43 to $.86 per gallon and a doubling of the electricity and fuel oil costs included in operating the plant. However, the capital investment and other costs (including labor) have been held constant. Under these assumptions with a corn price of $2.50 per bushel and a DDGS price of $100 per ton, the cost of gasohol is $.944 per gallon or $.084 per gallon higher than the wholesale price of gasoline. In this case the analysis indicates that even if the corn price is zero, the value of DDGS would have to equal $75 per ton for the cost of gasohol to have a cost per gallon as low as gasoline. It is likely that the costs of inputs other than electricity and fuel oil would increase in response to increasing energy prices. If this occurs, it will increase the divergence between the cost of gasohol and the wholesale price of gasoline.

The reader should note the analysis is based on the cost of producing ethyl alcohol. Neither the profit margin usually required to attract private investment nor an allowance for additional distribution costs associated with selling a blend of alcohol and gasoline have been included. For these reasons the difference between the break-even cost of gasohol and the wholesale price of gasoline may be somewhat larger than shown in Figures i and ii.

Figure i. Price of Gasohol for Varying Prices of Corn in the 34 Million Gallon Alcohol Plant with the Wholesale Price of Gasoline set at $.43 per Gallon.

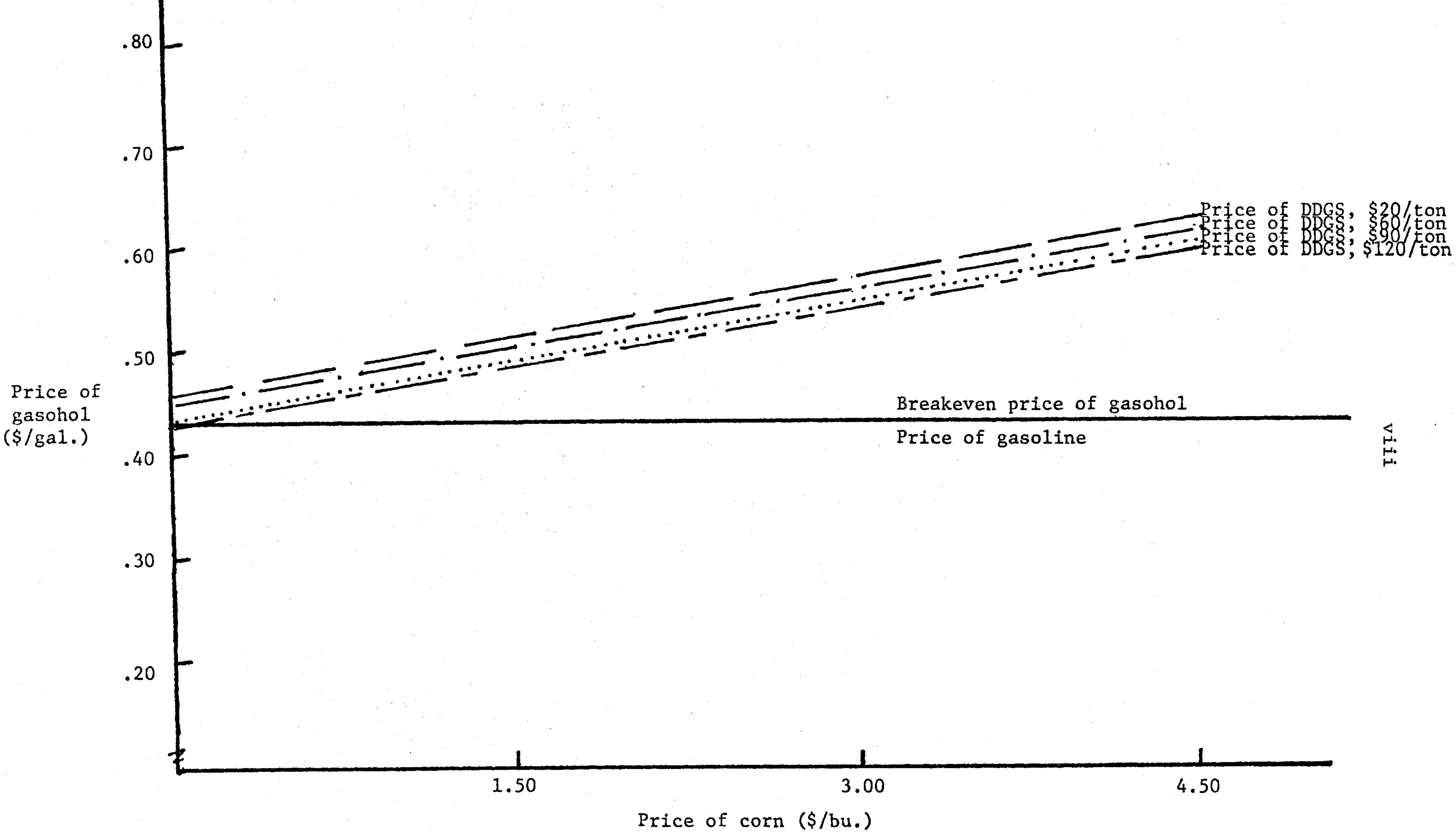
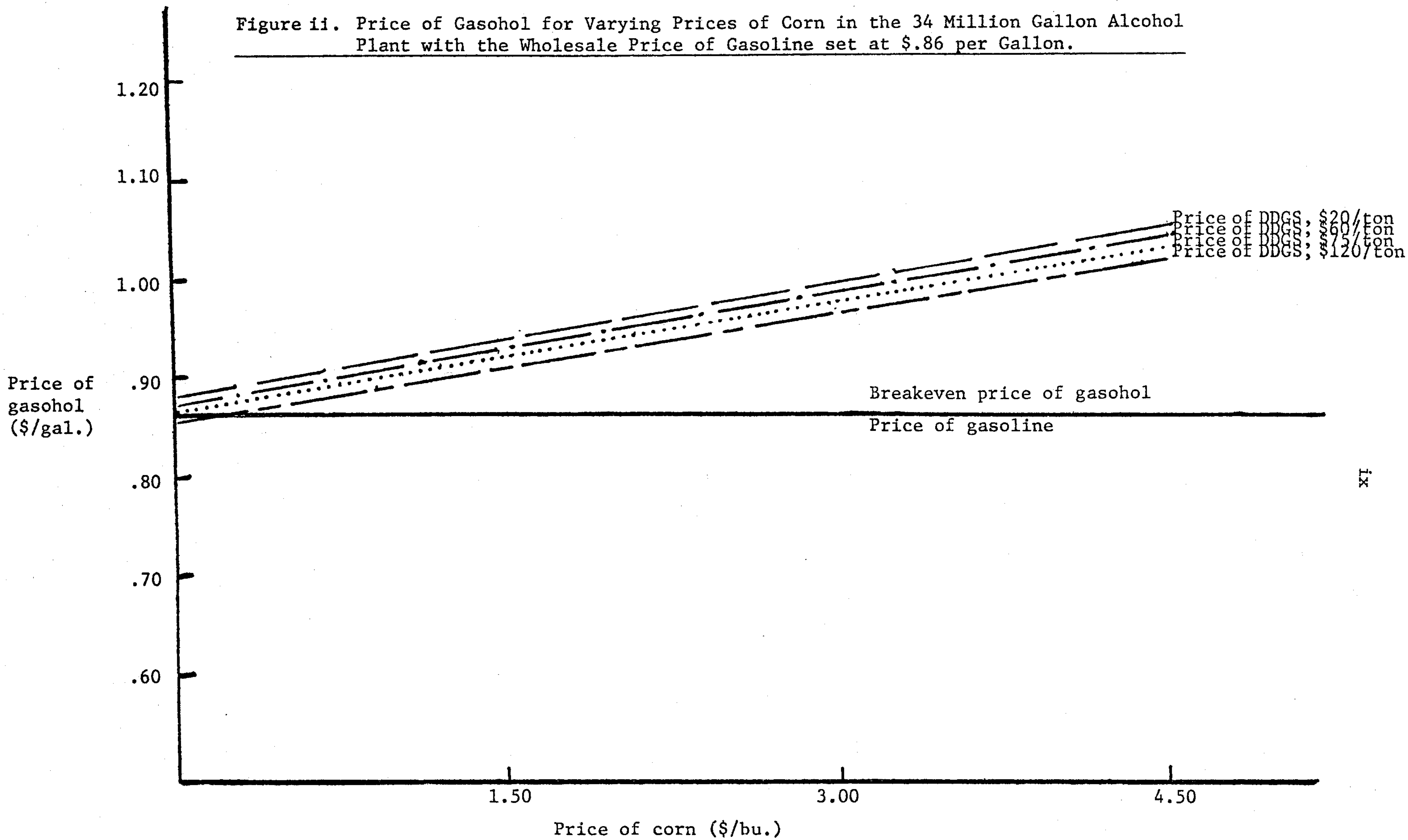


Figure ii. Price of Gasohol for Varying Prices of Corn in the 34 Million Gallon Alcohol Plant with the Wholesale Price of Gasoline set at $.86 per Gallon.



The possibility of subsidizing gasohol through the state and federal gasoline tax was analyzed. The discussion above indicates a subsidy of about $.09 per gallon would be required for corn prices of $2.50 per bushel and wholesale gasoline prices in the range of $.43 to $.86 per gallon. The $.09 subsidy could be accomplished by eliminating the $.04 federal tax on gasoline and reducing the state tax by $.05 per gallon.

Reducing collection of state and federal gasoline taxes would reduce funding for regular projects, supported by these revenues, particularly the highway fund. For instance if Minnesota were to adopt a total gasohol usage program, it would require 194 to 214 million gallons of alcohol per year. If alcohol is subsidized by $.50 per gallon ($.05 per gallon of gasohol) state gas tax revenues would be reduced $97-$107 million annually. Because the portion of the highway fund that is spent on interstate highways is matched by federal funds in a ratio of 90 federal dollars to 10 state dollars and the portion spent on secondary roads is matched 72 federal to 28 state dollars, the impact on the highway fund would be much greater than the loss in state tax dollars.

As the price of corn rises as under a national program, the subsidy to gasohol must be increased. The maximum subsidy that can be provided through reduction of federal and state tax in Minnesota is ($.09 state tax and $.04 federal tax elimination or) $.13 a gallon of gasohol.

Economics of Gasohol[1/]

by M. Litterman, V. Eidman and H. Jensen*

Introduction

When grain prices are low, farmers look for ways to increase demand and prices for agricultural products. An idea often revisited is converting grains into ethyl alcohol to blend with gasoline. The current name for such a fuel is gasohol. Gasohol is most often defined as a ten percent alcohol-ninety percent gasoline blend, which is the ratio used in this report. Diesehol is currently under investigation to determine the feasibility of alcohol diesel fuel blends.

The purpose of this study is to investigate the economic feasibility of ethyl alcohol as a motor fuel. Economic feasibility, as used in this study, means that the cost of producing the alcohol is less than or equal to the market value of the gasoline it replaces.

Several issues are related to economic feasibility. These issues are energy balance, fuel properties of an alcohol blend, market conditions and use of by-products of the alcohol production process, subsidy proposals to encourage alcohol production, effects of gasohol production on farm income, comparison of ethyl alcohol with other types of alcohol or other energy sources and finally, the social problem of bootlegging. A short overview of these issues follows.

Energy balance is defined as the ratio of the energy (BTU's) in a gallon of 200^{o} proof alcohol and its by-products to the direct energy (BTU's) used to produce the grain used in a gallon of alcohol plus that used in the plant to convert the grain into a gallon of alcohol. The BTU content of a gallon of alcohol and its by-products must be equal to or greater than the BTU's required to produce it for the process to be energy efficient. While energy efficiency is of interest, this report is primarily concerned with economic efficiency.

[1/] This report has been done at the request of and financed by the Minnesota Energy Agency.

We wish to acknowledge the helpful suggestions of H. A. Cloud and D. Thimsen, Professors, Agricultural Engineering Department, University of Minnesota, who reviewed the manuscript. We wish also to acknowledge the assistance of Professor R. D. Goodrich, Animal Science Department, University of Minnesota, who helped formulate cattle feeding rations so that an economic evaluation could be made of distillers' dried grain and solubles, a by-product of alcohol production. Finally, we wish to express our thanks to Midwest Solvents Company, Inc., Atchinson, Kansas, for providing us with basic data on plant investment and operating costs for alcohol production.

* M. Litterman is a Graduate Research Assistant and V. Eidman and H. Jensen are Professors in the Department of Agricultural and Applied Economics, University of Minnesota.

Fuel properties of gasohol considered in this report are: BTU content, octane number, emissions and general driveability. Gasohol is then compared with gasoline on the basis of these properties.

In the production of alcohol the two major by-products obtained are distillers' grains and carbon dioxide. These by-products are essentially obtained in equal quantities from a bushel of corn or wheat. The worth and use of these by-products, ultimately affects the economic feasibility of gasohol. Currently, the markets for distillers' grain are small, and for carbon dioxide, poorly developed. If gasohol is produced on a large scale, these by-product markets must necessarily expand to accommodate the increased by-product production. The by-product grain will have an impact, not only on its own price, but also on prices of competing commodities.

If gasohol turns out to be economically infeasible, it could still be produced if subsidized. Who gains from a subsidy depends on how the subsidy is set up. This report deals briefly with subsidies as well as farm income.

A possible goal of a gasohol program is to raise farm income. However, the farmer is only one agent in a gasohol production process. Others involved are the alcohol plant producers and the retailers of gasohol. Each agent involved hopes to make a profit.

This report examines grain alcohol in relation to other alcohol fuels and energy sources as fuel blends. The basis for comparing alcohol with other energy sources is economic feasibility.

Alcohol production involves social, as well as economic considerations. Ethyl alcohol can be diverted to human consumption either by separating the alcohol from the gasoline, by producing it illegally in a small on-farm still and claiming the alcohol will be used as fuel, or by obtaining it illegally from a large alcohol plant. Controlling bootlegging adds to the cost of administering a gasohol program.

This report analyzes gasohol programs at seven different levels. The first and smallest is the single plant level. Another level is gasohol for agricultural use only, which is examined at three levels: state, regional and national. The use of gasoline in agricultural production has decreased over the past years while the use of diesel fuel has increased. This change is evidenced by the fact that diesel-powered tractors have been substituted for gasoline-powered tractors over the past years. The trend is predicted to continue, with a projected decrease of gasoline tractors of 56% from 1970 to 1980. The number of diesel-powered tractors is expected to double during the same period [32, p. 21]. Therefore, we are experiencing a dramatic change in composition of fuel use in agricultural production. For this reason, gasohol programs involving only agricultural production tend to be small.[2] The remaining levels of gasohol programs examined are total usage at the state, regional and national levels. The principal user of gasohol for these levels is, of course, the automobile. Except for 1974, the trend of gasoline consumption for these levels was upward.

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[2] A later report will examine the economic feasibility of using alcohol as a blend with diesel fuel.

Tables 1 and 2 (Appendix I) show the amount of fuel used in agriculture. Table 1 shows gasoline and diesel fuel usage for crops at three levels: state, regional and national. Table 2 gives the same information for livestock. Since gasohol requires nine gallons of gasoline to be mixed with one gallon of alcohol, the alcohol production needed for each individual crop even at the U.S. level is small.

Alcohol Production

The method of making ethyl alcohol varies with the material used. Basically, three types of products can be used in the fermentation process. These are the saccharine materials (molasses, sugar beets, sugar cane), the starchy materials (grain, potatoes, Jerusalem artichokes) and the cellulosic materials (wood, agricultural residue). The saccharine materials are most often used for producing industrial alcohol by fermentation. For instance, sugar cane is widely used in Brazil to make alcohol for use in fuel blends. Molasses was the most widely used source up to and during World War II.

Interest today lies in using grain to make alcohol for use as a fuel blend. Essentially any grain can be used, but the best in terms of alcohol yield are corn and wheat. These two crops, corn and wheat, give the highest yield of alcohol per bushel, 2.7 and 2.6 gallons, respectively (Table 1). Problems exist, however, in the use of wheat. The gluten content of wheat creates a severe foaming problem. Therefore, wheat cannot be used by itself in producing alcohol. Wheat should be used only in combination with other grain, then only in proportions of one quarter or less. To overcome the foaming problem by other means requires larger containers to hold the fermenting wheat mash or removal of the gluten before fermentation. Both of these methods add greatly to processing costs.

The use of distressed (sprouted or moldy) grains has been suggested. Sprouting in distressed grains causes starch to be converted into sugar which is used by the seedling. This loss of starch content may be as high as 40%, thus lowering the alcohol yield considerably /12, p. 5/. While distressed grain can be used, assembling a constant supply of it for alcohol production is a problem.

Table 1. Alcohol Productivity of Field Crops[a]

Crop	Unit	Alcohol Yield (gallons)
Barley	bu.	2.05
Oats	bu.	1.05
Corn	bu.	2.70
Wheat	bu.	2.60
Potatoes	bu.	1.11
Sugar Beets	bu.	.72

[a] It should be noted that sources disagree frequently on the amount of alcohol per unit. For example, the yield of alcohol per bushel of corn ranges from 2.41 to 2.7. Although 2.7 may be on the high side we use 2.7 for corn and 2.6 for wheat in this study since these figures frequently are cited in the literature and give a currently much discussed program, gasohol, the benefits of somewhat uncertain conversion ratios.

Sources: Clark, D.S., Fowler, D.B., Whyte, R.B., and J.K. Wiens, Ethanol from Renewable Resources and Its Application in Automotive Fuels, p. 44 (potatoes, sugar beets) /5/.

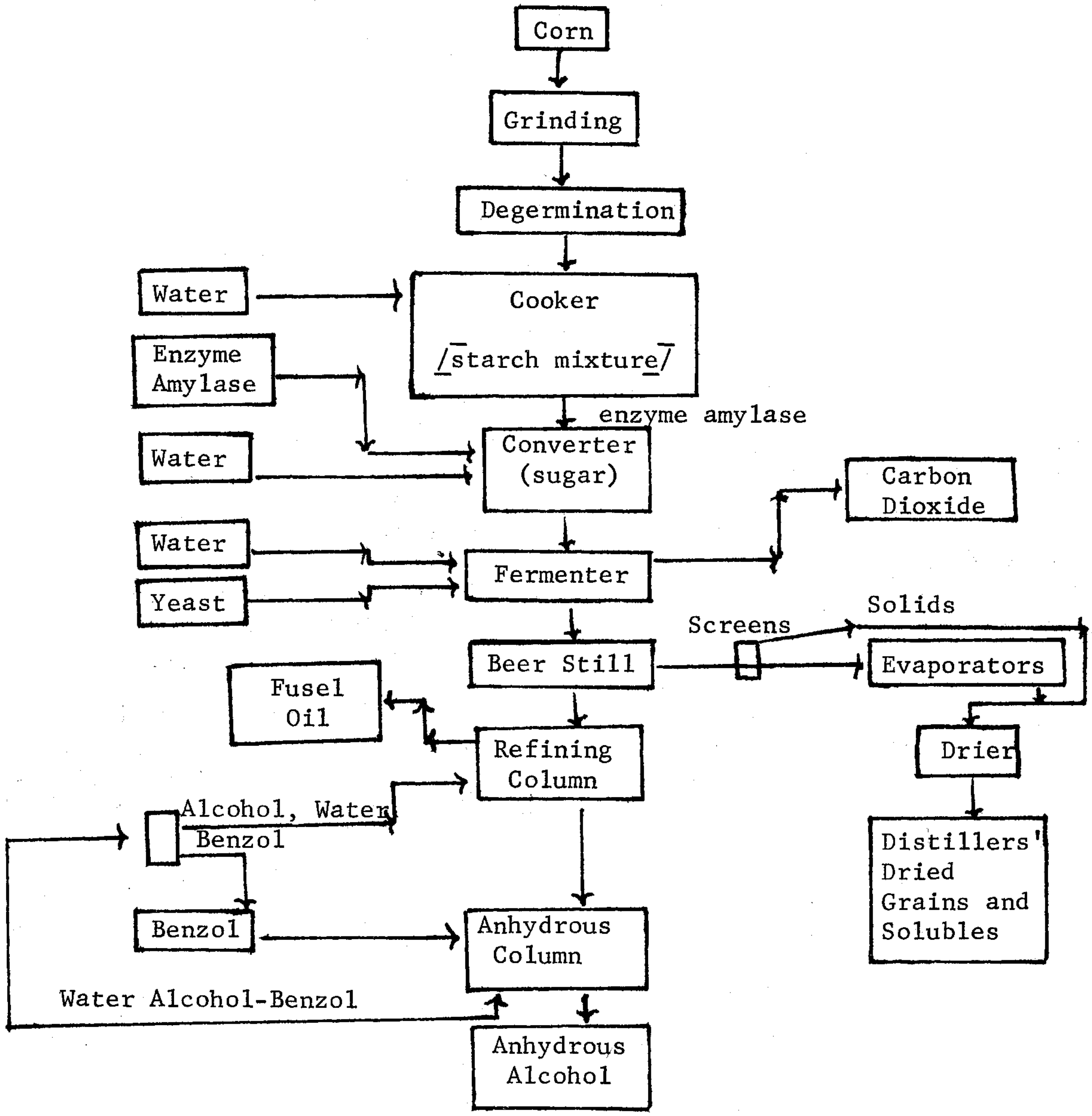
USDA, Motor Fuels from Farm Products, p. 24 (barley and oats) /31/.

Miller, D.L., Fermentation Ethyl Alcohol, 1976 (wheat and corn) /17/.

The actual process of making alcohol is very old and has changed very little over the years. The process used today is described below and illustrated in Figure 1. First the grain is ground to the correct fineness and water is added. This mixture is heated under pressure with steam, which serves to gelatinize the starch as it softens and disintegrates the grain. This gelatinized mixture is then blown to a vat where it is cooled to the mashing temperature of 60° C (140°F) and the enzyme amylase is added. This enzyme converts the starch into sugar.[3] The converted sugar solution is cooled to the fermenting temperature of about 18° to 29°C (65° to 85°F), transferred to fermenting vats and yeast is added. The yeast converts the sugar mixture into alcohol. This mixture of solids and

[3] The enzyme itself is an innovation or technical improvement in the process. The enzyme, amylase, is produced from mold on a small amount of grain. In the past, malt was added to the starch mixture; the malt enzyme, diastase, then converted the starch into sugar. Now, however, this more efficient process is used and the conversion factor of starch into alcohol is now up to 95% of the theoretical yield as opposed to 90% obtained with malt /25, p. 4/.

Figure 1. Alcohol Production Process



Source: USDA, Motor Fuel from Farm Products, p. 51./31/.

liquids is then sent through a series of distillation columns where the alcohol is separated from the residual grain. The alcohol is sent on through additional columns where it is refined to 190° proof. This 190° proof mixture is then dehydrated through an extraction distillation process to 200° proof ethyl alcohol. The residual grain is then dried to yield distillers' dried grains and solubles /6/, /31/ and /26/.

The 200° proof alcohol in its distilled form is potable or drinkable. Potability presents a problem for the U.S. Treasury Department, which controls production and taxes potable alcohol. Technically, this problem can be solved by an IRS approved denaturing formula. In this process a denaturing agent, such as wood alcohol, is added to make the alcohol unfit for human consumption. However, the problem is not completely solved with this solution as any denaturing agent added can be separated from the alcohol with varying levels of difficulty. A non-separable agent is not known at the present time, but further work is being done on this problem /31, p. 16/.

By-Products of Alcohol Production

The yield of distillers' dried grains and solubles (DDGS) is 18.36 pounds per bushel of corn and 16.9 pounds per bushel of wheat /17/. Almost equivalent amounts of carbon dioxide (CO_2) can be retrieved, or approximately 17.0 pounds of CO_2 per bushel of corn and 16.4 pounds per bushel of wheat /31, p. 79/. (The problem of using only a mixture of 25% wheat is ignored at this point.) Two other by-products from distillation are fusel oil and aldehydes. Alone they are quite volatile, so they are usually left in the alcohol /27, p. 5/.

Currently, distillers' dried grains and solubles is used primarily as a protein supplement. It is fairly high in protein (22-28%) but not high when compared with soybean meal's 44%. Distillers' dried grains and solubles, at present, comprises a relatively small portion of the protein feed market. However, DDGS production would increase sharply if gasohol were produced on a state or national level.

Currently, the market demand for carbon dioxide is limited. It can either be converted into a liquid or into dry ice and sold. Alternatively, it can simply be emitted as a by-product into the atmosphere.

The Use of Alcohol and the By-Products

Since gasohol is produced for use as a motor fuel, its performance as a motor fuel must be examined. Similarly, the potential market for distillers' grains must be analyzed to evaluate its effect on other markets and to determine its value as a by-product of alcohol production. Lastly, carbon dioxide may also have value as a by-product of alcohol production. These aspects of the product and by-products are discussed below.

Gasohol Compared with Gasoline as a Motor Fuel

Acceptance of gasohol depends largely on its performance properties as a motor fuel. If its performance properties exceed those of gasoline, gasohol may be accepted, even at a higher price. But, if gasohol performance properties are no better than those of gasoline, gasohol cannot expect to command a higher price than gasoline. Opinions vary about gasohol as a motor fuel, but most sources agree that gasohol is no better than gasoline.

Alcohol has some advantages as a fuel blend. First, it causes the mixture to expand slightly, resulting in more volume. Secondly, in the laboratory, alcohol increases the octane number, but not by as much as tetraethyl lead. Alcohol also lowers carbon monoxide emissions. But alcohol as a fuel blend also has disadvantages. Alcohol contains less energy per unit of volume than gasoline. Adding alcohol to the fuel creates other potential problems, which include harder starts, poor warm-up, engine corrosion and vapor lock.

One advantage of gasohol relates to a chemical property of alcohol. When alcohol is mixed with gasoline, the mixture expands by .23% /21/; hence a larger volume of fuel exists after mixing than before. A second desirable property of alcohol is that it increases the octane number of gasoline. The importance of an increase in octane, of course, is valuable as it decreases engine knock. Some believe that alcohol is a possible replacement for lead, which must be entirely eliminated from gasoline in 1985. This belief prevails because of the high research octane number exhibited by alcohol, 106, compared with 100 for premium gasoline /19, p. 6/. Another rating method, the motor octane number, is not nearly as high, 89, compared with 93 for premium gasoline /19, p. 6/. (See Table 2.) The road octane number (a third octane rating method) usually lies between the research and motor octane numbers (Figure 2). In fact, performance tests of alcohol as an antiknock agent, as rated by road tests rather than laboratory tests, show that the road octane number is closer to the motor octane number rating than the research octane number rating (Table 3). Table 4 compares alcohol and tetraethyl lead in both premium and regular unleaded gasoline using all three octane rating methods. The table shows that a 10% ethanol is never better than tetraethyl lead and it is usually less effective than tetraethyl lead in decreasing engine knock. Table 4 and Figures 2 and 3 illustrate the final point to be made about the octane raising qualities of alcohol. The point is that the lower the octane number of the main blending component, the more alcohol does to increase the octane number. Hence, if regular gasoline is used, the octane number increase due to alcohol is much higher than if higher octane premium is the base. (See Research, Motor and "Maximum" for Road tests in Figure 2 where ethanol is mixed with regular gasoline compared with similar tests for ethanol mixed with premium gasoline in Figure 3.) In summary, a 10% alcohol blend is not as effective in decreasing engine knock as a tetraethyl lead additive, although in most cases, alcohol increases the octane number slightly.

Table 2. Octane Values of Ethanol and Premium Gasoline

	Ethanol	Premium Gasoline
Research Octane	106	100
Motor Octane	89	93

Source: Rogers, J.D., Jr., Ethanol and Methanol as Automotive Fuels: E. I. Dupont De Nemours and Company, 1973 /19/.

Table 3. Road Octane Response of Alcohol in Premium Gasoline Alcohol Blend (90-10 ratio) (Laboratory and Road)

	Octane Number Changes from Premium Gasoline		
	Research Octane No.	Motor Octane No.	Road Octane No.
10% Ethyl-Alcohol Blend	1.8	.0	.4

Source: Rogers, J.D., Jr., Ethanol and Methanol as Automotive Fuels: E. I. Dupont De Nemours and Company, 1973 /19/.

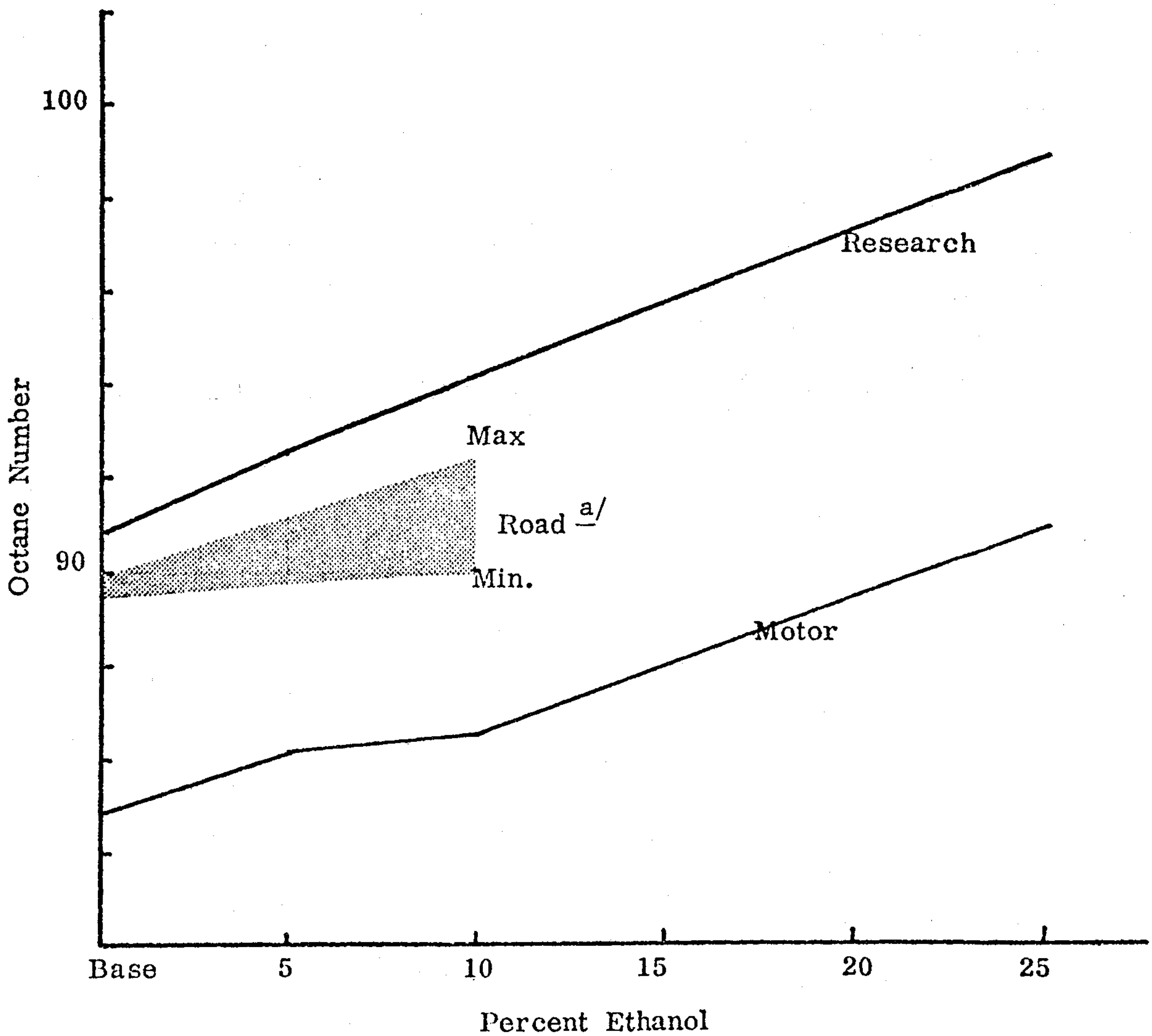
Table 4. Ethanol, Antiknock Effects

	Research	Motor	Road[a/]
Premium - Unleaded	100.4	90.0	98.3
Change in Octane Number			
10% Ethanol	+ 1.2	+ 0.4	- 0.1
1/2 gram lead/gal	+ 1.6	+ 2.2	+ 1.6
Regular - Unleaded	91.7	80.0	89.4
Change in Octane Number			
10% Ethanol	+ 2.0	+ 1.5	+ 1.5
1/2 gram lead/gal	+ 2.0	+ 2.6	+ 1.9

[a/] Premium Fuels - 6-car average
Regular Fuels - 13-car average

Source: Rogers, J.D., Jr., Ethanol and Methanol as Automotive Fuels: E. I. Dupont De Nemours and Company, 1973 /19/.

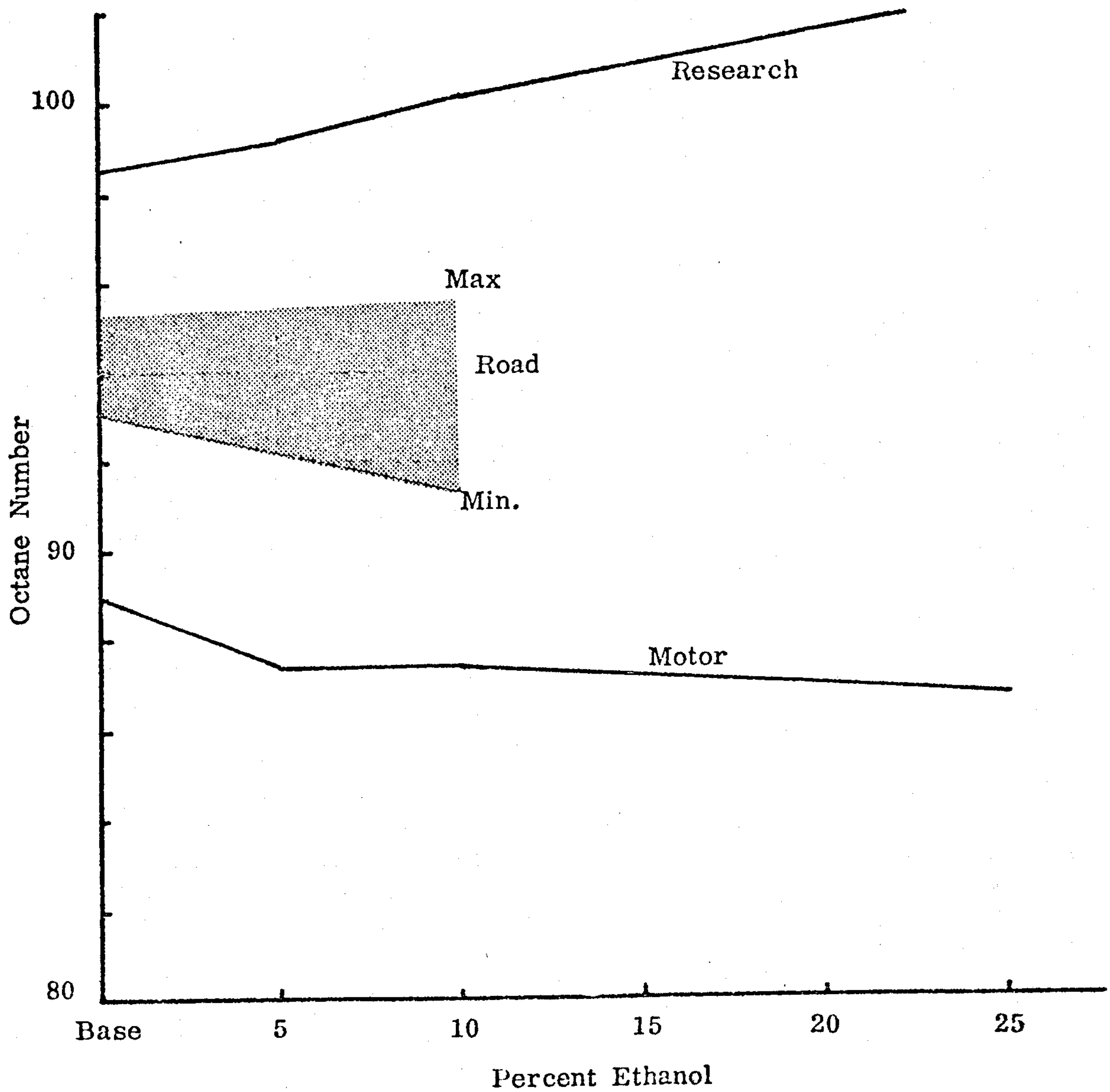
Figure 2. The Effect on Octane Number of Mixing Ethanol with Regular Gasoline



a/ The road octane number in this and the following figure exhibits a maximum and a minimum because the road octane number varies from car to car.

Source: Rogers, J.D., Jr., Ethanol and Methanol as Automotive Fuels: E. I. Dupont De Nemours and Company, 1973 /19/.

Figure 3. The Effect on Octane Number of Mixing Ethanol with Premium Gasoline



Source: Rogers, J. D., Jr., Ethanol and Methanol as Automotive Fuels: E. I. Dupont. De Nemours and Company, 1973 /19/.

A third possible advantage of gasohol is lower emissions of carbon monoxide (CO) and hydrocarbons (HC), although nitrogen oxide (NO_x) emissions may increase /2/, /7/, /19/. Further testing needs to be done. Decreased emissions of carbon monoxide and hydrocarbons appears to depend on the automobile in question. For instance, cars with higher compression ratios and richer carburetor settings usually exhibit decreased emissions of CO and HC due to the leaning effect of the alcohol /2, p. 15/ (described later). Table 5 illustrates this point. Notice that cars whose carburetors are left unadjusted show, in general, a decrease in CO and HC and an increase in NO. If the carburetor is altered to give the optimal fuel/air ratio for gasohol, however, the emissions are the same as for gasoline. To decrease emissions newer cars have relatively low engine compression and lean carburetion. Under these conditions, alcohol seems to lose its effectiveness in decreasing emissions. In any event emissions are not lowered enough to do away with pollution control equipment on the automobile; hence, any advantage over gasoline is minimal /2, p. 15/.

As noted earlier, a ratio of 1:9 alcohol to gasoline can be used in an automobile engine without making carburetor adjustments. This alcohol-gasoline blend makes the car act as if there is a leaner fuel/air mixture. Because of this behavior, engine operation with use of a blend differs slightly from operation with straight gasoline. There is less power as less energy is metered into the engine. To compensate for the reduction in power, the throttle must be opened wider to get the equivalent power of a richer mixture, resulting in a more efficient burning of the fuel. Because the fuel is burned more completely, less carbon monoxide and hydrocarbons are emitted. If the fuel mixture is too lean, poor combustion results and both hydrocarbon and nitrogen oxide emissions increase /2, p. 13/. If the mixture is made increasingly lean, nitrogen oxide emissions then decrease, but engine performance decreases. Engines start harder and acceleration is less rapid; the car stalls more often, surges during acceleration and when driving at constant speeds, and warms up poorly in cold weather /19, pp. 10-11/.

These problems can be corrected by adjusting the carburetor or injection system /2, p. 14/. These adjustments pose problems if the automobile is to be driven in states where gasohol is not available.

Fuel consumption is another performance criterion. Dr. William Scheller of the University of Nebraska contends that a two million mile road test conducted in Nebraska proved that miles per gallon with gasohol exceeded that for gasoline by up to 5% /20/. Other sources, the American Petroleum Institute, Dupont Petroleum Laboratory and the Environmental Protection Agency contend that miles per gallon remain unchanged or even decrease by 3-7% /2/, /7/, /19/. These latter sources generally agree that both fuel efficiency and fuel consumption are higher with gasohol than with gasoline. Increased fuel efficiency means more work is done per BTU, resulting in more miles per BTU. However, because of the much lower heat content of alcohol, 84,440 BTU's per gallon, compared with the 125,000 BTU's per gallon of gasoline /30/, less energy is available, so overall fuel consumption in gallons goes up. It has been observed in laboratory experiments that when the throttle is wide open, fuel consumption of gasoline is about equal to that of gasohol /7, p. 7-9/. Figure 4 compares fuel consumption of gasoline with 200° proof 25% alcohol-gasoline blend and 190° proof 25% alcohol-gasoline blend. The figure shows, generally, that gasoline gives more miles per gallon than either alcohol blend and that the 200^{o} proof blend is more efficient than the 190^{o} proof blend. Differences between gasoline and the 200^{o} proof blend are largest at the higher speeds. Most tests verify these results of slightly increased gas consumption with gasohol, whether they are performed in the laboratory or on the road.

The only result contrary to the above findings is a road test sponsored by the Agricultural Products Industrial Utilization Committee (APIUC) of Nebraska. This committee contends that mileage per gallon of gasohol increased by about 5% above that for gasoline. The evidence supporting this contention is that 45% of the people involved in the test came to this conclusion. The other 55% were undecided, disagreed or were unaccounted for /1, p. 61/. The problem in evaluating these results is that no control group existed with which to compare the results. No attempt was made to standardize the automobiles, engine adjustments or the type of driving done. There is also evidence that two of the five pumps used registered gallons incorrectly /23, p. 12/.

Several technical problems are associated with the use of gasohol. One of these is the problem of vapor lock at high (summer) temperatures. This problem occurs because ethanol has a relatively high blending vapor pressure in gasoline. At warm temperatures the fuel vaporizes easily and the vapor expands in the fuel line as the car is started and blocks fuel from entering the carburetor, causing the car to stop. Vapor lock with gasohol is more likely than with straight gasoline. To overcome this problem the gasoline base used needs to be reformulated to produce a lower vapor pressure, making vapor lock problems no worse than with gasoline alone. Reformulation, however, means that butane and pentane must be removed from the gasoline, which decreases the BTU content of the gasoline by an amount twice that added by the alcohol /2, p. 15/. The net effect is to increase fuel consumption.

Alcohol in gasoline dissolves resins and gums and when used in engines that are usually run on gasoline, may cause filters to plug. Alcohol can also remove the oil film from cylinder walls, by dissolving it /19, p. 12/. This dissolution may result in greater cylinder and ring wear.

A remaining technical problem is that water and extreme cold cause alcohol to separate. For instance water present in less than 1% of the solution can cause a 10% blend to separate /7, p. 7-13/. This poses potential problems for the engine, as separation will certainly affect driving performance. The main problem appears to be water in the fuel distribution system. Great care must be taken to ensure that water cannot enter the system. Mixing the alcohol and gasoline at the delivery site reduces this problem. Blending agents exist that can be added to decrease the problems of separability, but they do not completely eliminate it.

Based on the above evidence, no technical advantage appears to exist in the use of an alcohol-gasoline blend. The apparent laboratory advantage of increased octane turns out to be of no consequence on the road. Moreover, a number of disadvantages are related to its use. In short, gasohol cannot be recommended as superior to gasoline based on fuel properties.

Table 5. The Effect on Emissions of Mixing Ethanol with Gasoline

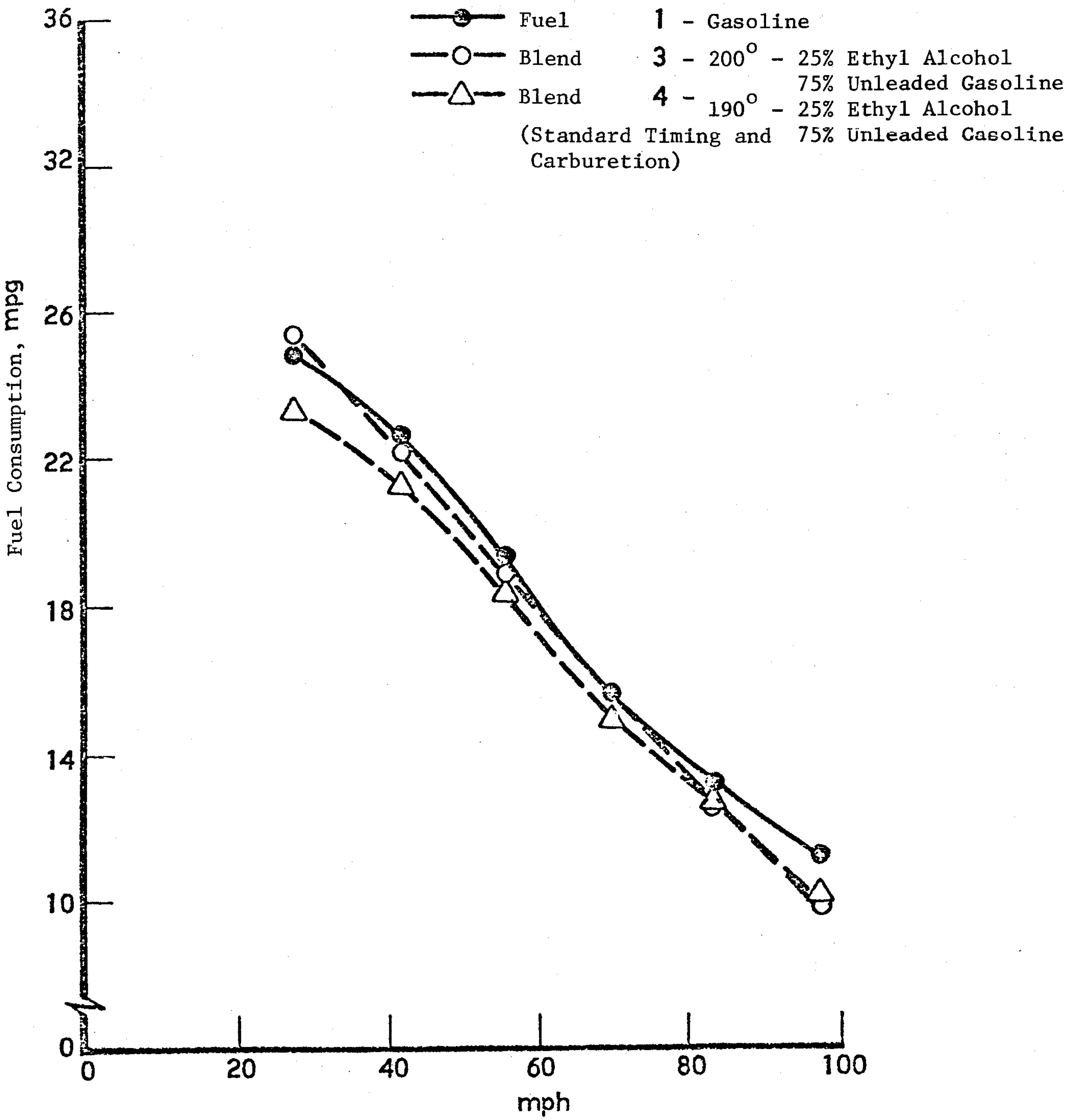
Study		Lean Mixture[a]	Rich Mixture[b]
Ethanol-Gasoline Blends			
Union	1956		About same HC, NO_x, more aldehyde
Chevron	1963	Less CO, HC, more NO_x, more formaldehyde	
Exxon	1964		Same CO, HC, NO_x
GMR	1964	Less HC, more NO_x (<15.6), less NO_x (>15.6)	
Texaco	1964	Less HC	Same CO, HC
SWRI	1964	Less HC	

a/ Carburetion is set as for gasoline, therefore the air/fuel mixture is leaner for the alcohol blend than for gasoline alone.

b/ Carburetion is adjusted for the alcohol blend, so the air/fuel mixture is richer than for gasoline alone.

Source: Rogers, J.D., Jr., Ethanol and Methanol as Automotive Fuels: E. I. Dupont De Nemours and Company, 1973 /19/.

Figure 4. ROAD LOAD ECONOMY - 1962 OLDSMOBILE[a/]



a/ Gasoline: Engine Compression 7.25:1
Gasohol : Engine Compression 12.0:1

Source: Environmental Protection Agency, Current Status of Alternative Automotive Power Systems and Fuels, Vol. III - Alternative Non-Petroleum Based Fuels, 1974 /7/.

Distillers' Dried Grains and Solubles as a Feed

Distillers' dried grains and solubles is a major by-product of ethyl alcohol production from grain. The process of converting grain into alcohol changes the starch in the grain into alcohol, but it virtually leaves unchanged the protein, vitamins, minerals, fats and fibers. The by-product grain is composed of solids and stillage. When the solids are separated from the alcohol and dried, the by-product is called distillers' dried grain (DDG). When the remaining stillage is evaporated, leaving the nutrients that are suspended in the liquid, the by-product is called distillers' dried solubles (DDS). The two components typically are dried together, the liquid leaving its residue on the solids; the product from this process is called distillers' dried grains and solubles (DDGS), sometimes referred to as dark distillers' dried grains. The yield of DDGS is about 6.8 pounds per gallon of alcohol produced from corn.

Distillers' dried grains are presently available on the market, coming mainly from potable alcohol distilleries. As noted earlier, DDGS is used as a protein supplemental feed. In 1952 DDGS composed only .8% of the market of high protein feed. Its use had expanded to 1.5% of the high protein feed used in 1975 /32, p. 8/. Although the rate of increase is large, a comparison with the tonnage of soybean meal used (Table 6) emphasizes the minor role DDGS currently plays as a high protein feed. Initiation of a regional or national gasohol program would result in the production of much larger quantities of DDGS. The market value of this by-product (and its effect on the cost of producing ethyl alcohol) depends on its value as a livestock feed.

Although it is thought of as a high protein feed, it can also be used as a source of energy. The digestible protein content of DDGS is about 22%, half of the protein content of SBM. The fat and fiber content of DDGS is 10-11% /32, p. 3/. Distillers' dried grains and solubles also has 2.9 Mcals/kg. energy content, compared with 2.81 Mcals/kg. in corn and 2.78 Mcals/kg. in soybean meal /18/. Thus, DDGS has potential both as a source of protein and of energy if dry matter constraints are not limiting. Because of its high fiber content, DDGS is primarily suitable as a feed for ruminants, but it can be used as a feed supplement for swine. However, the high fiber content of DDGS and the fact that it lacks some amino acids makes it undesirable for swine, and as protein supplement for poultry /32, p. 3/. Hence, the potential for increased demand for DDGS is mainly for ruminants. Given the bulky nature of the feed for feeder cattle and for dairy cows, a thorough study of the value of DDGS in the ration for both dairy and beef would be a lengthy study in itself and is not attempted here. However, least cost rations were formulated for one set of assumptions on cattle feeding to provide some information on the relative value of DDGS to other feeds commonly used at the current time.

The value of DDGS in feeding steers was estimated using a minimum cost linear programming framework. The feeds considered were: corn, corn silage (CS), alfalfa hay, soybean meal (SBM) and distillers' dried grains and solubles made from corn (DDGS). Minimum cost rations were formulated for steer calves from 430 to 1080 pounds. Rations were selected to feed for 1.8 pounds of gain per day up to 700 pounds and for 2.55 pounds per day from 700 pounds to market weight.

Table 6. Estimated Use of Soybean Meal and Distillers' Dried Grains for Domestic Feeding

Year (Beginning Oct. 1)	Soybean Meal (1,000 tons)	Distillers' Dried Grains (1,000 tons)
1952	5,510	186
1953	4,965	244
1954	5,428	251
1955	6,042	286
1956	7,093	290
1957	7,962	280
1958	8,938	342
1959	8,450	359
1960	8,837	352
1961	9,232	380
1962	9,556	362
1963	9,138	382
1964	9,236	409
1965	10,274	426
1966	10,820	425
1967	10,753	447
1968	11,525	437
1969	13,582	428
1970	13,467	382
1971	13,173	404
1972	11,972	428
1973	13,853	456
1974	12,200	475

Source: USDA, Agricultural Statistics.

The prices of corn, alfalfa hay, SBM and DDGS were allowed to vary independently. The prices of corn used were $1.50/bu., $3.00/bu. and $4.50/bu. The price per ton of corn silage is linked to the price of corn by the formula: (6 x price of corn/bu. + $2.00). This formula is used because each ton of corn silage should contain approximately six bushels of corn and the additional harvesting and storage cost is approximately $2.00 per ton.

The prices of alfalfa used were: $40/ton, $60/ton and $80/ton. The analysis was made for SBM prices of: $120/ton, $150/ton and $180/ton. Variable price programming was used with each of the 27 combinations of corn, alfalfa and SBM prices to find the amount of DDGS that would be included in the ration over a wide range of DDGS prices.

The composition of the cost minimizing ration for each of the 27 combinations of corn, soybean meal and alfalfa hay prices is given by price of DDGS in Figure 5. Inspection of the figure indicates the amount of distillers' dried grain and solubles in the ration depends on the relative ingredient prices. The least cost ration for <u>low</u> DDGS prices and most prices for corn, alfalfa, and soybean meal is composed of approximately 47% DDGS. (Notice, however, that the combination of $80/ton alfalfa hay, corn at $3.00 or more per bushel and very low DDGS prices makes feeding all DDGS least cost.) In this case DDGS is relatively inexpensive and it is being used as a source of energy as well as a source of protein. The amount of DDGS in the ration declines from 47 to 17% where corn silage becomes a cheaper source of energy. In this case the shift is from a ration of alfalfa hay and DDGS to alfalfa hay, corn silage and DDGS. The shift occurs at varying ratios of the DDGS price to the corn silage price and depends on the price of alfalfa hay (column 4, Table 7).

As the price of DDGS is increased relative to other feeds it becomes an increasingly expensive source of both energy and protein. When the ratio of the DDGS price per pound to the price of corn per pound increases to about .99, corn grain replaces some DDGS in the least cost ration, reducing the DDGS content from 17% to 8%. This occurs because corn is a less expensive source of energy than DDGS at this and higher price ratios.

Further increases in the DDGS price result in further reduction in the amount of DDGS included in the minimum cost ration. The variation in rations and the proportions of DDGS emphasizes the importance of considering the relative prices of the alternative feeds (corn, corn silage, alfalfa hay and soybean meal). In general the amount of DDGS is reduced to about 3% of the ration as alfalfa hay is substituted for some of the DDGS for lower alfalfa hay prices ($40 and $60 per ton) and soybean meal is substituted for DDGS for higher alfalfa hay prices ($80 per ton). Further increases in the price of DDGS make it an increasingly expensive source of both protein and energy causing it to be eliminated from the minimum cost ration. Soybean meal and alfalfa replace DDGS in the ration. The numbers in the final column of Table 7 indicate the price ratio of DDGS to soybean meal (.68 to 1.13) at which the remaining DDGS is eliminated from the cost minimizing ration.

Figure 5. Composition of Feed Ration for Variable DDGS Prices

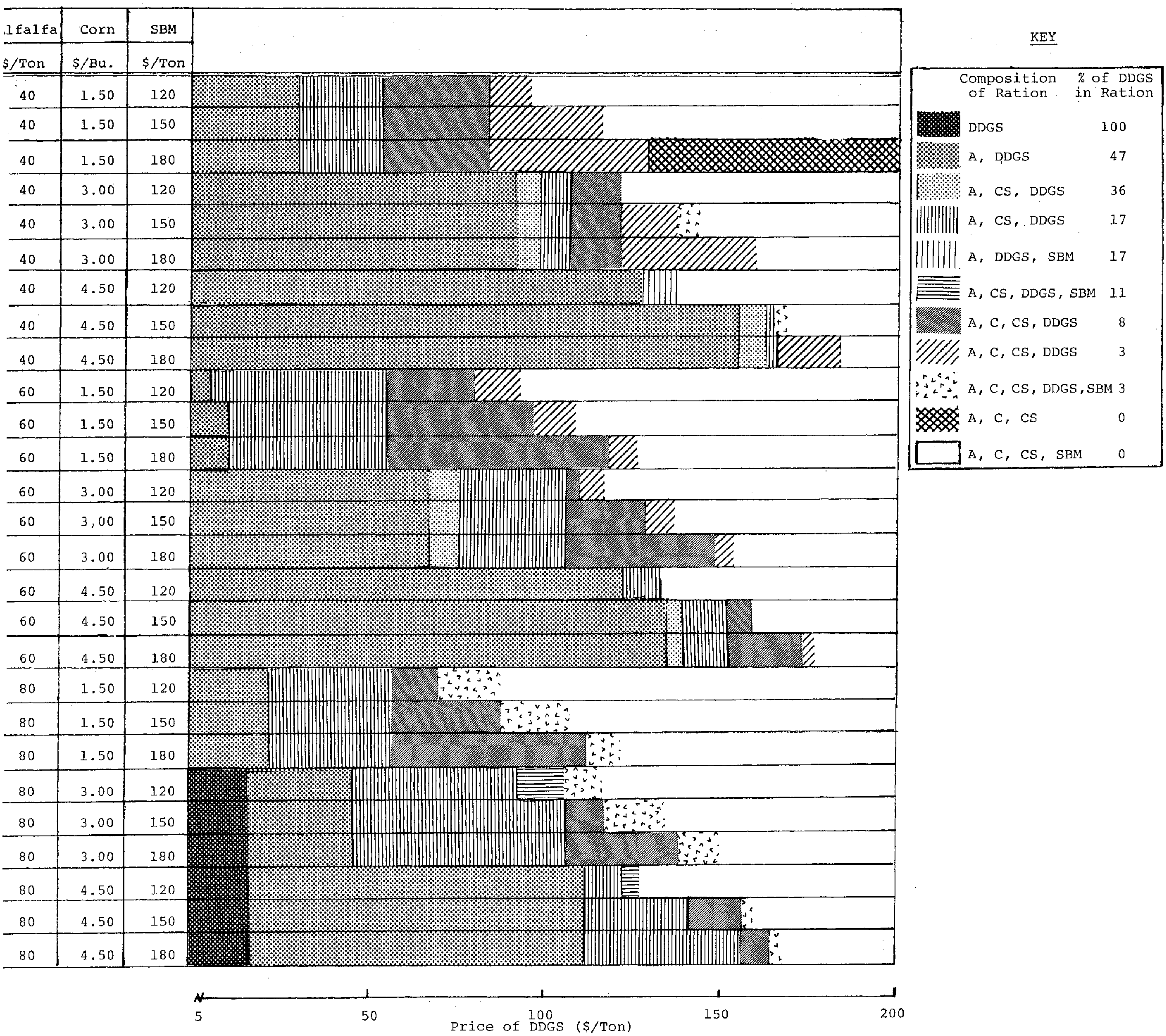


Table 7. Ratio of the Price of DDGS to Relevant Base for Different Percentages of DDGS in the Ration[a]

			PERCENT OF DDGS IN RATION			
			From 47 to 17	From 17 to 8	From 8 to 3	From 3 to 0
Alfalfa ($/TON)	Corn ($/BU)	SBM ($/TON)	$\frac{P_{DDGS}}{P_{CS}}$	$\frac{P_{DDGS}}{P_{C}}$	$\frac{P_{DDGS}}{P_{SBM}}$	$\frac{P_{DDGS}}{P_{SBM}}$
40	1.50	120	2.77	.99	.70	.78
40	1.50	150	2.77	.99	.56	.77
40	1.50	180	2.77	.99	.47	.73
40	3.00	120	4.9	.99	.96	.99
40	3.00	150	4.7	.99	.76	.93
40	3.00	180	4.9	.99	.64	.90
40	4.50	120	4.4	---	----	1.13[b]
40	4.50	150	5.4	---	1.10[b]	1.1
40	4.50	180	5.5	---	.92[b]	1.03
60	1.50	120	.37	.99	.68	.75
60	1.50	150	.7	.99	.68	.71
60	1.50	180	.7	.99	.67	.69
60	3.00	120	3.6	.99	.90	.97
60	3.00	150	3.6	.99	.85	.90
60	3.00	180	3.6	.99	.82	.84
60	4.50	120	4.4	---	----	1.10[c]
60	4.50	150	4.9	---	----	1.06[c]
60	4.50	180	4.9	.98	.96	.98
80	1.50	120	1.7	.99	.59	.75
80	1.50	150	1.7	.99	.62	.71
80	1.50	180	1.7	.99	.63	.68
80	3.00	120	2.3	---	.88[b]	.97
80	3.00	150	2.3	.99	.79	.88
80	3.00	180	2.3	.99	.76	.83
80	4.50	120	3.9	---	----	1.05[c]
80	4.50	150	3.9	.89	1.05	1.06
80	4.50	180	3.9	.98	.91	.97

[a] This table can be used in conjunction with Figure 5 in determining the ration components, as well as the P_{DDGS} at which the ration changes. Given the prices of alfalfa hay, corn and (Continued)

[a] (Continued)
soybean meal in any row, the remaining entries in the row indicate the price ratios at which the proportion of DDGS in the ration decreases as the price of DDGS is increased.

An illustration will help the reader interpret this table. With the prices of alfalfa set at \$40/ton, the price of corn at \$1.50/bu. and the price of SBM at \$120/ton (first row) DDGS enters the ration at the 47% level until the point when the ratio of P_{DDGS}/P_{CS} reaches 2.77, Col. 4, (with CS at \$11/ton, P_{DDGS} is 2.77 times that or \$31/ton); at this point CS is substituted in the ration for DDGS and the percentage of DDGS drops to 17%. DDGS was being used as an energy source here. In the fifth column then, the base changes from CS to C, since corn now is substituted for DDGS in the ration. DDGS composed 17% of the ration for ratios of P_{DDGS}/P_C less than .99 (P_C per pound approximately equal to P_{DDGS} per pound), but at a ratio of .99 DDGS is replaced by corn in the ration and DDGS drops to 8% of the ration. At this point DDGS is still being replaced as an energy source. As the price of DDGS rises, it is being replaced as a protein source thus the rationale for the SBM in the denominator of the sixth and seventh columns. The sixth column indicates that DDGS makes up 8% of the ration for ratios of P_{DDGS}/P_{SBM} less than .70; at .70 (P_{SBM} at \$120/ton implies P_{DDGS} of \$84/ton. SBM replaces DDGS in the ration and DDGS drops to 3% of the ration. The seventh column extends the ration changes in the sixth for at ratios of P_{DDGS}/P_{SBM} less than .78, DDGS composes 3% of the ration, but at price ratios of .78 (P_{SBM} at \$120/ton implies P_{DDGS} of \$94/ton), SBM completely replaces DDGS in the ration.

[b] DDGS percentage in ration drops from 17% to 3%.

[c] DDGS percentage in ration drops from 17% to 0%.

These results can be summarized as follows. The amount of DDGS that is included in the least cost ration is highly dependent on the relative price of other feeds. At very low DDGS prices, DDGS is a cheaper source of energy than corn silage and it is used extensively in the ration as a source of both protein and energy. Where the price of DDGS is less than corn per pound, DDGS is a lower cost source of energy than corn. When the price of DDGS is only slightly less than the price of SBM, DDGS is competitive as a source of supplemental protein. At DDGS prices above the price of corn, but considerably below the price of SBM, the price of other feeds will determine if DDGS is used.

This analysis provides the basis to analyze the DDGS price adjustments that would result from extremely large quantities of DDGS made available through the development of a gasohol program. DDGS will compete not only with protein feeds such as SBM, but it will also compete with and impact on the prices of feeds presently used for energy such as corn, corn silage and alfalfa.

Carbon Dioxide

The final major by-product of alcohol production is carbon dioxide. As mentioned earlier, approximately 17.0 pounds of CO_2 are produced from every bushel of corn.

Carbon dioxide can be collected, purified and changed into more useful forms. It can be compressed into a liquid or evaporated from the liquid to form dry ice. A market exists for both the liquid CO_2 and the dry ice. The market for the dry ice, however, is not as viable as markets for the alcohol or DDGS. The average price for dry ice at the alcohol plant is about $2.00 per ton /12, p. 5/. Until 1960, the greatest demand for CO_2 was for dry ice, but since then tastes have changed making the liquid form more valuable. The liquid can be used for carbonation of soft drinks, meat processing and fire extinguishers.

The cost of capturing the CO_2 from alcohol production and transforming it into a liquid or dry ice is generally higher than the market price. Therefore, it is normally allowed to escape into the atmosphere. Carbon dioxide is a gas that cannot be seen or smelled and is not dangerous in the sense of toxic pollutants. Nevertheless, certain concentrations of it in the atmosphere may have adverse effects. Increasingly large amounts of carbon dioxide may cause what is commonly called the greenhouse effect, that is, carbon dioxide allows the sun's heat in but once inside it is trapped; the heat cannot escape. The exact effect of a specified change in the CO_2 level is unknown, but it is thought that eventually the earth's temperature will rise slightly, and may cause enlargement of arid regions.[4/] Given the uncertainty about the possible effects of emitting CO_2 from alcohol production for gasohol, this report makes no attempt to assess the costs, if any, of such emittance.

Energy Analysis of Alcohol Production

In energy analysis of alcohol production we are primarily interested in comparing the BTU content of the fossil fuels and electricity used to produce alcohol with the BTU content of the alcohol output. Hence, in this analysis we account for the amount of fossil fuel and electric energy used to produce the grain and run the alcohol plant on the input side. On the output side we account for the energy content of the alcohol and the by-products. The analysis could be extended to include other forms of direct energy, such as solar, and the indirect energy used in alcohol production. In such an accounting the energy required to produce the tractors, and other farm machinery, together with the alcohol producing equipment, etc., would be included. Indirect energy use is not included because these figures are not readily available.

Energy Input and Output of Alcohol Production

The form of energy is an important factor to consider in an energy balance analysis. In actuality, energy comes in many forms and some forms may restrict its use. For example, coal in its solid form cannot be used as an automobile fuel. Thus, society must either find or manufacture a fuel that can be used in existing equipment or it must adapt to a new technology that can utilize the energy in its original form. In the automobile example, society could opt for using the coal to make another form of energy, for example, liquified coal or gasohol. Alternatively, we could institute a mass transit system that uses electricity produced from coal.

Many energy forms are used in gasohol production. These include coal, steam, electricity, gasoline, diesel fuel oil and in some processes, natural gas. Some of these forms cannot be used in automobiles unless substantial changes are made in the mode of travel, while others are used currently for transportation and farming. Consequently, in considering gasohol as an alternative fuel, we must determine if fuel versatility increases.

[4/] One possible solution to the CO_2 problem is to pump the carbon dioxide into a greenhouse. The plants will absorb the carbon dioxide in their growing process, eliminating the problem of what to do with the CO_2. If the plants were greenhouse produced tomatoes, for instance, one alcohol plant producing 17 million gallons per year would require a greenhouse of approximately 244 acres to absorb the 107 million pounds of CO_2 emitted each year as tomatoes need 50 pounds of CO_2/acre/hr. /25, pp. 60-61/. Thus, the solution may be difficult in practice. However, smaller greenhouses built near the plant seem more feasible and could alleviate the CO_2 problem to some extent. Questions of greenhouse capital cost and set-up, operational costs, land acquisition and analysis of effect on the markets of the greenhouse crops are beyond the scope of this paper.

In determining the energy balance, we first estimate how much energy is used to produce corn and wheat. This information is provided in Table 8 on a state, regional, and aggregate U.S. basis for various farming activities. These data show that fertilizer is the largest single energy user in corn and wheat production. Fertilizer energy usage varies from 44.4 to 54.8% of the total. Energy use in fertilizer is followed by an aggregate of activities related to production, which vary from 29.9 to 61.2% of the total.

The figures important to the energy balance analysis are the U.S. aggregate figures. For corn, 107,405 BTU's are used to grow one bushel. For a bushel of wheat the figure is slightly less, 103,697 BTU's. The energy balance analysis is done on a per gallon basis, using 2.7 gallons of alcohol per bushel of corn and 2.6 gallons per bushel of wheat as the conversion figures. This implies that as a U.S. average it takes about 39,780 BTU's to grow the corn used in one gallon of alcohol.

The energy content of selected fuels is given in Table 9. For a complete analysis, the BTU content of the by-products must be included. The by-product grain contains approximately 7,647 /27/ BTU's per pound. If we assume 6.8 pounds of feed are obtained as a by-product in producing each gallon of alcohol from corn (6.5 pounds from each gallon produced from wheat) then approximately 52,000 BTU's from by-product grain is associated with a gallon of alcohol. Since carbon dioxide cannot be burned, no BTU's result. The other by-products, fusel oil and aldehydes, are volatile and the quantities available depend on the production process used; however, regardless of production process, the quantities are always very small and, as noted above, are usually left in the alcohol. Hence, these volatile by-products are not considered as by-products in this analysis.

A North Dakota study /12/ estimated the amount of energy used to convert corn into alcohol. This study, summarized in Tables 10 and 11, assumed steam, electricity and coal were used in the conversion process. We also computed the direct energy used to produce alcohol based on data provided by Midwest Solvents Company. Midwest Solvents' direct energy sources were electricity and natural gas. However, if a plant were to be set up in Minnesota, natural gas would not be a feasible fuel source. Therefore, we converted the BTU content of the natural gas data from Midwest Solvents into gallons of No. 6 fuel oil.[5/]

5/ Coal rather than No. 6 fuel oil may be used as the major source of fossil fuel in a Minnesota plant producing ethyl alcohol. However, data on construction and operation costs for coal fired plants comparable to those presented in Tables 13 and 14, respectively, were not available to the authors. Conversations with Midwest Solvents personnel indicate investment costs in the boilers and related air pollution control equipment would be "substantially higher." Additional land area would be required to store coal delivered in large quantities and some additional labor and equipment would be needed to handle the coal. Furthermore an environmentally acceptable method of disposing of the ash would be required. Hopefully these higher investment and operating costs would be offset by lower energy costs. Western coal purchased in train load lots currently costs approximately $1.25 per million BTU's (based on a delivered price of $20 per ton for 8,000 BTU per pound cost) compared to $2.08 per million BTU's with fuel oil (based on $.32 per gallon for No. 6 fuel oil having 153,600 BTU per gallon). A detailed engineering study providing investment and operating cost data is required to determine the effect of shifting to a coal fired plant on the economic feasibility of ethanol production.

Table 8. Energy Used in Corn and Wheat Production (1974 Base)

U.S.	Corn (Billion BTU)	Corn Percent of Total	Corn BTU's/Bu.	Wheat (Billion BTU)	Wheat Percent of Total	Wheat BTU's/Bu.
Irrigation	45,732	9.2%		21,320	10.6%	
Fertilizer	245,414	49.2%		89,372	44.4%	
Pesticide	16,691	3.3%		1,458	.7%	
Production Related*	191,419	38.3%		89,318	44.3%	
Total	499,256	100.0%	107,405	201,468	100.0%	103,697
Minnesota						
Irrigation	168	.4%		--	--	
Fertilizer	20,508	52.8%		4,898	54.8%	
Pesticide	1,507	3.9%		48	.6%	
Production Related	16,634	42.9%		3,987	44.6%	
Total	38,817	100.0%	107,852	8,933	100.0%	107,303
West North Central Region						
Irrigation	34,653	18.4%		1,856	2.4%	
Fertilizer	91,529	48.5%		27,858	35.8%	
Pesticide	6,040	3.2%		458	.6%	
Production Related	56,369	29.9%		47,690	61.2%	
Total	188,591	100.0%	128,334	77,862	100.0%	97,515

*Production Related: Includes activities such as: planting, cultivating, harvesting, drying grains, etc. (Anything directly related to the production process.)

Source: USDA, FEA, Energy and U.S. Agriculture: 1974 Data Base /28/, /29/.

Table 9. Energy Value of Selected Fuels

	BTU/unit
Gasoline	125,000 BTU/gal.
Diesel (No. 2)	140,000 BTU/gal.
Alcohol (200^{o} proof)	84,400 BTU/gal.
Fuel Oil No. 6	153,600 BTU/gal.
Electricity	11,000 BTU/KWH[a/]
Coal	10,000 BTU/lb.

a/ BTU/KWH here refers to the amount of energy required to produce one KWH of electricity.

Sources: H. J. Klosterman, O. J. Banasik, M. L. Buchanan, F. R. Taylor, and R. L. Harrold, Production and Use of Grain Alcohol as a Motor Fuel: An Evaluation, 1978 /12/.

USDA, FEA, A Guide to Energy Savings for the Field Crop Producer, 1977 /30/.

American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., ASHRAE Handbook of Fundamentals, N.Y., Chapter 13, p. 234 /3/.

Table 10. Utilities Required for the Conversion of Corn into Alcohol[a]

	Requirements Per Gallon of 200^{o} Proof Alcohol
Steam - 50 pounds per square inch gauge 15 pounds per square inch gauge	109.2 lb.
Electricity	.28 kw.
Coal (10,000 BTU/lb.)	1.87 lb.

[a]The plant described here was designed to produce 20 million gallons of 200^{o} proof alcohol per year.

Source: H.J. Klosterman, O.J. Banasik, M.L. Buchanan, F.R. Taylor and R.L. Harrold, Production and Use of Grain Alcohol as a Motor Fuel: An Evaluation, p. 7, 1977 /12/.

Table 11. Energy Requirements to Operate the Alcohol Plant

	BTU's/Unit	Estimated Energy Input/Gallon
Steam Total: 109.2 lb./gal.[a]	1,400 BTU/lb.	152,880 BTU
Electricity: .28 kwh/gal.[a]	11,000 BTU/kwh	3,080 BTU
Coal: 1.87 lbs./gal.[a]	10,000 BTU/lb.	18,700 BTU
	Total process energy/gallon	174,660 BTU

[a]From Table 10.

Source: Same as Table 10.

Using the data from Table 14 footnotes, we estimated that to produce a gallon of 200° proof alcohol, 3.92 KWH (66,600,000 KWH ÷ 17 million gallons) of electricity and .87 gallons of No. 6 fuel oil (14,842,800 gallons ÷ 17 million gallons) are needed. With knowledge of the BTU's required to produce a KWH of electricity and a gallon of No. 6 fuel oil, (Table 9) we calculated the total BTU's of direct energy needed to produce a gallon of 200° proof alcohol:

11,000 BTU's/KWH x 3.92 KWH	=	43,120 BTU's
153,600 BTU's/gal of fuel oil x .87 gal	=	133,632 BTU's
		176,752

The figure of 176,752 BTU's/gallon of 200° alcohol is slightly higher than the North Dakota figure of 174,660 (Table 11). We are using the lower of these two estimates in the following energy analysis to avoid bias against alcohol production. Conversion can also be accomplished with natural gas or fuel oil /16/.

Energy Balance of the System

The North Dakota study estimates that 174,660 BTU's per gallon are used to convert the corn into alcohol. The total energy used in the production of alcohol (Table 12) then is the sum of the energy used to produce the corn in a gallon of alcohol plus 174,660 BTU's, the energy used in converting the corn into alcohol or 214,440 BTU's per gallon. If this figure is compared to the resultant energy in the alcohol and DDGS, 136,400 BTU's, we obtain an energy ratio of .636, that is, for each BTU of fossil fuel used in the production of alcohol, .636 BTU's are obtained in the form of alcohol and DDGS.

This analysis can be changed slightly by removing the by-product feed. Here, we look only at the BTU's used to produce the alcohol and resultant BTU content of the alcohol. This is done to determine more accurately the energy balance related to alcohol alone. The by-product feed has a beef feed value of .44 bushels of corn /27/.[6]

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[6] This figure is obtained in the following way: It is assumed that 2.7 gallons of alcohol are obtained from a 56 pound bushel of corn and 6.8 pounds of DDGS are obtained from one gallon of alcohol, or 18.36 pounds of DDGS per bushel of corn are obtained. We then take the ratio 18.36/56 = .33 or the amount of DDGS per bushel of corn and multiply this by the beef feeding value of DDGS, (using corn as a basis) of 135%. We have: .33 (1.35) = .44. This differs from /27/ because that study uses a lower value for the amount of DDGS per bushel of corn. It should be noted that the 1.35 figure used by the USDA is somewhat arbitrary and is not appropriate for a national gasohol program. As suggested in our discussion on page 18, a more appropriate ratio is 1.0.

Table 12. Energy Analysis of Alcohol Production-Two Methods[a]

	Bushel Basis (BTU)	Gallon Basis[b] (BTU)
Method 1		
Input		
Energy required to produce corn	107,405	39,780
Energy used to convert grain into alcohol	471,582	174,660
Total	578,987	214,440
Output		
Energy content of alcohol	227,880	84,400
Energy content of DDGS	140,400	52,000
Total	368,280	136,400
Ratio: Output/Input = 136,440/214,439 = .636		
Method 2		
Input		
Energy required to produce corn used in alcohol (.56 x energy input above)	60,147	22,277
Energy used to convert grain into alcohol	471,582	174,660
Total	531,729	196,937
Output (same as above)		
Ratio: Output/Input = 84,400/196,937 = .43		

a/ Alcohol is assumed to be produced from corn.

b/ Assumes 2.7 gallons of alcohol per bushel of corn.

Source: Tables 8, 9 and 11.

Allocating the energy used to produce corn between alcohol and DDGS in this manner suggests only 56% of the 39,780 BTU's used in corn production should be counted in the production of a gallon of alcohol. Fifty-six percent amounts to 22,277 BTU's. Adding 22,277 to the energy for conversion of 174,660 BTU's results in a total energy input of 196,937 BTU's. Dividing the 84,440 BTU's in alcohol by 196,937 BTU's we obtain an energy ratio (output to input) of .43.

The results of these analyses indicate a negative energy balance; more energy is used to produce alcohol (and its by-products) than is obtained from it (and its by-products). Since many of the BTU's used in corn production are already in the form of gasoline or diesel, it is not at all evident that a change in form of this type is sufficient to warrant such energy inefficiency.

One criticism that can be made of this analysis is that it does not use corn stalks and leaves as an energy input for converting corn into alcohol. An analysis using this crop residue has been done by Dr. William Scheller of the University of Nebraska. His analysis is reproduced in Appendix I, along with a discussion of it. Since no alcohol plant in existence uses the crop residue and since data on use of crop residue as an energy input in producing alcohol are not available, crop residue has been omitted from the energy balance analysis in this report.

The energy balance possibly can be made more favorable by annexing a feedlot operation. This modification allows the distillers' grains to be fed wet. Since over half of the steam used is for drying the grains /6, pp. 3-17/, feeding wet decreases the energy used significantly. However, the drying operation cannot be eliminated entirely as the moisture content may be too large to ensure adequate weight gain /6, pp. 4-5/. The feedlot attached to a 17 million gallon per year alcohol plant means an additional investment in feeder cattle to keep 20,000 head of cattle on feed at all times, together with 80 acres of land, buildings and equipment /6, pp. 4-7/. A waste recycling plant would likely need to be added, too. If such a plant is included, 210 acres of land must be acquired, and energy will be needed to run the plant /3, pp. 4-12/. The addition of the feedlot adds complexity to the alcohol plant operation; for this reason, it should be investigated thoroughly before it is added to gasohol plant plans.

The Effect of Gasohol on the Energy Situation

The cost of gasohol must be tied to net energy use in the production of gasohol. There are basically three points to this issue that should be considered. These are the cost per BTU of gasohol, the effect of gasohol on oil imports and the use of gasohol instead of other energy sources.

The cost per BTU of gasoline at current prices is less than the cost per BTU of gasohol because the gasoline price is relatively lower than the gasohol price and gasoline has a higher BTU content per gallon. This analysis is incomplete, however, as it does not consider alternative methods of using the main component of alcohol (grain) in obtaining energy. To proceed with this analysis, consider that approximately 2.7 gallons of alcohol can be attained from a bushel of corn. The energy content of this alcohol is approximately 228,000 BTU's. If we subtract from this the BTU's that are used in producing the corn, specifically going towards alcohol (but not DDGS) production, 60,148 BTU's, a net energy balance of 167,852 is obtained.[7/] (Note, this ignores processing energy.) If the same bushel of corn is exported at $2.50 a bushel this would purchase roughly 1/7 of a barrel of oil (with about $18.00 per 42 gallon barrel) or 6 gallons. The energy content of this is 750,000 BTU's, roughly 4½ times as much energy as can be obtained from the corn directly /10/. The implication is that the use of corn in alcohol production is energy inefficient.

Another point that may be raised is: "You've shown that you can buy more BTU's by exporting the corn than you can obtain directly by fermenting it, but in that case aren't you forcing the U.S. to continue importing oil, making the U.S. more dependent on OPEC? Won't gasohol free the U.S. from this dependence?" The answer, unfortunately, is no. A simple analysis frequently cited proceeds as follows: Gasohol consists of 10% alcohol, so the national use of gasohol will decrease gasoline use by 10%, thus decreasing oil imports by 10%. This argument is fallacious in that it ignores the fact that more energy from fossil fuels is used to make the gasohol than is obtained from the fuel. From the energy analysis above, it was shown that 1.57 to 2.33 times as much energy is used in making alcohol as is obtained in the end product. Oil dependence cannot be reduced when gasohol production requires the net use of more energy than is presently used today. Although much of the energy used in alcohol production is coal, about half of it is gasoline, diesel and natural gas or fuel oil. Expanded use of gasohol would require expanded use of these products too.

It should also be realized that grain is only partially a renewable resource. Fertilizers for grain production use large quantities of natural gas in their production, a resource rapidly being depleted. Thus, grain should not be considered separately from its most limiting factors in discussing its easily renewable supply. For these reasons gasohol will not end oil dependence.

Another factor in gasohol use is that once its use is adopted, we are locked into it, at least for the life of the alcohol plants. Adoption on a national scale may mean that 588 plants, each producing 17 million gallons of alcohol would be built (assumes projected gasoline use of about 100 billion gallons for the U.S. - Table 20). If each plant costs approximately $24 million (Table 13), the total initial investment is $14 billion (operating costs would be additional) roughly 1% of the current GNP, a considerable sum to discard if something better comes along. It should also be noted that the energy involved in making the capital has not been included in the energy analysis; if it were, its effect would lower the unfavorable energy balance even further. This type of capital investment will preclude research in other energy areas that may actually lessen our dependence on imported oil, such as solar, geothermal, wind or even nuclear power.

[7/] The estimate of 60,147 is obtained by using the 22,277 BTU's per gallon figure derived earlier (Method 2, Table 12) then multiplying by 2.7 (the number of gallons per bushel).

Our analysis of the energy balance in alcohol production shows (1) gasohol uses more energy in its production than it in turn produces, (2) gasohol will not decrease and may even increase oil imports, (3) gasohol locks us into a technology for 15 years and (4) gasohol use may preclude research in other energy areas. More specifically, our analysis shows that for every BTU used to make alcohol, between .43 and .636 BTU's are obtained. Thus, energy balance ratios alone are not favorable to production of alcohol as a motor fuel. Whether such production is economically feasible is discussed in the following sections.

Costs of Alcohol Production

In any cost of production analysis, size of plant is an important factor in determining unit costs. In alcohol production, information on costs in relation to size of plant is limited. For this study we were fortunate in obtaining cost estimates from Midwest Solvents Company for several plant sizes. Midwest Solvents operates an alcohol plant in Atchison, Kansas.

Capital Costs and Economies of Size

Available evidence suggests that economies to size do exist in ethanol alcohol production. One reason is that plant capacity can be increased without increasing plant investment costs by the same proportion. More exactly, you can double plant capacity but investment costs will be increased only about 1.5 times.[8/] An important reason is that adding one distillation column greatly increases plant capacity without much increase in investment costs.

Table 13 shows the total investment cost (1976 dollars) for several plant sizes. The table also gives investment costs per gallon of alcohol. The plant size most commonly discussed in the literature processes 20,000 bushels of corn per day. Table 13 shows that the investment cost per gallon for this plant size as $1.44. The largest plant size in Table 13 processes 40,000 bushels of corn per day and has an investment cost of $1.13 per gallon.

Annual ownership costs are tied to plant investment costs. To calculate costs per gallon of producing alcohol and to determine whether economies of size do indeed exist, we need to estimate ownership and operating costs.

Costs Per Gallon

The cost of converting grain into alcohol is discussed for two plant levels, the plants using 20,000 and 40,000 bushels of corn per day. These plants are assumed to produce 17 million gallons of 200^{o} proof alcohol per year and 34 million gallons per year, respectively. The analysis of costs for these two plant sizes illustrates that economies to size exist in converting grain into alcohol.

[8/] See USDA, Motor Fuels from Farm Products, /31, p. 65/ and Table 13 of this study.

Table 13. Capital Investment Costs for Plants of Various Sizes (1976 Dollars)

(1) Plant Capacity (Bu. Corn/ day)	(2) Alcohol Produced Per Day (200° Proof Gallons)[a]	(3) Alcohol Produced Per Year (Col. 2 x 312 day/year)	(4) Total Plant Investment Costs ($)	(5) Investment Cost Per 200° Proof Gallon/Year ($)
5,000	13,500	4,212,000	9,975,250	2.37
10,000	27,000	8,424,000	15,533,250	1.84
15,000	40,500	12,636,000	20,158,000	1.60
20,000	54,000	16,848,000	24,275,000	1.44
25,000	67,500	21,060,000	28,042,000	1.33
30,000	81,000	25,272,000	31,547,750	1.25
35,000	94,500	29,484,000	34,850,750	1.18
40,000	108,000	33,696,000	37,990,000	1.13

[a]/Assumes 2.7 proof gallons per bushel of corn.

[b]/Assumes 26 working days per month.

Source: Midwest Solvents Company, Inc., Atchison, Kansas, December 1977 /16/.

The first costs considered in alcohol production are the ownership costs. These costs include depreciation, interest, insurance and taxes. For the purposes of this report, we assume the life of the alcohol plant is 15 years. Estimates of plant life vary from 10 to 20 years.[9/] With straight line depreciation, this 15 year plant life implies a depreciation rate of 6.67%. Interest is assumed to be 5% of the initial investment cost which is the same as 10% of one half the initial investment or the average amount of capital tied up. Insurance is assumed to be .33% of the initial investment cost and taxes 1% of the initial investment cost. These percentages sum to an annual ownership cost rate of 13% of initial investment costs. This 13% can then be multiplied by the total plant investment cost and divided by the gallons of alcohol produced per year by the two plants to arrive at the annual plant ownership costs per gallon:

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[9]/Personal communication, Midwest Solvents Company, Inc., Atchison, Kansas.

Annual ownership costs per gallon:

(1) For 17 million gallon plant $= .13 \times \frac{\$24,275,000}{17,000,000} = 18.6¢$

(2) For the 34 million gallon plant $= .13 \times \frac{\$37,990,000}{34,000,000} = 14.5¢$[10/]

The second group of costs to include in alcohol production are operating costs. These costs include fuel, labor, maintenance, etc. Using the figures supplied by Midwest Solvents Company and the Minnesota Energy Agency, we calculated the operating costs per gallon for the 17 and 34 million gallon alcohol plants (Table 14).[11/] The plants are assumed to operate 312 days per year. The electricity usage was supplied by Midwest Solvents Company, but the rate charged for the electricity is a rate which is appropriate for a plant in Minnesota. Peak load demand was a factor in the electricity cost calculation as were the various usage rates for subsequent kilowatt hours, giving an average cost per kilowatt hour of 2.54¢. The Midwest Solvents plant uses natural gas which is infeasible for new industry in Minnesota. Hence, for this analysis, No. 6 fuel oil was used to replace natural gas. Number 6 fuel oil is more costly than natural gas; in fact, at present prices, it is nearly double the cost on a BTU basis, making alcohol more expensive.

Because processes are automated, the same amount of labor is required to run both the smaller and the larger plants. The cost data in Table 15 show significant cost economies to size of plant. For the 17 million gallon plant, alcohol costs 54.5¢ per gallon, excluding costs of grain. For the 34 million gallon plant, alcohol costs 39.4¢ per gallon.

A by-product feed credit was given for the DDGS priced at \$100 per ton. A credit was not given for the carbon dioxide because of its questionable value. The cost figures in Table 15 differ considerably from those in Appendix II. The estimates in Appendix II do not include interest on investment, taxes and insurance. While it is difficult to determine what has been included in the conversion costs in Appendix II, it is reasonable to assume that those estimates are based on lower energy costs because they were developed prior to 1976. The estimates in Table 15, although higher, are more current and provide a more relevant basis for the analysis in the remaining sections.

[10/] Unit costs reflect rounding plant sizes up from 16,848,000 gallons to 17 million and 33,696,000 gallons to 34 million.

[11/] Other studies are often quoted for conversion costs of grain into alcohol. These studies do not provide the detailed breakdown that this analysis gives. However, they are commonly cited in the alcohol fuel blend literature. The most notable of these studies was done by D. L. Miller. His analysis is included in Appendix II.

Table 14. Total Annual Operating Costs for Alcohol Plants of Two Sizes

Cost Item	Plant Size	
	17 million gallons	34 million gallons
Electricity	$1,693,512[a/]	$3,387,024[a/]
Fuel Oil (No. 6)	4,749,696[b/]	9,499,392[b/]
Labor	2,079,948	2,079,948
Maintenance Material	1,212,000	1,818,000
Payroll Taxes	156,000	156,000
Chemicals	211,200	422,400
Water	336,000	672,000
General Administration	540,000	540,000
Miscellaneous	900,000	1,350,000
	11,878,356	19,924,764

a/ Based on 66,600,000 KWH's for the 17 million gallon plant and 133,200,000 KWH's for the 34 million gallon plant, at an average cost of 2.54 cents per KWH (NSP 1977-78 rates).

b/ Based on 14,842,800 gallon requirement for fuel oil @ $0.32 per gallon (1977-78 price) for the 17 million gallon plant and on 29,685,600 gallons for the 34 million gallon plant.

Source: Midwest Solvents Company, Inc., Atchison, Kansas /16/, Energy and Policy Conservation Report, MEA, 1978, p. 100 for fuel oil price data.

Table 15. Annual Costs Per Gallon of Converting Corn into Alcohol by Plant Size

Costs and Credits	Plant Size: 17 Million gal./yr. (¢/gal.)	34 Million gal./yr. (¢/gal.)
Ownership Costs	18.6	14.5
Operating Costs	69.9	58.9
Ownership Plus Operating	88.5	73.4
By-product Feed Credit[a]	34.0	34.0
Total Cost (Excluding corn costs) less by-product feed crddit	54.5	39.4

[a]/Based on DDGS priced at $100/ton or $0.05/lb. and 6.8 lbs. of DDGS/gal of alcohol or $100 x .0005 x 6.8 = $0.34.

Source: Table 14.

Alcohol Costs with Grain Costs Included

It is apparent that as the by-product feed price, the cost of fuel and the cost of grain change, the cost of alcohol will also change. A simple equation can be used to determine the cost of alcohol with these costs as variables. The equation is:

$$(1)\ C_A = \frac{C_C}{2.7} + C_{OWN} + C_E + C_{FO} + C_O - (P_{DDGS}(.0005)(6.8))$$

where

C_A = Cost of alcohol ($/gallon)

C_C = Cost of corn ($/bushel)

C_{OWN} = Ownership costs per gallon alcohol basis

C_E = Cost of electricity per gallon of alcohol

C_{FO} = Cost of fuel oil (price of fuel oil/gallon times gallons per gallon of alcohol)

C_O = Other operating costs per gallon of alcohol basis

P_{DDGS} = Price of DDGS ($/ton)

The equation is estimated figuring 2.7 gallons of alcohol/bushel of corn and 6.8 pounds of DDGS/gallon alcohol. If the costs used in the above analysis are substituted into (1) the equation becomes:

$$(2)\ C_{A/gal} = \frac{C_C}{2.7} + .186 + .0996 + .279 + .32 - (P_{DDGS}(.0005)(6.8))$$

for the 17 million gallon per year plant and

$$(3)\ C_{A/gal} = \frac{C_C}{2.7} + .145 + .0996 + .279 + .21 - (P_{DDGS}(.0005)(6.8))$$

for the 34 million gallon plant.

With the price of DDGS set at $100/ton and the price of corn varying between $1.50 and $4.50 per bushel, Table 16 shows the resultant alcohol cost. From these data, it is apparent that even with corn at the low price of $1.50 per bushel the cost of alcohol is higher than the price of gasoline, even if we take advantage of economies to size of plant. This is significant since we are assuming alcohol is replaced on an equivalent basis with gasoline. Therefore, to be competitive alcohol must cost the same as gasoline. This preliminary analysis indicates that alcohol costs more than gasoline per gallon.

Table 16. Cost of Ethyl Alcohol When Grain Cost is Included

Cost of Grain Per Bushel ($)	Plant Size: 17 Million Gallons ($)	Plant Size: 34 Million Gallons ($)
1.50	1.10	0.95
3.00	1.66	1.51
4.50	2.21	2.06

Economic Feasibility of Gasohol

This section of the report is concerned with the economic feasibility of gasohol. More specifically, will the price of gasohol (a 10% alcohol-90% gasoline blend) be competitive with the price of gasoline without government subsidies? One might think that since gasoline prices are rising, albeit, in discontinuous jumps, that the answer to this question of economic feasibility might be; yes, eventually. The answer is more complicated than it seems, however. We cannot look solely at the price of gasohol. We must also look at the effects of a given level of gasohol production on the markets for the by-product feed and the effect of this increased by-product on the market for soybean meal, its closest competitor.

First in determining if gasohol is economically feasible we must decide at which level the gasohol program will be run. This report looks at seven levels of replacing gasoline with gasohol. These levels are as follows:

(1) One 17 million gallon per year alcohol plant

(2) Minnesota state, agricultural use only

(3) 5-state regional level for agricultural use only[12/]

(4) United States, agricultural use only

(5) Minnesota state, total gasoline usage

(6) 5-state region, total gasoline usage

(7) United States, total gasoline usage

Once the level of alcohol production is determined, a guaranteed supply of grain must exist, or else innumerable complications exist. These complications are

[12/] 5-state region includes: Minnesota, Iowa, Illinois, Missouri and Nebraska.

problems that may exist with automobiles in switching frequently between gasoline and gasohol and the increased costs of alcohol as a result of idle alcohol plants. Other problems exist. These complications imply that alcohol cannot be made only from so-called surplus grain, that is, grain left over from production after all other demands have been met.

Along with determining the level of usage of gasohol we must determine the amount of gasoline that will ordinarily be used at each level. With this information we can then estimate the amount of grain required and the resultant quantities of by-product feed that will be put on the market. The following analysis is done for 1980. Gasoline usage for 1980 is projected from 1974 data /32/, under each of three assumptions:

(i) total gasoline usage will decrease 5% from 1974 levels by 1980

(ii) total gasoline usage will remain unchanged from 1974 levels

(iii) total gasoline usage will increase by 5% from 1974 levels

While these projections are somewhat arbitrary, they should bound the range of actual use. The projection of "1980 gasoline use in agriculture only" is based on the Iowa State study /32/. These figures are presented in Table 17. The decrease in gasoline use in agriculture shown in this table is due to the large shift to diesel fuel.

Effect on Grain Markets

In determining economic feasibility of gasohol we first discuss the effect on grain markets. To do this it is important to specify the corn and wheat crops and the percentage of each crop used for various levels of gasohol programs. Since the size of the 1980 crop is unknown, two figures are used. The first is the maximum potential crop. This is the highest level of production ever achieved in the United States. If a large scale gasohol program is instituted, this is probably the relevant level to consider. It assumes maximum acreage planted, good weather and government programs geared to increasing production. The figures accompanying this set of assumptions are 6.2 billion bushels for corn[13/] and 2.1 billion bushels for wheat.[14/] A more realistic set of assumptions accompanying a smaller scale program is lower prices, average weather, government programs similar to those of the late 1960's and a stable world demand; production levels, given these assumptions, are similar to those of the late 1960's. The appropriate figures were obtained by taking a simple average of production of 1966-1970 for corn and wheat. The figures obtained are 4.5 billion bushels for corn and 1.4 billion bushels for wheat. Note, for the sake of simplicity, the fact that only one quarter of the grain used for making alcohol should be wheat, (unless a more expensive fermentation process is used) will be ignored.

[13/] Reference /32/

[14/] All other crop figures obtained from the USDA.

Table 17. Projected Gasoline Usage for 1980

	Gasoline (Million gal.)		Gasoline (Million gal.) Projected 1980		
	1974	Projected 1980	% Change in use -5	% Change in use 0	% Change in use 5
Agricultural Usage:					
Minnesota	162	104			
5-State Region	719 - 819	465			
United States	4,350[a/]	3,900 - 4,000			
Total Usage:					
Minnesota	2,041[b/]		1,940	2,041	2,144
5-State Region	12,075[b/]		11,500	12,075	12,700
United States	99,180[b/]		94,200	99,180	104,100

[a/] 1973 Use

[b/] These figures differ from those used in reference /32/ as the figures used as a basis for their projections were substituted for the 1973 numbers they used.

Source: Wisner, R.N. and Gidel, J.O., Economic Aspects of Using Grain Alcohol as a Motor Fuel, With Emphasis on By-Product Feed Markets, Iowa State University, 1977, /32/.

The one-plant (17 million gallons) gasohol program level, using both corn and wheat, is considered first. Since gasohol uses one part alcohol to nine parts gasoline, 17 million gallons of alcohol will be mixed with 153 million gallons of gasoline. Table 17 shows that total gasoline use in Minnesota in 1974 was 2,041 million gallons, which implies that Minnesota, alone, would need 12 of these plants. The impact of a single plant is small (Tables 18 and 19). Only 6.3 million bushels of corn will be required, which is only .14% of the average annual crop and only .10% of the maximum potential crop. If 6.8 pounds of by-product feed, distillers' dried grains and solubles, are obtained from each gallon of alcohol, then one plant provides 58,000 tons of DDGS. In terms of the 1973-74 commercial high protein feed supply, this is only .12% of the total, but it comprises 12.2% of the 1973-74 United States DDG supply. This is a significant increase for just one plant. Because most of the numbers are relatively small, a one plant gasohol program will have little effect on the corn crop, the high protein feed supply, the DDGS supply and the price of soybean meal.

Table 18. Effects Of One 17 Million Gallon Alcohol Plant Using Corn[a]

Level of Gasohol Program	Alcohol Needed (mil gal)	Gasoline Needed (mil gal)	Corn Required (mil bu)	% Of Potential 6.2 Billion Bu. Crop In 1980	% Of Average 4.5 Billion Bu. Crop In 1980	DDGS Obtained (Thousand Tons)	% Of 73-74 High Protein Feed Supply[b]	% Of 73-74 DDG Supply
1-17 million gallon/yr. alcohol plant	17	153	6.3	.10	.14	58	.12	12.2

a/ 2.7 gallons of alcohol/bushel and 6.8 pounds of DDGS/gallon of alcohol are assumed.

b/ In 44% protein equivalent.

Source: Reference /32/.

Table 19. Effects of One 17 Million Gallon Alcohol Plant Using Wheat[a]

Level of Gasohol Program	Alcohol Needed (mil gal)	Gasoline Needed (mil gal)	Wheat Required (mil bu)	% Of Potential 2.1 Billion Bu. Crop In 1980	% Of Average 1.4 Billion Bu. Crop In 1980	DDGS Obtained (Thou and) Tons)	% Of 73-74 High Protein Feed Supply[b]	% Of 73-74 DDG Supply
1-17 mil gallon/yr. alcohol plant	17	153	6.5	.31	.46	55	.12	11.6

a/ 2.6 gallons of alcohol/bushel and 6.5 pounds of distillers' dried grains and solubles/gallon of alcohol are assumed.

b/ In 44% protein equivalent.

Source: Reference /32/.

For wheat, the figures are not much different in the one plant case. The fact that the yield of alcohol per bushel is slightly lower than from corn (2.6 gallons per bushel) means that slightly more wheat must be used. But because the wheat crop is smaller than the corn crop the amount of wheat used implies that one plant uses a larger portion of the crop, .31% of the maximum potential crop and .46% of an average crop. The yield of DDGS is about 6.5 pounds per gallon of alcohol, making the percentage of high protein feed supply and DDG supply almost the same as for corn.

The amount of grain varies with the size of the program. Considering corn first, we show in Table 20 that gallons of the alcohol range from 104 million for Minnesota agricultural use only to 104,100 million gallons for total U.S. usage. The more meaningful figures, however, are the percentage of the corn crop that will be needed for the production of alcohol. The figures are again given for the maximum potential crop and an average crop. If the gasohol program just covers agriculture in Minnesota, only a very small percentage of the U.S. corn crop will be used, .063% and .087% respectively. However, if the gasohol program is run on a national level, replacing total gasoline usage with gasohol, 56.2 to 62.1% of a maximum corn crop or 77.5 to 85.6% of an average corn crop would go into alcohol production.

The figures for wheat are even larger (Table 21). Again, because the wheat crop is smaller than the corn crop, the percentage figures are much higher. For instance, if we again consider the Minnesota agricultural use only level, the percentage of the crop used is 1.9% or 2.9% of all maximum potential or average crop, respectively. The figures also show that a gasohol program level for total gasohol usage in the five-state region is the highest one that could be instituted. The level for the whole U.S. program would require the entire wheat crops of approximately two or three years to get enough alcohol to fuel the economy with gasohol for one year. This, recall, assumes that only wheat is used in alcohol production. It would be feasible to combine wheat and corn in a 25% to 75% ratio, but this may not be economically wise as the alcohol yield of wheat is lower and its original cost is higher.

These figures suggest that a gasohol program at the regional or national level will increase the demand for grain and raise farm prices for these commodities. The impact on corn prices is high at the five-state regional and U.S. levels where all gasoline is replaced with gasohol in the first year of the gasohol program. The amount of price increase is determined by an impact multiplier from the USDA feedgrain model.[15/] /33/ The impact at the regional level is an increase of corn prices by 23-25¢ and at the total U.S. level the increase is $1.88-$2.08 per bushel of corn. The impact of each program level is shown in Table 22.

[15/] This multiplier is obtained by solving a system of simultaneous equations where supply of corn is essentially decreased by the amount of increase of demand. This insures that this demand will be met.

Table 20. Projected Gasoline Use, Alcohol Needed, Corn Requirements and Percentage of 1980 Estimated U.S. Corn Crop at Various Levels of Gasohol Use

Level of Gasohol Program	Total Projected Gasoline Use: 1980 (Mil. Gals)	Alcohol Needed: 1980 (Mil. Gals)	Corn Required: 1980 (Mil. Bu)	Percent of Potential 6.2 Bil. Bu Crop-1980	Percent of Average 4.5 Bil. Bu. Crop-1980
Agricultural Use Only:					
Minnesota	104	10.4	3.9	.063	.087
5-State Region	465	46.5	17.2	. 28	. 38
United States	3900-4000	390-400	144-148	2.3-2.4	3.2-3.3
Total Gasoline Use:					
Minnesota	1940-2144	194-214	72-79	1.16-1.28	1.6-1.8
5-State Region	11,500-12,700	1150-1270	425.5-469.9	6.9-7.6	9.4-10.4
United States	94,200-104,100	9420-10,410	3485.4-3851.4	56.2-62.1	77.5-85.6

Source: Reference /32/.

Table 21. Projected Alcohol Requirements, Wheat Requirements and Percentage of 1980 Estimated U.S. Wheat Crop at Various Levels of Gasohol Use

Level of Gasohol Program	Alcohol Needed: 1980 (Mil. Gals)	Wheat Required 1980 (Mil. Bu)	Percent of Potential 2.1 Bil. Bu. Crop-1980	Percent of Average 1.4 Bil. Bu. Crop-1980
Agricultural Use Only:				
Minnesota	10.4	4	1.9	2.9
5-State Region	46.5	17.88	8.5	12.8
United States	390-400	150-154	7.1-7.3	10.7-11.0
Total Gasoline Usage:				
Minnesota	194-214	75-82	3.6-3.9	5.3-5.9
5-State Region	1150-1270	442-488	21.0-23.2	31.6-34.9
United States	9420-10,410	3623-4004	172.5-190.7	258.7-286.0

Source: Reference /32/.

Table 22. Effect of Various Levels of Gasohol Program on the Price of Corn

Gasohol Plant Level	Increase in U.S. Corn Price[a] $/bu
1-20 million gallon plant	.004
Agricultural Use Only:	
Minnesota	.002
5-State Region	.009
United States	.078 - .079
Total Gasoline Usage:	
Minnesota	.039 - .043
5-State Region	.229 - .254
United States	1.88 - 2.08

[a]/Impact multiplier obtained from: Womack, A., The U.S. Demand for Corn, Sorghum, Oats and Barley: An Econometric Analysis, University of Minnesota, Economic Report 76-5, August 1976 /33/.

A comparable analysis was not made for wheat as it was assumed that results would be similar. Note, however, that the U.S. does not produce enough wheat annually to supply a national gasohol program of total usage. The impact for the farmer will be discussed in more detail in a later section of this report.

While a gasohol program will tend to increase corn prices, it is expected to decrease soybean prices, at least in the short run. To determine the effect on prices of soybean meal and DDGS, we must first determine how much DDGS production is increased by increased alcohol production. These figures are given in Table 23 for corn and Table 24 for wheat. The way to interpret the percentage figures in these two tables is to consider them to be the amount of increase in the DDG supply and, consequently, the increase in high protein supply. It should also be noted that the by-product feed is DDGS but presently the market exists for DDG. Therefore, some disparity exists in the basis. These figures should only be regarded as determining the order of the increase, not the exact increase.

Table 23. Projected Quantities of By-Product Feed Obtained as a Percentage of Protein Feed Supply and DDGS Supply in 1973-74 at Various Gasohol Usage Levels When Corn is Used

Level of Gasohol Program	DDGS Obtained (Thous. Tons)	Percent of 73-74 High Protein Feed Supply a/	Percent of 73-74 DDG Supply
Agricultural Use Only:			
Minnesota	35.4	.09	7.8
5-State Region	158.1	.4	34.5
United States	1326-1360	3.3-3.4	289.5-296.5
Total Gasoline Usage:			
Minnesota	659-729	1.6-1.8	144.6-159.8
5-State Region	3910-4318	9.8-10.8	853.7-942.8
United States	32,028-35,394	80-88.4	6993-7727.9

a/ Computed as percent of total supply in 44% soybean meal equivalent. Assumes 6.8 pounds of DDGS/gallon of alcohol.

Source: Reference /32/.

Table 24. Projected Quantities of By-Product Feed Obtained, as a Percentage of Protein Feed Supply and DDGS Supply in 1973-74 at Various Gasohol Usage Levels When Wheat is the Crop Used

Level of Gasohol Program	DDGS Obtained (Thous. Tons)	Percentage of 73-74 High Protein Feed Supply a/	Percentage of 73-74 DDG Supply
Agricultural Use Only:			
Minnesota	35.4	.085	7.7
5-State Region	151.1	.36	33.1
United States	1268-1300	3.0-3.1	278-285
Total Gasoline Usage:			
Minnesota	630.5-695.5	1.5-1.7	138-153
5-State Region	3737.5-4127.5	9.-9.94	819.6-905.2
United States	30,615-33,832.5	73.8-81.5	6713.8-7419.4

Assumes 6.5 pounds of DDGS/gallon alcohol.

a/ In 44% protein equivalent

Source: Reference /32/.

Table 23 shows a significant increase in all DDG supplies at all program levels, except perhaps the Minnesota agricultural use only level. Even use in the five-state region for agricultural use only increases DDG supply by one third. Phenomenal increases, though, are seen at the five-state and U.S. total gasohol usage levels, increasing the DDG supply by 8.5 or 9.5 times at the regional level. Since DDG is such a small part of the high protein feed supply, the increases in high protein supply are smaller. At the U.S. total usage level, however, the increased DDG supply almost doubles the supply of high protein feed. This can, of course, be expected to affect soybean meal prices.

Table 24 shows the effects of increased DDGS if wheat is used in alcohol production. Since the yield of DDGS is only slightly smaller for wheat, its effects are nearly identical to those for corn. For this reason, these results will not be discussed further.

To determine the effect of increases in distillers' dried grain supplies on distillers' dried grain prices, the Iowa State Study estimated the price response to DDGS supplies by regressing distillers' dried grain price on its own quantity and other relevant variables /32/. The coefficient or quantity in this demand equation then was used to determine the price response. The results obtained in this study indicate that a 10% increase in DDG supplies will decrease price by 2%. This implies demand is elastic as large quantity increases are absorbed with little impact on price. Given this information, we can calculate the effect on DDG prices from an increase in its supply (Table 25). The authors of the study /32/ qualify this result saying that it applies for reasonable quantity increases but for very large quantity increases, one would expect a much larger response of price than that shown. With this in mind, we see from Table 25 that price decreases would be substantial for the U.S. agriculture only level and for all three levels when gasohol is used on a total use basis. These price decreases coincide with the increased DDG supply.

The farmer may not be concerned with the price of distillers' dried grains, as he does not produce them directly. However, as the increased supply of DDG enters the market it will affect the price of soybean meal as DDG and soybean meal are substitute feeds. The Iowa State Study quantifies the effects of DDGS supplies on SBM prices. The authors of that study used the quantity of grain protein meal supply as a proxy variable for DDG quantity. From Table 25, we see that significant decreases in soybean meal prices come at the U.S. agricultural use only and total gasohol usage program levels. Very large decreases come at the five-state regional and U.S. total usage levels; the soybean meal price decreases are 20% to 32% and over 70%, respectively. These translate into 60¢ to 95¢ per bushel of soybeans at the regional level and over $2.00 per bushel at the national level. With soybean prices around $6.50 per bushel this is a price decrease ranging from 9 to 13%.

The Iowa State Study extrapolates from the past, thus, the results may not be applicable when DDGS is used more widely as a feed /32/. Our analysis of feeding rations, described earlier, indicates that if DDGS is widely available it can be adapted for feeding ruminants and the price of DDGS will lie between that of corn and soybean meal on a pound for pound basis. Therefore, if DDGS is widely available, it will be used as a source of energy and its price will not drop much below the price of corn on a pound for pound basis.

Table 25. Potential Impact on DDG Prices and Soybean Meal Prices for Various Levels of the Gasohol Program

	Potential Impact On DDG Prices	Potential Impact On Soybean Meal Prices	Potential Impact On Soybean Prices b/
Agricultural Use Only:			
Minnesota	1.56% decrease	.2% decrease	Negligible
5-State Region	5.2%-7.0% decrease	1.0% decrease	3¢/bu. decrease
United States	43%-58% decrease	7%-10% decrease	21¢-30¢/bu decrease
Total Gasoline Usage:			
Minnesota	23-25% decrease	5%-9% decrease	15¢-28¢/bu decrease
5-State Region	a/	20%-32% decrease	60¢-95¢/bu decrease
United States	a/	a/ over 70% decrease	over $2.00/bu decrease

a/ Decrease in prices would be large but precise estimates are impossible to obtain. Past price-quantity relationships suggest these prices would become negative with the large supply increased involved here.

b/ Based on initial soybean meal price level of $125/ton and soybean meal yield of 47.6 lb/bu. higher initial soybean meal prices will lead to greater impact on soybean prices.

Source: Reference /32/.

The effect of the DDGS price on the SBM price is somewhat harder to establish. When DDGS price is about equal to the SBM price, on a pound for pound basis, the two feeds compete as a protein source. At DDGS prices lower than SBM prices, the DDGS is used as an energy source. Thus, it is not clear that SBM prices will fall substantially as the DDGS supply increases. In any event, if SBM prices fall to compete with lower DDGS prices, they too will not drop below the price of corn (pound for pound basis) as this is the bottom point of the DDGS price.

Since our study deals only with one type of ruminant, beef steers, we can probably generalize the argument to include feeding of other ruminants, but not to feeding poultry and swine. However, since ruminants compose a large portion of animals fed, the foregoing analysis should reflect fairly accurately what can be expected to happen. The prices of DDGS and SBM will probably not drop as low as Tables 23-25 indicate as long as the corn price increases.

The preceding discussion implies that farmers may move some acreage out of soybean production into corn production. The Iowa State Study argues that a large shift is unlikely for two reasons. First, three quarters of the high protein feed will be composed of DDGS instead of soybean meal. But since DDGS is not as balanced a feed as soybean meal because of the absence of some amino acid, it is unlikely that livestock feeders will eliminate all soybean meal from the ration. The second reason given by the Iowa State Study is that domestic soybean oil supplies will be greatly decreased allowing less of other vegetable oil to be exported. This will tend to increase the price of soybeans, preventing a total acreage shift /32/. Other reasons would tend to prevent a complete shift from soybeans to corn. There exists a difference in timing in planting and harvesting the crops that prohibits a total shift out of soybeans into corn. A complete shift of acreage of this type would call for a tremendous resource shift not only in the grain but in the livestock industry, as well. Even if a complete shift occurs, it would take several years to accomplish it.

The Effects of Corn and Gasoline Prices on the Economic Feasibility of Gasohol Production

Having considered the impact of various levels of gasohol programs on corn, wheat and soybean prices, we can now determine at what level these prices result in competitive prices for gasohol. This implies that the price for a gallon of alcohol should be the same as a gallon of gasoline since we assume that alcohol replaces gasoline on an equivalent basis.[16/] The wholesale price for gasoline in 1977-78 was about 43¢ a gallon. This assumes a price of about $18.00 a barrel (42 gallons = one barrel). We saw in Table 16 that the price (cost) of alcohol is always substantially higher than the price of gasoline. However, we are more interested in the actual price of gasohol.

16/ The price of alcohol used in this analysis is a base minimum or the cost of producing it. A profit margin, transportation charges and other distribution costs have not been included.

As a basis for an analysis of gasohol prices we will use equation (1), page 37 of the cost section. We will again consider the two plant sizes, 17 and 34 million gallons of alcohol per year. In this analysis we allow five costs to vary: corn, DDGS, gasoline, electricity and No. 6 fuel oil. For simplicity the variables in equation (1) that will remain constant are summed. These are:

(1) the ownership costs: C_{OWN}

(2) the other operating costs: C_O

The equation to determine the price of gasohol, using the costs for C_{OWN} and C_O from the cost section, is then,

$$(4)\quad P_{GASH_1} = .9\, P_{GAS} + .1 \left[\frac{C_C}{2.7} + C_E + C_{FO} + .507 - (P_{DDGS}(.0005)(6.8))\right]$$

for the 17 million gallon plant.

For the 34 million gallon plant the equation for gasohol price determination is:

$$(5)\quad P_{GASH_2} = .9\, P_{GAS} + .1 \left[\frac{C_C}{2.7} + C_E + C_{FO} + .357 - (P_{DDGS}(.0005)(6.8))\right]$$

where

P_{GASH_1} = Price of gasohol from 17 million gallon alcohol plant

P_{GASH_2} = Price of gasohol from 34 million gallon alcohol plant

P_{GAS} = Price of gasoline (wholesale)

The price of gasohol can be determined if we know the prices of the variables in equations (4) and (5). For the present assume that the price of gasoline is \$.43/gallon, wholesale, and let the price of electricity and fuel oil be what they were in the cost analysis, \$.025/KWH and \$.32/gallon respectively. We can then vary the price of corn and the price of DDGS to see at what point the price of gasohol equals that of gasoline. Figure 6 shows the price of gasohol from a 17 million gallon alcohol plant when DDGS is \$134/ton, \$120/ton, \$60/ton and \$20/ton. We see that as the price of DDGS decreases it furnishes a smaller feed credit, increasing the price of gasohol. If a large gasohol program is instituted a lower price of DDGS would be realized, so a \$60/ton price would not be unrealistic. In any case, gasohol is more expensive than gasoline for all prices of corn, except for prices of DDGS above \$134/ton. Figure 7 shows a similar picture for the 34 million gallon alcohol plant. The economies of size are evident, as for each price of corn, the price of gasohol is less than in Figure 6. However, the price of gasohol is still above the breakeven price, except for DDGS above \$90/ton. If DDGS is \$90/ton and the price of corn is zero, gasohol is equal in price to gasoline using the 34 million gallon alcohol plant.

Figure 6. Price of Gasohol for Varying Prices of Corn in the 17 Million Gallon Alcohol Plant with the Wholesale Price of Gasoline set at $.43 per Gallon

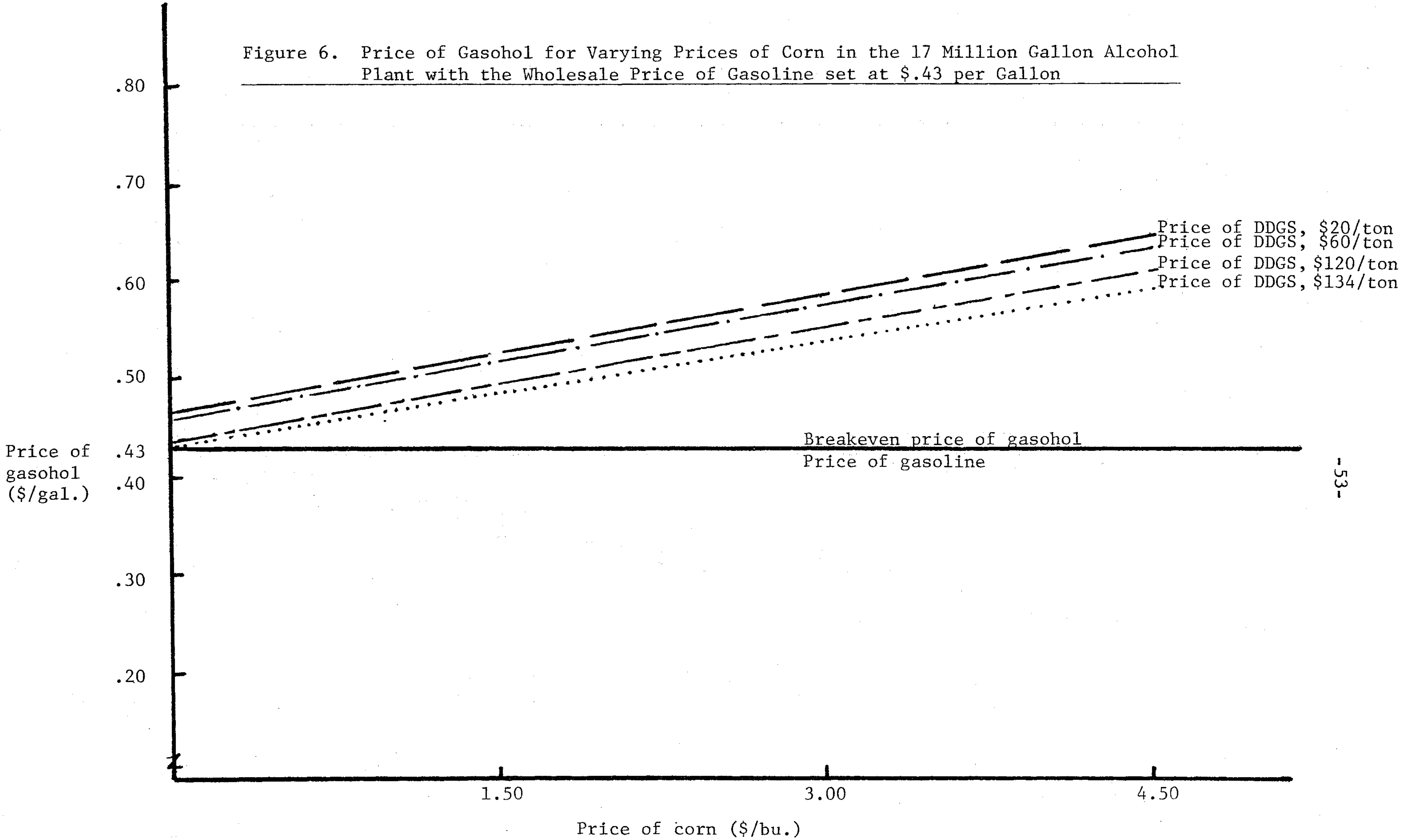
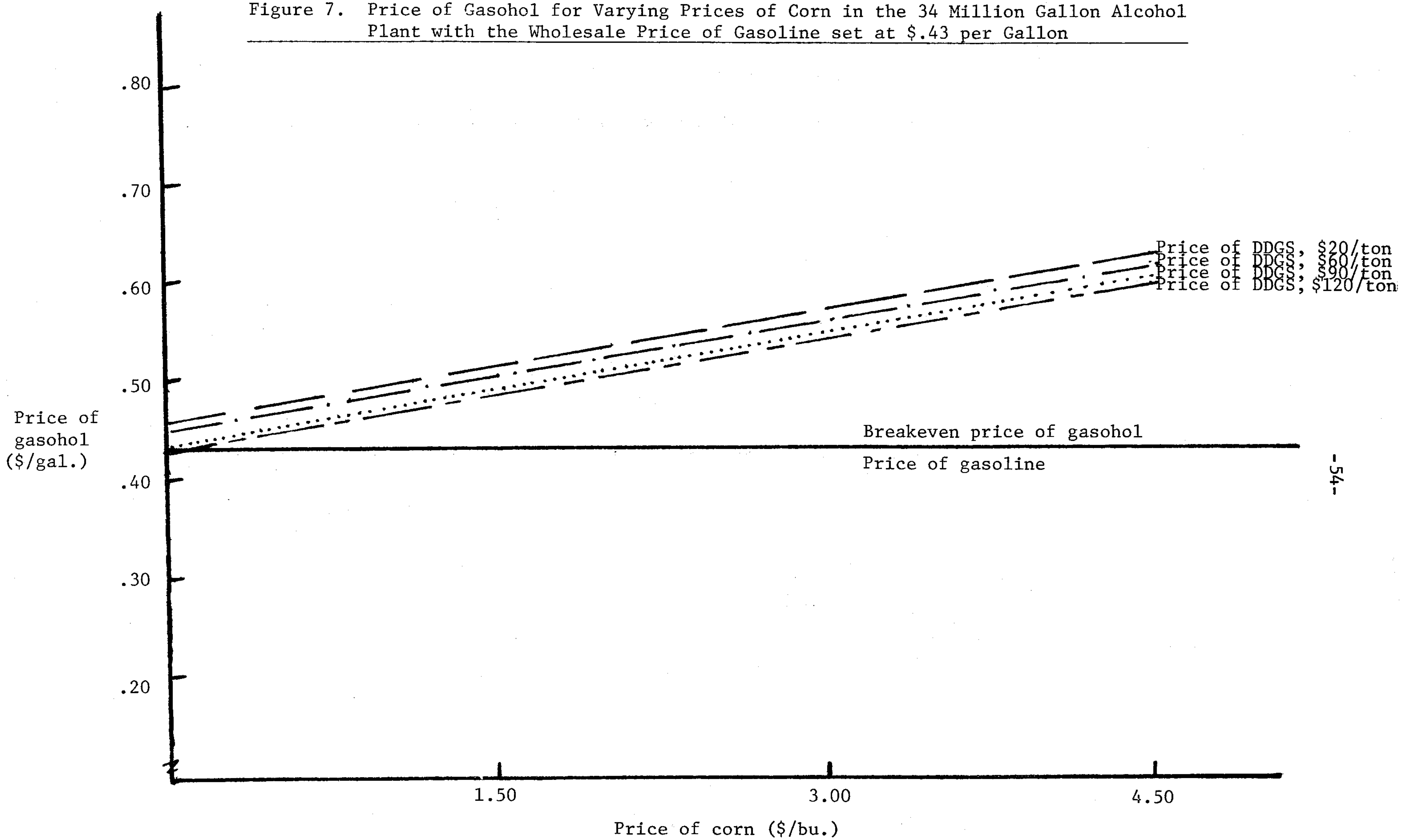


Figure 7. Price of Gasohol for Varying Prices of Corn in the 34 Million Gallon Alcohol Plant with the Wholesale Price of Gasoline set at $.43 per Gallon



Gasohol proponents argue that if we were to have a doubling in oil prices gasohol will be profitable. This argument rests on a single price change, the price of gasoline. This analysis, however, is fallacious as it assumes all other energy prices and all other prices for that matter remain constant. However, the price level, in general, and the price of all other energy sources, in particular, vary with the price of oil. Therefore, if we increase the price of gasoline, we must increase the price of the other energy sources as they are fairly close substitutes. Therefore, as we double the price of gasoline, we will make a simplifying assumption and double the prices of other energy inputs in the alcohol plant. This situation is illustrated in Figures 8 and 9, for the 17 and 34 million gallon alcohol plant, respectively. Figure 8 shows gasohol price above the price of gasoline for all prices of corn and DDGS except when DDGS price is at $119/ton. If the price of corn in this instance is zero, gasohol is competitive with gasoline. The same situation occurs in Figure 9 with DDGS priced at $75/ton. Essentially, then at these DDGS prices, gasohol is profitable only if corn is very cheap or free. From data in Figures 6 through 9, we conclude that gasohol is more expensive than gasoline, regardless of the price of corn or the price of gasoline.

Since wheat is a higher priced crop than corn (per bushel) with a lower yield of alcohol and distillers' dried grains and solubles, it is less desirable in the use of alcohol. Distillation is also more expensive because of the foaming problem. For these reasons gasohol produced from wheat is even more expensive than gasohol produced from corn.

In conclusion, then, gasohol will always cost more than gasoline, regardless of the price of gasoline or corn, assuming the price of DDGS is below $110/ton. Economies to size of alcohol plant do not change this conclusion even if alcohol is produced in the 34 million gallon plant. This analysis indicates that gasohol is not economically feasible without some type of subsidy program. Since any combination of prices could leave gasohol competitive if it is subsidized heavily enough, the question of subsidy and its effect on the market for gasohol is examined in the following section.

The Subsidy Issue

Based on the previous analysis a subsidy would be needed in order to make gasohol competitive with gasoline.

Subsidy - How One May Work

The type of subsidization considered does not subsidize farmers or alcohol plants directly, but rather it subsidizes alcohol plants indirectly. The way this subsidization is done is through the state and federal tax on gasoline. When gasohol is purchased by the consumer, the same price is charged for it as for gasoline. However, the state and/or federal tax is not collected on gasohol, as it is on gasoline. This allows the gasohol retailer to pay a higher wholesale price to the alcohol plants. This then, enables the alcohol producer to pay the market price for the grain. It is interesting to note that farmers are

Figure 8. Price of Gasohol for Varying Prices of Corn in the 17 Million Gallon Alcohol Plant with the Wholesale Price of Gasoline set at $.86 per Gallon

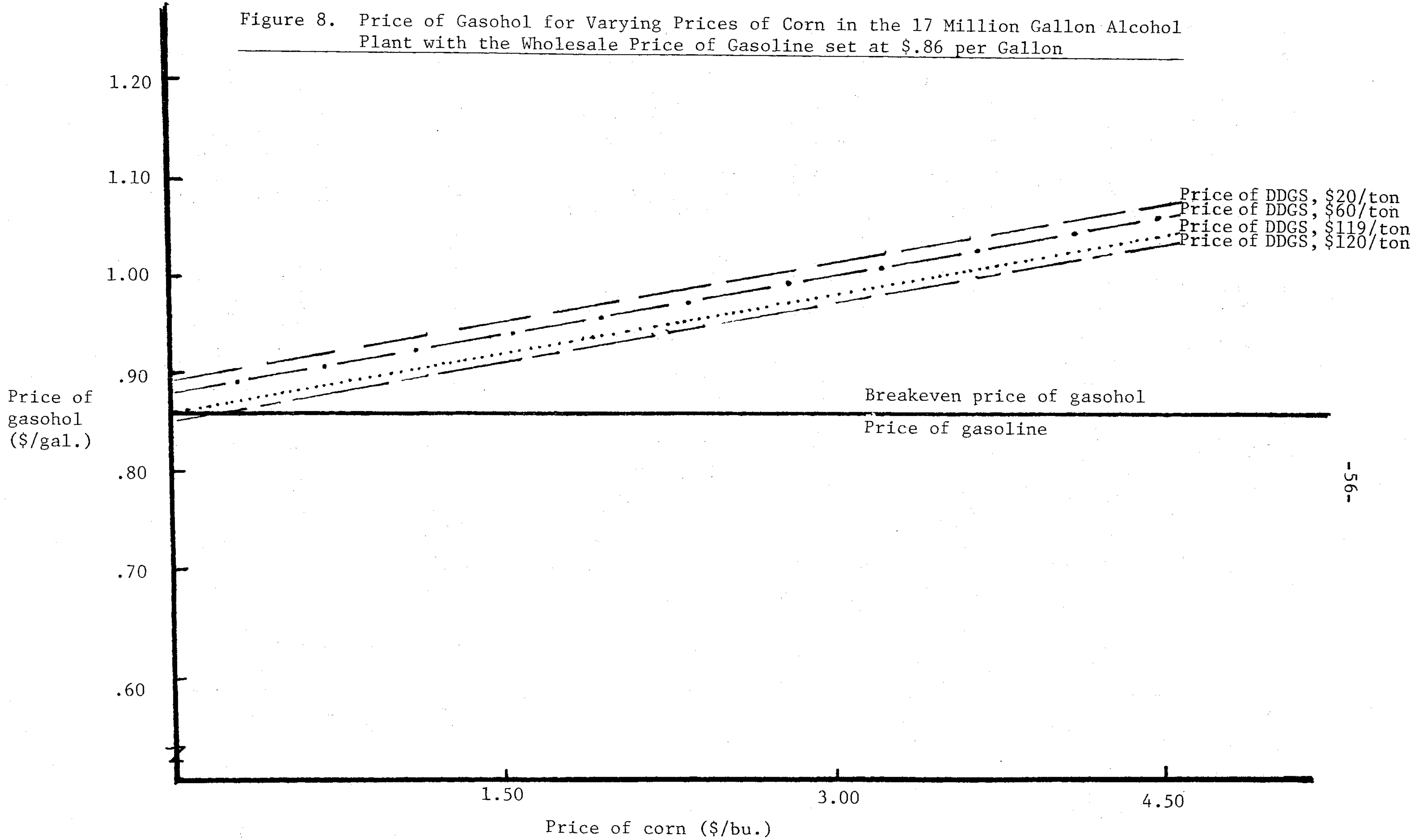
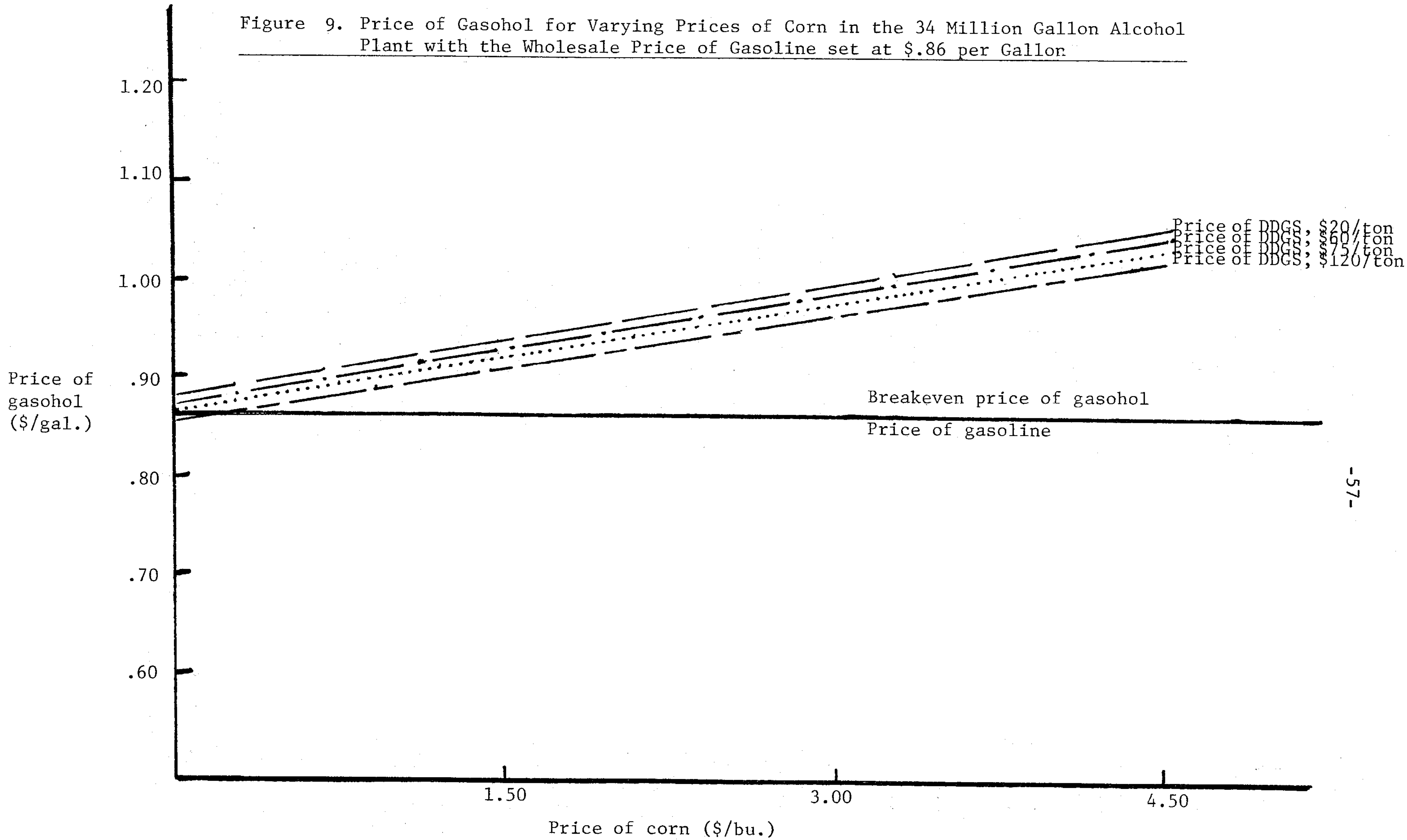


Figure 9. Price of Gasohol for Varying Prices of Corn in the 34 Million Gallon Alcohol Plant with the Wholesale Price of Gasoline set at $.86 per Gallon



presently exempt from the $.04 per gallon federal tax for gasoline used in farming. At the present time, this amounts to a $115 million tax refund /27/. With the enactment of a national gasohol program and if federal tax is no longer collected, as gasohol proponents desire, the farmer is essentially charged $.04 more per gallon of gasohol, unless present laws are altered.

To better understand how this subsidy works, consider the case of Nebraska which has enacted a bill to eliminate the state tax on the gasoline in gasohol with the effect of a $0.05 decrease per gallon of gasohol. Nebraska senators are also calling for a national bill that will do away with the federal $.04 tax on gasoline entirely. If we assume that the federal tax is not collected and $.05 of the state tax is not collected, we can see the workings of the subsidy. Here we assume that the wholesale price of gasoline is at 1977-78, that is, $0.43 per gallon and that the price of DDGS is $120 per ton and the price of corn is $2.70 per bushel. Table 26, then, illustrates that the difference in price between gasohol and gasoline is $0.09. Since the tax of $0.09 is not collected on gasohol, the prices of the two fuels are now equal, as shown in Table 27. The subsidy then enables service stations to pay nine cents more per gallon of gasohol.

Several points are still to be made concerning the implications of this subsidy, but first it should be noted that Dr. William Scheller of Nebraska gives a slightly different analysis. He claims that fuel consumption is 5% less with gasohol, compared with gasoline, warranting a fuel credit. He also claims an increase in octane number that warrants a credit. However, as has been discussed, major petroleum laboratories have not substantiated these results, so it is felt that Scheller's claims lack supporting evidence. Scheller also claims that the fuel is expanded by .23%, a point which is not generally disputed. Accenting this claim can credit a gallon of alcohol by up to $0.01, or $.001 credit per gallon of gasohol, but this point does not entirely compensate for the lower heat content of the gasohol.

The discussion of the subsidy deals with gasohol. Since nine cents in federal and state taxes are not collected on the gallon of gasohol, retailers can pay nine cents more for each gallon of gasohol. However, since gasohol is only one tenth alcohol, it takes ten gallons of gasohol to obtain one gallon of alcohol. So this allows the retailer to pay $0.90 per gallon for alcohol above its competitive price. To be a competitive fuel, alcohol must cost essentially the same as gasoline or about $0.43 per gallon. Using equation (3), we see that a gallon of alcohol costs $1.33 with $2.70 corn and $120/ton for DDGS. This price excludes markup, transportation and marketing costs. Since the retailers can spend $0.90 more per gallon because of the subsidy, a price of $1.33 + markup is now attractive to the retailer whereas without the subsidy, no alcohol would be purchased.

Of course, if a national program is instituted the price of corn may approach $4.00. These subsidies, so constructed, will not be large enough to make gasohol competitive even if all federal and state tax is eliminated. Figure 7 shows that with a corn price of $4.00, and a DDGS price of $120/ton, the price of gasohol will be $0.57 per gallon. Even if the price of DDGS is $145/ton, the price of gasohol is $0.56/gallon. Moreover, with a $0.12 per gallon ($.04 federal and

Table 26. Comparison of Gasoline and Gasohol Price at the Retail Level

Item	Gasoline ($/gal.)	Gasohol ($/gal.)
Fuel (wholesale)	.43	.52
Transportation	.01	.01
Station Markup	.09	.09
State Tax[a]	.08	.08
Federal Tax	.04	.04
Pump Price	.65	.74

[a] Currently 35 states tax gasoline at 8¢ or higher. In Minnesota, the state tax is 9¢ on the gallon.

Source: Reference /27/.

Table 27. Comparison of Gasoline and Gasohol Price at the Retail Level With a Gasohol Subsidy

Item	Gasoline ($/gal.)	Gasohol ($/gal.)
Fuel (wholesale)	.43	.52
Transportation	.01	.01
Station Markup	.09	.09
State Tax	..08	.03
Federal Tax	.04	---
Pump Price	.65	.65

Source: Reference /27/.

$.08 state tax elimination) subsidy, the fuel price is still too high to make gasohol cost the same as gasoline. Hence, if corn prices reach very high levels, other more direct subsidies will be required.

Subsidy - Who Pays For It

When a subsidy is given, someone must pay for it. In this case, because state and federal taxes are not collected, the regular projects funded by these taxes no longer receive this funding. In this subsidy scheme, the highway fund is diminished. The effect on the highway fund must be measured on a state by state basis as the effect on each state will differ. The reasons are that the number of gallons of gasohol will vary, the amount of the subsidy on a per gallon basis makes a difference, and the ratio of federal matching funds affect the size of the subsidy in total, and thus the effect on the highway fund. For instance, if Minnesota were to adopt a total gasohol usage program, it would need, according to Table 20, 194-214 million gallons of alcohol. If alcohol is subsidized by $.50 per gallon ($.05 state subsidy on a gallon of gasohol), the state gets $97-107 million less per year for its highway fund. Given that the state gasoline tax in Minnesota is $.09 per gallon, a five cents subsidy on a gallon of gasohol decreases the highway fund by more than one-half.

This money, alone, is not all that is at stake, however. The portion of the highway fund that is spent on interstate freeways is matched by federal funds in a ratio of nine federal dollars to every state dollar. For all work on secondary roads the federal matching ratio is 72 federal dollars to every 28 state dollars.[17/] Hence, the total highway fund is reduced a great deal more than the apparent decrease in the state fund.

As the price of corn rises, as under a national gasohol program, the subsidy to the alcohol plant must rise. If the gasohol program is subsidized in the previously described way, alcohol can be subsidized only up to $1.30 per gallon in Minnesota ($.09 state tax and $.04 federal tax elimination) or $.13 on a gallon of gasohol. If the price of gasohol does increase to the point where all state and federal tax is eliminated, the highway fund for this state and every state will be zero. Other ways must, then, be devised for subsidizing either the alcohol plant or the highway fund. In either case, the government will enter in a large way. If the goal is to raise farm income, it seems that other ways would be more direct and less costly in administrative costs than governmental subsidization by decreasing the fuel tax or direct subsidization of the highway fund.

An added point often made in favor of gasohol is the jobs an alcohol plant will create. This is a one-sided analysis as it ignores the jobs that will be lost because of the decreased highway fund. Since the gasohol plant uses a large amount of capital and relatively small amounts of labor, it is unlikely that a net increase in jobs will result because of gasohol production.

[17/] Minnesota Transportation Department figures, personal correspondence.

Hence, if a gasohol program is instituted at the national level, raising the price of corn and thus the price of gasohol, in all likelihood billions of dollars per year in highway funds, nationally, will go toward the support of gasohol plants. This figure, of course, does not include the federal matching funds that would be lost because of the state highway fund decreases. Ultimately, this indirect subsidy may prove to be insufficient as the price of gasohol rises, and then another more direct subsidy will be required. If this is the case, it may then be cheaper and easier to subsidize the farmer directly since that appears to be the main goal behind the gasohol program.

Impact of Gasohol on Farm Income

We have already discussed the economic feasibility of gasohol with only some reference to the impact on the farmer. This section deals more explicitly with the effect on farm income.

We have previously discussed the economic feasibility of gasohol and the conclusions were that gasohol is more expensive than gasoline regardless of the price of corn or gasoline. Therefore, to make gasohol competitive with gasoline, it must be subsidized.

A subsidy can be instituted in a number of ways. However, we will make several assumptions that are in keeping with the type of subsidy being recommended by gasohol proponents. These assumptions are that alcohol producers buy grain from the farmer at market price and the government, in essence subsidizes the alcohol producer by an amount equal to the difference in the price of gasoline and gasohol. We can see how farm income is affected by recalling that the first year a gasohol program at a national level will raise the price of corn about \$2.00 a bushel above the current price. Corn then will bring at least \$4.00 a bushel. Given this situation, gasohol will then be priced at \$0.59 per gallon or about \$0.16 above the price of gasoline (Figure 7, using P_{DDGS} of \$60/ton). Of course, a smaller scale gasohol program would raise corn prices less calling for a smaller subsidy. Thus, the impact on farm prices is basically a function of the size of the gasohol program that is instituted.

Recall that as alcohol is produced on an increasingly large scale, four things happen. First, the price of corn goes up. Second, distillers' grains are produced in very large quantities exerting some downward pressure on its price. Third, DDGS, competing with soybean meal, exerts a downward pressure on the soybean meal price. The fourth effect is that as DDGS supply becomes large, it will compete with corn as feed, exerting an upward pressure on the DDGS price, preventing the DDGS price from bottoming out. This in turn may stabilize the soybean meal price. The natural response of the farmer to these changes will be to shift out of soybean production into corn production. The shift probably will not be acre for acre for the reasons already discussed. With a government subsidy, it seems likely that the grain farmer's income will increase somewhat with a gasohol program. The exact increase in income will depend on the size of the gasohol program, the resultant increase in corn price and the shifting of acreage out of soybeans.

The increased presence of DDGS, along with the disappearance of corn and of soybean meal, in addition to its relatively lower price will make DDGS a highly available, if not a most desirable feed. Because of its high fiber content, digestion time for ruminants is much longer. Weight gain is also slower, thus, lengthening the time of feeding. This increases the costs to livestock producers and may ultimately decrease the number of livestock producers and the number of livestock raised /27/. If DDGS is cheap enough, it may even be used as a hog and poultry supplement with similar effects. Thus, the livestock producer's net income may decrease /27/. The overall aggregate farm income, then, will probably rise only slightly.

Gasohol, Other Alcohol Fuels and Energy Sources

Up to this point, we have been discussing gasohol. The analysis has shown that a major expense in gasohol is the grain. Also, a major part of the energy used in the alcohol process is grain production. Together these indicate that if a cheaper, more energy efficient source is found, an alcohol fuel or fuel blend would not be as unfavorable as gasohol.

A cheap, plentiful source of material is municipal waste, from which methanol can be produced. Methanol has essentially the same properties as ethanol. It has a lower BTU content than gasoline and is separated from gasoline by the presence of water. Problems of vapor lock are slightly worse with methanol than ethanol. The important point about methanol is that it does not use a valuable resource as a base. Rather, it is made with a substance that is usually discarded.

In fact, ethanol (or ethyl alcohol) is the most expensive of the alcohol fuels. Consider this comparison, prepared for Energy Research and Development Administration, /4/ given in Table 28. It clearly illustrates that ethanol produced from any source costs considerably more than methanol, or gasoline for that matter. It also shows that gasoline, after its 1974 quadrupling in price, is still among the most inexpensive of fuels.

The use of any alcohol blend fuel still leaves the United States dependent on oil technology and large foreign oil imports. Assume for the moment that the methanol or ethanol process uses no oil in its production. If oil reserves are assumed to last only 25 years longer, the use of alcohol fuels can extend this period to 27.5 years /12/. Even if there are 50 years of oil reserves remaining, the use of alcohol extends this period only five more years. This is a minor extension of oil reserves.

Needed is a fuel or energy system that is less oil dependent. A possible non-oil based fuel is the use of straight methanol for automobile engines where the methanol production process uses energy other than from oil and natural gas and as little coal as possible, and that the engine be modified to accommodate the fuel. Other technologies such as solar energy, geothermal energy and nuclear energy can also provide alternatives if technological development continues to decrease their cost and in the case of nuclear energy, increase its safety. Much work in these areas needs to be done to adapt them to use in transportation.

Table 28. Comparison of Costs of Selected Liquid Fuels

Product	Source	Process	$/10^6 BTU
Methanol	Tree Crop	Pyrolysis/Synthesis	5.20
Methanol	Municipal Solid Waste	Pyrolysis/Synthesis	6.45
Methanol	Coal	Insitugasification	2.68
Ethanol	Corn @ $2/Bu.	Fermentation	12.50
Ethanol	Corn @ $1/Bu.	Fermentation	8.99
Ethanol	Waste Paper	Enzymatic	8.87
Gasoline	Petroleum	35¢/Gal. at Refinery	2.77

Source: Anderson, Carl J., Biosolar Synfuels for Transportation, Prepared for ERDA by Laurence Livermore Laboratory, University of California, January 1977 /4/.

Social Considerations - Boot Legging

Another facet of alcohol production that deserves mention is social in nature. It involves the use of alcohol from the fuel blend as beverage alcohol. This problem is of concern to the U.S. Treasury Department because this department collects the taxes on potable alcohol. No tax would be collected on alcohol or gasohol.

Ethyl alcohol can easily be separated from gasoline by adding water to the mixture. It can then be siphoned off. To prevent siphoning off the alcohol, a denaturant, such as wood alcohol can be added, but part of the problem is that a denaturing agent does not exist that cannot be separated from the alcohol. Once the separation is done, shaking the alcohol with activated charcoal removes any remaining gasoline odor and leaves a completely potable alcohol /6, p. 7-13/. This could be done to avoid local state tax on alcohol for uses other than gasohol. Since it is not a costless procedure, it is impossible to tell exactly how widespread this practice will be.

There is also the possibility that the alcohol could be sold illegally from the plant. To guard against this, and to abide by U.S. regulations, extra precautions would have to be used by the plant. These include added security measures, such as locks, seals, fences, valves and piping, bonding for potential tax liability and detailed bookkeeping forms recording all inputs and ouputs /27/. This would add to the cost of producing the alcohol, making an unfavorable economic situation even worse.

Appendix I

Dr. William Scheller of the University of Nebraska has presented an analysis (Table 3) of the energy balance somewhat different from that presented in our report. Scheller uses a lower value for the BTU content of alcohol, a slightly higher figure for the energy for corn production and a lower figure for alcohol conversion. His most important difference is that he includes 75% of the corn residue in the energy output. These differences result in a positive energy balance of 27,700 BTU's. Including the crop residue is open to question because of its impracticality. It is impractical because of the great bulk of the residue and the difficulty in collecting it. Moreover, if removal of the residue is practiced too extensively in the plains states, severe soil erosion problems may develop.

The corn residue also adds nutrients to the soil and improves soil tilth; if the residue is removed more fertilizer has to be added to the soil thus adding to the energy used in grain production. Table 4 shows the nutrient content in the residue. From this table, we see the corn stover contains about two-thirds of the fertilizer nutrients contained in the whole corn plant. Therefore, the removal of it means more fertilizer has to be added. Scheller, however, does not take this into consideration in his analysis. From his presentation, it also isn't clear whether he includes the extra energy needed in readying the crop residue for transport to the alcohol plant. Alcohol plants in existence today do not use crop residue in fueling their plants /16/.

For this reason, Scheller's analysis is recalculated in Table 5, omitting the crop residue and its processing and transportation. Omission results in a negative energy balance of 95,500 BTU's per gallon of alcohol. As noted above, the difference in estimates of energy content of alcohol and energy consumption in farming and alcohol plant operations between Scheller's and other analyses in this report is significant. If the USDA estimate for the energy used in the farming operation, the North Dakota or the Midwest Solvents estimate for alcohol plant operation, and BTU content of alcohol used is the same as Table 12, an even larger net energy use is obtained. The result is shown in Table 6. Thus, a wide range of results can be obtained from an analysis of the energy balance depending on the technology used in grain production and plant operation, as well as the amount of crop residue that is included. The authors believe the analysis included in Table 12 is the most appropriate one to use for a general analysis of the energy balance resulting from ethyl alcohol production from corn in the United States.

Appendix I, Table 1. U.S. Fuel Requirements for Agricultural Production

Crops	Value of Production	Acres (1000)	Yield (Bu.)	Gallons of Gasoline (1000)	Gallons of Diesel (1000)
CORN					
Minnesota	1,241,600	5,900	61.0	64,862	29,186
West North Central Region	7,138,899	30,269	60.3	307,619	246,077
U.S.A.	16,328,085	65,194	71.3	685,421	470,688
SOYBEANS					
Minnesota	675,500	4,080	21.0	30,937	22,377
West North Central Region	3,393,199	18,590	30.2	138,860	102,664
U.S.A.	9,480,088	53,582	23.5	387,501	342,898
SMALL GRAINS[a/]					
Minnesota	612,600	5,850	----	38,921	15,649
West North Central Region	5,085,734	51,922	----	308,585	129,080
U.S.A.	9,676,879	112,375	----	651,789	450,625
FORAGE[b/]					
Minnesota	576,059	4,004	----	60,046	13,309
West North Central Region	2,787,340	28,723	----	214,459	167,480
U.S.A.	8,329,619	71,987	----	601,649	301,458
SPECIALTY CROPS & MISC.[c/]					
Minnesota	244,576	968	----	12,497	11,972
West North Central Region	799,131	4,774	----	48,508	45,957
U.S.A.	15,374,567	104,333	----	544,918	720,874

Data includes energy used directly on the farm for production purposes

[a/] Includes: spring wheat, winter wheat, barley, oats, sorghum

[b/] Includes: alfalfa, other hay, sorghum silage, corn silage

[c/] Includes: burley tobacco, citrus, cotton, flaxseed, flue cured tobacco, fruit and nuts, peanuts, potatoes, rice, shade tobacco, sugar beets, sugar cane, sweet potatoes, vegetables-processed fresh, other crops

West North Central Region includes: Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Kansas

Source: Energy and U.S. Agriculture: 1974, Data Base, Vol. 2, USDA, FEA [29].

Appendix I, Table 2. U.S. Fuel Requirements for Agricultural Production

Livestock	Value of Production ($1000)	Inventory (Thousand Head)	Gallons of Gasoline (1000)	Gallons of Diesel (1000)
RUMINANT LIVESTOCK[a]				
Minnesota	1,172,014	2,883	25,335	9,307
West North Central Region	7,073,457	28,510	137,988	140,106
U.S.A.	24,872,896	94,218	630,955	268,408
POULTRY				
Minnesota	212,155	N/A	2,968	201
West North Central Region	556,379	N/A	7,823	669
U.S.A.	6,295,924	N/A	71,336	4,231
HOGS				
Minnesota	479,598	5,918	8,593	7,491
West North Central Region	3,845,640	43,962	51,890	40,141
U.S.A.	6,863,313	85,933	115,074	79,777

Data includes energy used directly on the farm for livestock production purposes

[a] Includes: beef cows and calves, beef feedlot, milkcows, sheep and lambs

West North Central Region includes: Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas

Source: Energy and U.S. Agriculture: 1974, Data Base, Vol. 2, USDA, FEA /29/.

Appendix I, Table 3. Overall Energy Balance for Grain Alcohol Production From Corn Using 75% of the Field Waste

Energy Production	BTU/Gal. Alcohol
Ethyl Alcohol	75,600
Aldehydes, Fusel Oil	1,100
75% of the Stalks, Cobs, Husks	124,400
Total	201,100
Energy Consumption	
Farming Operation	46,000
Transportation of the Stalks, etc.	1,200
Alcohol Plant	108,000
Net Consumption in By-Product Production	18,200
Total Net Energy Production	27,700

Note: There is a slight difference in the energy content of the alcohol used in the farming operation and alcohol plant reported here compared to that used in the rest of the text. However, these are the figures Dr. Scheller uses.

Source: The Use of Ethanol-Gasoline Mixtures for Automotive Fuel, Dr. William A. Scheller, University of Nebraska /21/.

Appendix I, Table 4. Nutrient Value Contained in Crop Material

	Major Fertilizer Nutrients (lbs./acre)			
	N	P	K	N+P+K
Total Plant	145	24	154	323
Grain	72	15	19	106
Stover	73	9	135	217
Cost[a] to Replace Nutrients in Stover	$8.76	$3.15	$13.50	$25.41

[a]Costs: N @ 12¢/lb., P @ 35¢/lb., K @ 10¢/lb.

Assumed Yield: Total Plant 5.98 tons/acre
Grain 101 bu./acre

Source: "Agricultural and Wetland Sources," Subcommittee II, Report to Minnesota Energy Agency, September 1977.

Appendix I, Table 5. Scheller's Overall Energy Balance for Grain Alcohol Production From Corn, Modified by Omitting 75% of the Field Waste

Energy Production	BTU/Gal. Alcohol
Ethyl Alcohol	75,600
Aldehydes, Fusel Oil	1,100
Total	76,700
Energy Consumption	
Farming Operation	46,000
Alcohol Plant	108,000
Net Consumption By-Products Production	18,200
Total Net Energy Production	-95,500

Note: The same disparity appears here in BTU content of ethyl alcohol, etc., as in Table 3.

Appendix I, Table 6. Overall Energy Balance for Grain Alcohol Production From Corn Omitting 75% of the Field Waste, Incorporating Previous Estimates of Energy Use

Energy Production	BTU/Gal. Alcohol
Ethyl Alcohol	84,400
Aldehydes, Fusel Oil	1,100
Total	85,500
Energy Consumption	
Farming Operation	39,780
Alcohol Plant	174,660
Net Consumption By-Products	18,200
Total	232,640
Total Net Energy Reduction	-147,140

Appendix II

Appendix II, Table 1. Conversion Costs of Alcohol From Corn
Calculated by D. L. Miller
(Exclusive of Corn Cost)
(1976 Base)

Alcohol	Cents/Gallon
190° Proof (2.82 gallons/bu.)	
Base Conversion Cost	44.2
Depreciation ($1.95 million/year 10 years, 17.7 million gallons/year)	11.0
	55.2
By-Product Feed Credit (6.8 pounds/gallon alcohol at $100/ton)	34.0
Net	21.2
200° Proof (2.7 gallons/bu.)	
Alcohol (1.048 gallons at 21.2 cents/gallon)	22.2
Cost of Dehydration	3.2
Total Cost (excludes wheat and non-production activities)	25.4

Source: Miller, D. L., Fermentation Ethyl Alcohol, 1976, p. 308 /17/.

Appendix II, Table 2. Conversion Cost of Alcohol From Wheat
Calculated by D. L. Miller
(Exclusive of Cost of Wheat)
(1976 Base)

Alcohol	Cents/Gallon
190° Proof (2.72 gallons/bu.)	
Base Conversion Cost	45.1
Depreciation ($1.95 million/year 10 years, 17.2 million gallons)	11.4
	56.5
By-Product Feed Credit (6.5 pounds/gallon of alcohol at $100/ton)	32.5
Net	24.0
200° Proof (2.6 gallons/bu.)	
Alcohol (1.048 gallons at 24 cents/gallon)	25.2
Cost of Dehydration	3.2
Total Cost (excludes wheat and non-production activities)	28.4

Appendix II, Table 3. Conversion Cost of Alcohol From Grain Calculated by Indiana Study

Alcohol	Cents/Gallon
190° Proof (2.8 gallons/bu.)	
Base Conversion Cost	36.10
Depreciation	11.30
	47.40
By-Product Feed Credit (6.33 pounds/gallon alcohol, $100/ton)	30.70
Net	16.70
200° Proof (2.7 pounds/bu.)	
Alcohol (1.048 gallons at 16.7 cents/gallon)	17.50
Cost of Dehydration	3.20
Total Cost (excludes grain and non-production activities)	20.70

Source: Corcoran, W. P., Brackett, A. T. and Lindsey, F., Indiana Grain Fermentation Alcohol Plant, 1976, pp. 2-5.

Appendix II, Table 4. Cost of Ethyl Alcohol When Grain Price is Included[a/]

Price of GRAIN ($/Bushel)	D. L. Miller's Estimates of the Cost of Alcohol When Using: CORN (2.7 gallons 200°/bu.) ($/gallon)	WHEAT (2.6 gallons 200°/bu.) ($/gallon)	Indiana Estimates of the Cost of Alcohol When Using: GRAIN (2.7 gallons 200°/bu.) ($/gallon)
1.50	.809	.861	.762
1.75	.902	.957	.855
2.00	.994	1.054	.947
2.50	1.180	1.247	1.133
3.00	1.364	1.439	1.317
3.50	1.549	1.639	1.502
4.00	1.733	1.824	1.691
4.50	1.921	2.014	1.874
5.00	2.106	2.209	2.059

[a/] Based on 1976 production costs, excludes profit, transportation, marketing, etc.

Source: Same as Appendix II, Tables 2 and 3.

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