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GASOHOL: ECONOMIC FEASIBILITY STUDY

Final Report

MASTER

By
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July 1978

Work Performed Under Contract No. EF-77-G-03-1681

Development Planning and Research Associates, Inc.
Manhattan, Kansas

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GASOHOL

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Prepared for
Energy Research and Development Center
University of Nebraska, Lincoln
In cooperation with Nebraska
Agricultural Products Industrial Utilization
Committee and the State of Nebraska
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EXECUTIVE SUMMARY

This report, "Gasohol Economic Feasibility Study," was prepared by Development Planning and Research Associates, Inc. under a contract with the Energy Research and Development Center of the University of Nebraska in cooperation with the Agricultural Products Industrial Utilization Committee and the State of Nebraska. Funding for this study was provided to the Energy Research and Development Center by the U. S. Department of Energy and the Old West Regional Commission.

The primary objective of the study was to:

- determine the fiscal and market conditions under which the production of gasohol would be profitable for private producers

For purposes of this study, gasohol is a motor fuel consisting of 10 percent agriculturally-derived anhydrous ethanol and 90 percent unleaded gasoline. The study assumes that gasohol can be a fuel substitute for gasoline; indeed, the cost of gasoline will significantly influence that for gasohol. Gasoline prices are determined by factors external to ethanol; thus, the economic feasibility study of gasohol is in large part an economic feasibility study of fuel-grade ethanol production.

More specifically, the study examined the following:

- the technical aspects of distributing, marketing, and using gasohol
- the costs of the distribution and marketing of ethanol and gasohol
- the energy balance of ethanol production
- the cost of producing ethanol
- the factors influencing ethanol plant size and location
- the conditions that would make ethanol economically feasible for private producers

Introduction

The report was necessarily based on a synthesis of existing data and studies. In many cases, the requisite data and information were not available or were contradictory. Such limitations were noted.

Efforts to develop new definitive data were not undertaken nor considered appropriate under the study's Terms of Reference. The reader of this study should recognize that its findings cannot be considered comprehensively definitive. Neither the time nor the resources allocated to the study by its Terms of Reference permitted the Contractor's developing the sophisticated and technical engineering data and econometric models needed for completeness. The findings of the study, as presented, were based on the best available evidence and the most logical assumptions warranted by present conditions and implications. The frequent tentativeness of the findings described below were dictated by the study's limitations.

Geographic Coverage

The study was confined to a seventeen state area encompassing the Cornbelt, Lake States, the Great Plains, and Colorado, Wyoming and Montana (Figure 1).

Raw Materials Considered

The consideration of raw materials was limited to major commodities commonly produced in the seventeen state region. Specifically, these include:

- corn
- grain sorghum
- wheat
- potatoes
- sugar beets
- molasses
- starch

Limitations

Because definitive data on ethanol and gasohol are not available and because existing data are frequently contradictory, certain limitations to the study were unavoidable. The limitations include:

- insufficient evidence to make conclusive cost adjustments for fuel economy, octane enhancement and for vapor pressure differences that might be associated with gasohol

- insufficient data to conclusively determine the possible costs of moisture-free ethanol and gasohol distribution and storage

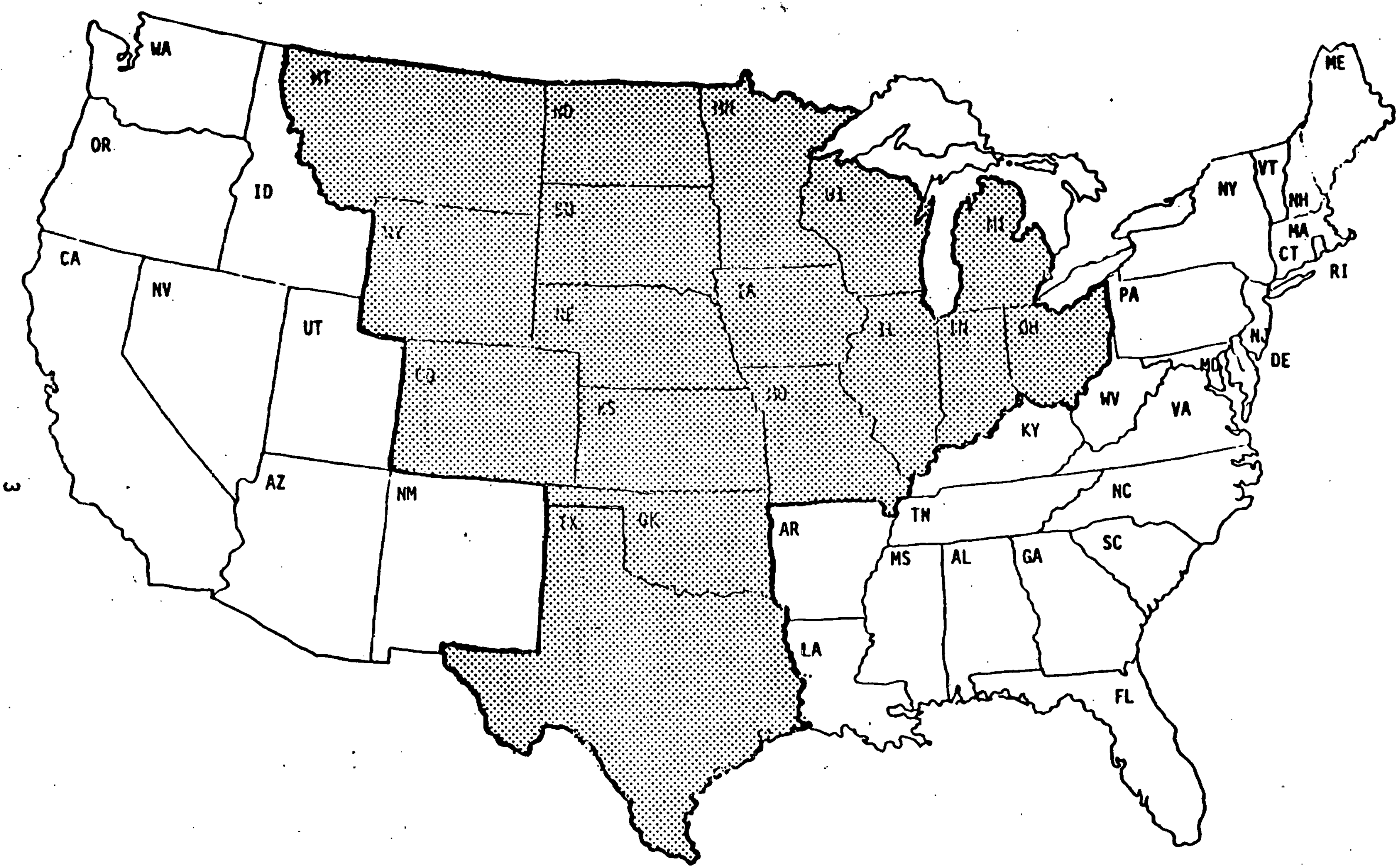

Figure 1. State map of study area

- unavailability of a generally accepted energy accounting procedure to determine conclusively the energy balance of ethanol production

- insufficient ethanol plant investment and operating cost estimates for plants with greater than 20 million gallons per year capacity. (The larger plant cost estimates prepared for this analysis are of reconnaissance grade quality.)

- insufficient available data to measure definitively the economic impacts resulting from the prices of the distillery by-products consequent to a large regional gasohol program. 1/ (The product volumes would be significant and could seriously depress the prices of high-protein animal feeds, and thus, increase ethanol production costs through the reduction of by-product credits.)

- the unavailability of comprehensive economic and technical analyses measuring the impacts of a large regional ethanol industry on other farm crops and associated agricultural processing. (The evidence suggests significant dislocations on soybean production and processing.)

Chapter I: Report Organization

This brief chapter describes the general organization of the report.

Chapter II: Gasohol: Technical Characteristics and Cost of Ethanol

In determining the competitive cost (price) of ethanol for use in gasohol, several technical characteristics of gasohol were considered. It was not the purpose of this study to conduct a technical analysis of gasohol; rather the study sought to assess the technical state-of-the-art as it might influence the economic analysis.

Technical Characteristics

There are several technical characteristics of gasohol which have potential cost and value impacts. Major findings include the following.

- Gasohol can be burned in unmodified internal combustion engines. All subsequent comments regarding gasohol will be made in this context.

1/ The processing of grains and other commodities into ethanol yields signigificant quantities of distillers by-products which can be used as high protein animal feeds.

- Although the relative fuel economies of gasohol and gasoline are not known conclusively, the available evidence indicates that (1) gasohol increases fuel economy (miles per gallon) in engines operated below ambient air temperatures of 67°F, (2) that above that level, gasohol decreases fuel economy, and (3) that carburetion settings (a function of engine vintage and characteristics) influence gasohol's potential fuel economy. Available data are limited, it is the contractor's opinion that differences in fuel economy are negligible.

- There are no conclusive determinations regarding the octane enhancement of mixing ethanol with gasoline. Generally the lower the octane of the base gasoline, the greater the octane enhancement of mixing ethanol. At typical gasoline octane ratings, road octane enhancement is probably in the order of one or two road octane numbers. If the octane enhancement could be specified, refinery cost savings might be realized by the processing of special base gasolines to be used in gasohol. Because enhancement values could not be determined, the study assumed that regular unleaded gasoline would be utilized.

- An examination of the available literature and data indicated no vapor lock problems associated with gasohol; however, no experimental establishment of the Vapor Lock Index was found. If vapor lock problems are encountered, minor modification (the removal of certain hydrocarbons) in the base gasoline would be expected to correct the problem.

- The only definitive adjustment for gasohol stems from the volume increase of .23 percent from mixing gasohol with gasoline.

- The use of gasohol would not eliminate the need for automotive catalytic converters.

- Although the data relating to use of gasohol in automobile engines are not exhaustive, they support the assumption that ethanol-blended gasohol does not increase engine corrosion problems significantly. Long term studies of actual use, however, are needed to confirm this conclusion.

- The water tolerance of gasohol is limited. That for gasohol is temperature dependent, ranging from less than .2 percent at 0°F to about .4 percent at 90°F. These values argue that moisture-free ethanol and gasohol storage and transportation will be required.

Implication of Technical Characteristics

Available evidence suggests certain implications and working assumptions regarding gasohol and this analysis.

- A benefit of \$.001 per gallon of gasohol (\$.01 per gallon of ethanol) should be taken for the volume increase resulting from mixing ethanol and gasoline.

- Due to the lack of definitive estimates on octane enhancement and Vapor Lock Index characteristics, corresponding adjustments in base gasoline for blending were not estimated and it was assumed that the base gasoline would be regular unleaded gasoline. As additional data become available, their cost impact should be analyzed within appropriate refinery models.

- The available evidence on gasohol fuel economy (vis-a-vis gasoline) does not warrant assigning a positive or negative fuel economy cost adjustment. Additional fuel economy tests are desirable.

- Cost adjustments should not be credited or debited to gasohol for changes in emissions, corrosion, or engine wear. Again additional experimental and use data should be considered.

- Due to the low water tolerance of ethanol in gasoline, mixing should be done at refinery load-out, pipeline or bulk station terminals, or at retail service stations. Pipeline and barge transportation of ethanol or gasohol appear to be precluded unless technological developments such as emulsifying agents would permit such transportation.

- Transportation, storage and handling, and dealer markup costs for ethanol and gasohol will be similar to those for gasoline--with the possible exception of incremental costs for maintaining essentially a moisture-free ethanol and/or gasohol storage and transportation. These costs appear to be small, but additional study is needed to validate this conclusion.

Imputed Ethanol Cost

Gasoline prices will establish a base against which gasohol will compete. Estimated refinery gate prices for unleaded regular gasoline were about \$.40 (1977 dollars) per gallon and an additional \$.12 per gallon for distribution and dealer markup.

- Since gasoline costs are a major determinant of gasohol costs and because gasohol will have to compete with gasoline, the imputed competitive price of ethanol, adjusted for the volume difference, was estimated to be \$.41 per gallon, f.o.b. ethanol plant (excluding taxes).

- Possible cost benefits assigned to gasohol from changes in the costs for base gasoline production and added costs for moisture control in distribution and storage may tend to be offsetting, but their relative relationship could not be determined.

Chapter III: Ethanol: General Characteristics and Production Technology

Ethanol is a two carbon member of the generic family of alcohol. It may be produced by the fermentation of carbohydrate agricultural products or by the chemical synthesis of petroleum products. This study is confined to the fermentation of selected agricultural products from the seventeen state region.

- The production technology for the fermentation and distillation from grains and other raw materials such as potatoes and molasses is well established.

- Prior to fermentation, starch bearing products (grains, potatoes, starch) are first hydrolyzed to convert the starches to sugar. Those agricultural products--sugar beets and molasses--yielding direct sugars do not require hydrolysis.

- For fuel use fermentation ethanol is distilled to 200 proof (anhydrous) ethanol and then, by law, denatured.

- The high gluten content of wheat causes excessive foaming during fermentation and requires special processing equipment or the blending with the wheat of corn or grain sorghum up to 20 to 25 percent.

- In addition to ethanol, the fermentation and distillation processes produce significant quantities of distillers by-product, carbon dioxide, and water.

- Future technological advancement in ethanol production will center principally on (1) developing its carbohydrate sources, i.e., increasing the quantity of and the accessibility of sugar and starch in raw materials and the utilization of cellulose, (2) developing micro-organisms with a greater ethanol tolerance, and (3) developing more rapid fermentation and less energy intensive distillation processes. There are no known revolutionary technologies near commercialization stages.

Chapter IV: Ethanol: Input-Output Relationships of Raw Materials and Energy

Crucial to the economics of ethanol production are the input-output relationships of the raw materials and energy.

Raw Material Yields

The fermentation of the specified raw materials produces four products--ethanol, carbon dioxide, distillers by-products and water-with their yield proportions dependent upon the initial starch or sugar contents of the materials.

- Yields of ethanol are approximately 2.6 gallons per bushel of corn, grain sorghum and wheat, 1.4 gallon per hundred weight of potatoes, 20.3 gallon per ton of sugar beets, 0.4 gallon per gallon of molasses, and 0.06 gallon per pound of starch.

- By-product yields are approximately 16.8 pounds per bushel of corn and grain sorghum, 20.7 pounds per bushel of wheat, 14.8 pounds (75 percent moisture basis) per hundredweight of potatoes, 264 pounds per ton of sugar beets, 15.6 pounds (75 percent moisture basis) per gallon of molasses, and .1 pounds per pound of starch.

- By-product protein quality varies widely. Distillers dried grains have a 29 to 30 percent protein content and can be used as relatively high-protein animal feed. Molasses stillage has a protein content of about 20 percent. Potato and beet stillage are about 10 percent protein. Starch stillage is essentially protein free. All protein contents are given on a dry weight basis.

Energy Balance

Energy is required to convert raw materials into ethanol and the by-products. Unfortunately, there are no generally accepted energy accounting procedures which comprehensively show the relationships between energy inputs and the energy outputs of both ethanol and distillers by-products. Energy balances were estimated with three different approaches and none indicates a positive energy balance.

- Corn is generally assigned a caloric content of 377,000 Btu per bushel (145,000 Btu per gallon of ethanol), ethanol is 84,000 Btu per gallon and distillers dried grain is 50,000 Btu per gallon of ethanol.

- The average energy required to produce and harvest a bushel of corn is 106,000 Btu and includes invested energy in fertilizers and agricultural chemicals but excludes invested energy in durables such as equipment.

- Process energy for grain fermentation was estimated to be 131,000 Btu per gallon. Approximately 52 percent of the process energy is used in distillation and 42 percent in stillage drying.

- One approach considered the caloric content of all raw material inputs and all the energy inputs and outputs. Under this approach the efficiency was 49 percent (Table 1).

- A second approach valued the corn raw material input at its production and harvesting energy input value. Under this approach an efficiency of 78 percent was obtained.

- Under the allocation approach, the energy input for corn was allocated on the basis that distillers dried grain has a feeding equivalent to .41 bushels of corn. This suggests that 59 percent of the corn input energy should be allocated to ethanol. It further assumes that certain process energy is directly assignable to either ethanol or distillers dried grain. Shared process energy was allocated to ethanol at 59 percent. This method yielded an efficiency for ethanol of 86 percent.

- Inclusion of agricultural production energy retained in crop residue in the energy balance has been proposed since these residues could replace fossil fuels for processing energy. However, the removal of crop residues would require energy for collection and handling. Also excessive removal could lead to soil degradation and additional fertilizer energy requirements. For these reasons, the potential contribution of crop residues was omitted from the energy balance estimates.

Energy Sources

Various sources of process energy have been proposed for ethanol production, although most commonly coal and fuel oil are used.

- For this study's analysis, it was assumed that low sulfur Wyoming coal (10,500 Btu per pound) would be used.

- Solar and biomass energy sources have been proposed, but these sources are presently economically impractical.

- Cogeneration energy systems have also been proposed. While theoretically possible, the practical use of cogeneration requires that it be considered in initial plant designs. Waste steam from most existing installations is of too low a quality to be used in ethanol production.

Table 1. Energy balance for corn ethanol production computed by three different approaches.

Item	Caloric content	Corn input energy	Allocated
	----------(1,000 Btu/gal ethanol)----------		
Input			
Corn	145	41	24
Process energy	131	131	74
Total	276	172	98
Output			
Ethanol	84	84	84
Distillers dried grain	50	50	--
Total	134	134	84
Energy loss	142	38	14
Efficiency (percent)	49	78	86

Chapter V: Ethanol: Raw Material Costs and By-Product Credits

It was not within the scope of this study to project raw material and by-product prices. Over the long run, however, agricultural prices tend to be equal to costs of production. As a basing point for the analysis, average prices in constant 1977 dollars were determined.

- The average historical price of corn has been about $2.50 per bushel. Grain sorghum has been slightly less, while wheat has averaged about $3.35 per bushel (Table 2). Other raw material price averages are shown in Table 2.

- Distillers dried grains have averaged about $110 per ton (Table 2). Other by-product prices are somewhat lower, reflecting lower feeding values. In the case of potato and molasses stillage, the prices represent a 75 percent moisture product.

- Carbon dioxide was assumed to have no value. (In specific local areas viable markets exist.)

- The price analysis of distillers dried grain indicates that it is price elastic, currently. The supply quantities of DDG are now small. If large quantities become available, a large percentage price decrease would be required to clear the market, i.e., it will become price inelastic.

- Net raw material costs are raw material costs less by-product credits. Grain sorghum ($.52 per gallon of ethanol) and corn ($.60 per gallon) are the low net cost materials (Table 2) Starch, lacking by-product credit, is the highest cost material. To place these net costs in perspective, it was calculated that gasohol would have to sell at $.41 per gallon. Thus, under average price conditions, the selling price would not cover net raw material costs.

- Sample grade grains would be a less costly raw material; however, the availability of sample grade grain is too variable and geographically dispersed for it to be considered a reliable raw material.

Chapter VI: Ethanol: Plant Investment and Operating Costs

Investment and operating cost estimates (in 1977 dollars) were made for grain ethanol plants ranging from 10 to 120 million gallons per year and for non-grain ethanol plants at about 10 MGY capacity. Cost estimates were synthesized from published studies and direct contacts with industry personnel. No engineering studies were available for sizes and types of plants other than 20 million gallon grain ethanol plants. Estimates for the larger grain plants and non-grain plants must be considered of reconnaissance quality. Based on these estimates, significant economies of size are demonstrated.

Table 2. Net raw material cost in 1977 dollars

Item	Units	Corn	Grain Sorghum	Wheat	Cull Potatoes	Sugar beets	Starch	Molasses
Raw material price	dollars	2.50/bu	2.30/bu	3.35/bu	20/T	26/T	.08/lb	.36/gal
Conversion	gal ethanol	2.6/bu	2.6/bu	2.6/bu	28.8/T	20.3/T	.06	.4/gal
Unit raw material cost	$/gal ethanol	.96	.88	1.29	.69	1.28	1.20	1.0
By-product price	dollars	110/T	110/T	110/T	6/T[1/]	93/T	0	$15/T
Conversion	lbs by-product	15.8/bu	16.8/bu	20.7/bu	296/T	264/T	.1/lb	15.6/gal[1/]
Unit by-product credit	$/gal ethanol	.36	.36	.44	.03	.60	0	0.12
Net raw material cost	$/gal ethanol	.60	.52	.85	.66	.68	1.20	1.12

1/ Potato and molasses distillers by-products @ 75 percent moisture.

Source: DPRA estimate

- Investment costs (excluding working capital) per gallon of ethanol capacity were estimated to be $1.91, $1.56 and $.93 for the 10, 20 and 120 million gallon per year grain ethanol plants, respectively (Figure 2). Total estimated investment for a 20 MGY plant is about #31 million. A 100 MGY plant was estimated to cost $97 million.

- Investment costs per gallon for non-grain plants were: $1.09 for starch, $1.14 for molasses, $3.80 for potato, and $3.58 for sugar beets.

- Total direct and indirect operating costs including fuel, labor, plant overhead, administration and marketing (but excluding income taxes, depreciation and interest) were $.44 and $.30 per gallon of ethanol for the 10 and 120 million gallon per annum grain ethanol plant (Table 3).

- Similar cost values for non-grain plants were $.48 per gallon of ethanol for potatoes, $.45 for sugar beets and $.30 for starch and molasses.

Chapter VII: Financial Analysis of Ethanol Production

The financial analysis assumed that investors will base their investment decisions on the potentiality of their profitability. The financial analysis employed was discounted cash flow analysis using nominal dollars, i.e., reflecting inflation. The nominal costs were converted back to real terms $$1977) and to per gallon equivalents to facilitate presentation and understanding. In addition to the costs previously presented, working capital, sustaining capital, interest, debt repayment, cost of equity capital, and income tax were included.

Base Condition Results

The array of plant configurations were analyzed using historical raw material and by-product prices, 15 percent cost of equity, a 10 percent interest cost, 30 percent leverage, and 50 percent income tax rate. These terms were selected to reflect typical financing conditions.

- Total estimated costs of grain ethanol were estimated to range from $1.50 to $1.15 per gallon (Table 4). Subject to the limitations of the cost estimates, definite economies of size are apparent, although the decline in costs from the 80 MGY to the 120 MGY plants is quite small. Following raw material costs, capital recovery is the largest cost factor and includes debt service, income taxes, and return on and of equity investment.

- Excepting molasses, the non-grain plants demonstrate higher costs of production (Table 5). In the case of potatoes, the high capital recovery and low by-product credit are significant factors. In the

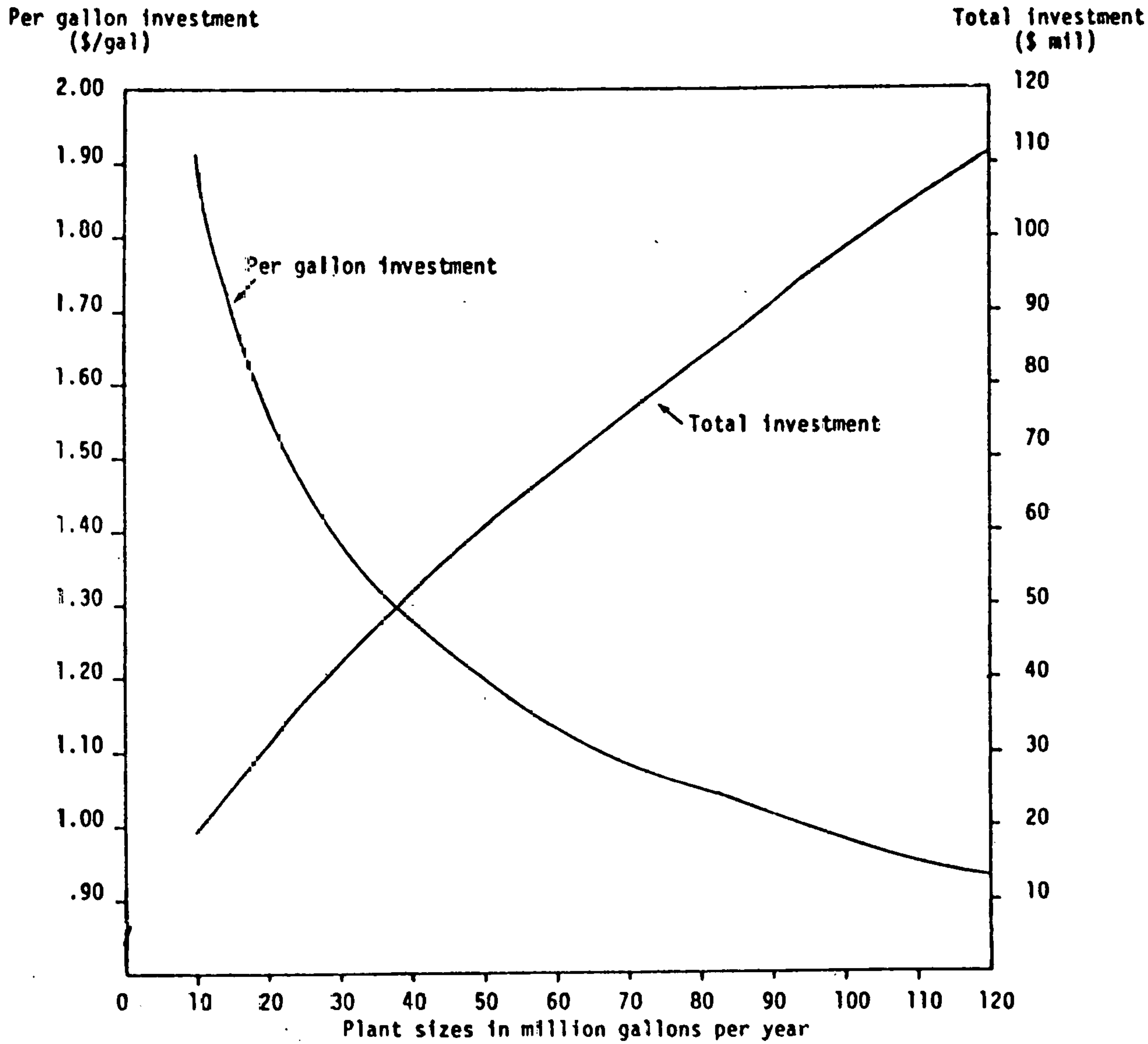

Figure 2. Estimated investment for grain ethanol plants by size of plant

Table 3. Estimated operating costs for grain ethanol production by size of plant in 1977 dollars

Cost	Plant size (mil gal per year) 10	20	40	60	80	100	120
	($/gal)						
Direct costs							
Energy	.19	.19	.19	.19	.19	.19	.19
Labor	.09	.06	.04	.04	.03	.03	.03
Other	.01	.01	.01	.01	.01	.01	.01
Total	.29	.26	.24	.24	.23	.23	.23
Indirect							
Plant overhead	.09	.06	.05	.05	.04	.04	.04
Administration	.04	.03	.02	.02	.02	.02	.02
Marketing	.02	.02	.01	.01	.01	.01	.01
Total	.15	.11	.08	.08	.07	.07	.07
Total direct and indirect	.44	.37	.32	.32	.30	.30	.30

Source: DPRA estimate.

Table 4. Total cost of grain ethanol production by plant size under base conditions in 1977 dollars

Cost	Ethanol plant size (million gallon)						
	10	20	40	60	80	100	120
	($/gal)						
Energy	.19	.19	.19	.19	.19	.19	.19
Other direct	.10	.07	.05	.05	.04	.04	.04
Indirect	.15	.11	.08	.08	.07	.07	.07
Capital recovery	.46	.38	.32	.29	.27	.26	.25
Raw material	.96	.96	.96	.96	.96	.96	.96
By-product credit	-.36	-.36	-.36	-.36	-.36	-.36	-.36
Total	1.50	1.35	1.24	1.21	1.17	1.16	1.15

Source: DPRA estimate

Table 5. Total cost of ethanol production for different raw materials under base conditions in 1977 dollars

Cost	Grain 1/	Potato 2/	Sugar beet 3/	Starch 1/	Molasses 1/
	($/gal)				
Energy	.19	.25	.23	.13	.13
Other direct	.10	.08	.08	.07	.07
Indirect	.15	.16	.15	.10	.10
Capital recovery	.46	.87	.83	.28	.28
Raw material	.96	.69	1.28	1.20	.97
By-product credit	-.36	-.03	-.60	.00	-.12
Total	1.50	2.02	1.97	1.78	1.43

1/ 10 million gallons per year

2/ 7.2 million gallons per year

3/ 9.7 million gallons per year

Source: DPRA estimate

case of sugar beets, raw material costs and capital recovery are high. Starch, while having a low capital recovery cost, faces high raw material costs with no by-product credit. A molasses plant was estimated to have lower costs than a comparable size grain plant. Although molasses is not as abundantly available as corn, it would appear to offer potential relative to the other commodities.

- Under these specifications and estimated costs, ethanol production costs are about 3 to 5 times greater than the expected competitive ethanol selling price of $.41 per gallon. Substantial gasohol-user benefits would have to accrue to match production costs. Thus, under representative "busines as usual" situations, the production of fuel grade ethanol is not economically feasible.

Cost Sensitivity

Sensitivity analyses were done on investment, grain prices, distillers dried grain prices, and energy to demonstrate their impact on production costs. The analyses were done for the 20 MGY and 100 MGY grain plants, the former representing a commonly proposed plant size and the latter a plant size that might emerge under an extensive regional gasohol program.

- A ± 25 percent change in plant investment resulted in a 6 percent change ($1.35 ± .08) in the cost per gallon of the 20 MGY plant and a 4 percent ($1.16 ± $.05) change in the cost per gallon of a 100 MGY plant.

- A $1.00 change in the per bushel price of grain translated to a $.38 to $.39 per gallon change in production costs. A $20 per ton change in distillers dried grain price translated to about $.06 to $.07 per gallon change in production costs. Changes in these costs have significant impacts. It is noted that a large regional gasohol program will likely cause grain price increases and distillers dried grain price decrease, and their combined effect would result in a net increase in ethanol production costs.

- A ± 25 percent change in processing energy costs would change production costs about 4 percent. This assumes all other costs would remain constant. However, if real energy costs increased, it would be expected that other cost elements would also rise.

Incentives for Ethanol Production

The preceding analyses indicate that fuel grade ethanol production is not financially feasible without government incentives. Similar government incentives to stimulate energy production are used in the United States; indeed, a recent estimate placed the total federal outlays at $123 - $133 billion since 1918 for all forms of energy.

This study considered the effect of such incentives as those for financing, tax credits, direct construction grants and direct payments.

- Combinations of 10 percent cost of equity leverage ratios up to 90 percent and interest rates down to 5 percent were analyzed. At a 7 percent interest rate, 90 percent leverage, and 10 percent cost of equity--a combination selected as typical of government supported financing--the estimated cost of ethanol production was $1.16 and $1.03 per gallon for the 20 MGY and 100 MGY plants, respectively. This compares to the base case of $1.35 and $1.16, respectively. From this analysis, it was concluded that such government financing incentives would not be sufficient to equate price and full costs.

- Investment tax credits up to 50 percent of qualified investment and full income tax credit were also found to be insufficient.

- Direct construction grants ranging up to 100 percent were analyzed. Even at this level, the estimated cost of production was still about $1.00 per gallon, nearly 2.5 times greater than the needed competitive selling price.

- These preceding analyses demonstrate that significant subsidies through direct payments or fuel tax exemptions would be required to support ethanol production. It is estimated that a $.94 per gallon subsidy ($.094 per gallon of gasohol) would be required for a 20 MGY plant and $.75 per gallon ($.075 per gallon of gasohol) for the 100 MGY plant. This would amount to about $18.5 million annually for a 20 MGY plant and $74 million annually for a 100 MGY plant. This estimate assumes that subsidies would be taxable. The estimated income tax are $.13 and $.09 per gallon for the 20 MGY and 100 MGY plants, respectively. It is noted that these estimates make no allowances for the increased grain and reduced distillers dried grain prices that are expected with a large gasohol program.

Feasibility of Ethanol Production Under Higher Gasoline Prices

It has been suggested that if gasoline prices were to double, ethanol production would become feasible. This argument implies differential inflation; however, since energy prices tend to move together, ethanol processing energy would increase somewhat proportionately. Furthermore, non-energy prices would be expected to increase with a real increase in energy prices. At a minimum, the increases in non-energy costs would ultimately reflect their own energy costs. It seems unlikely that sustained differential inflation would occur. Thus, it is concluded that increases in gasoline will not effectively alter the findings presented above.

Chapter VIII: Ethanol: Plant Size, Market and Site Selection Factors

This study also analyzed the determinants of plant size and location. This generalized analysis considered raw material assembly costs, ethanol production costs, and the distribution costs for ethanol and distillers dried grains. A wide range of supply densities and market distances were estimated.

- For most plausible supply and market situations, it was found that plant costs by size of plant decreased faster than associated transportation costs increased.
- The least unit (per gallon) cost plant size is large, although the cost curve is relatively flat beyond those of the 60 million gallon annual capacity over a range of transportation conditions. While the underlying analysis is logical, it should be recognized that if specific plant construction is contemplated, more exhaustive and sophisticated analyses should be undertaken.
- Distillers by-products will likely be hauled greater distances than either grain or ethanol because their markets are less concentrated.
- It was concluded that ethanol plants should be raw material supply oriented.
- In addition to raw material supplies, large quantities of coal would be required (123,000 tons for a 20 MGY plant and 620,000 tons for a 100 MGY plant) and would argue for good rail access to western coal. Since the major portion of grain would be received by truck, a central highway network is also important.

Chapter IX: Comments on Impacts of Regional Gasohol Program

The seventeen state study area currently accounts for 39 percent of the total U.S. gasoline consumption; thus, a gasohol program for this region could be sizable. Assessments of the impact of such a regional program are difficult to make and require determining its size and development rate. Additionally, such an impact analysis could not be conclusive without the prior development of a rigorous regional, national, and international econometric analysis. Major structural shifts would be expected. Within these limitations, pertinent comments can be offered, based on recently completed impact analyses and indicative computations.

- Based on U.S. Department of Energy gasoline projections for the nation and assuming a constant market share for the seventeen state region, gasoline consumption was projected to increase from a 1975 level of 40.6 billion gallons to 65.2 billion gallons by 2000. Ethanol requirements under a 100 percent replacement of gasoline by gasohol program would be 4.4 billion gallons in 1980, 4.8 in 1985, 5.4 in 1990, 5.9 in 1995 and 6.5 billion gallons in 2000. Less ambitious programs would reduce this requirement.

- A 100 percent program would require about 25 million additional acres of cropland, depending on the relative quantities of grain used (with yield increases, the amount of land would not increase over time). Assuming no cropping shifts from a projected baseline, there would be adequate cropland resources. However, under a massive program, it would be expected that much of the required land would be that diverted from soybean production since the latter would decrease as soybean prices declined.

- The impact on farm prices cannot be determined with certainty. Soybean prices would be expected to fall, perhaps $1.00 to $2.00 per bushel. Grain prices would be expected to increase, although this would, to a large extent, depend on how fast a program was phased-in.

- Net farm income is projected to increase only slightly under a national gasohol program. A regional program would be expected to have similar consequences; however, extensive technical and economic analyses beyond the scope of this study would be required to demonstrate this conclusively.

- The soybean crushing industry would be expected to encounter plant closures as a result of the competition exerted by distillers dried grains. A full regional gasohol program would produce 15.6 million tons of DDG by 1985 and 21.1 million tons by 2000 compared to the current 15 million tons of total U.S. soybean meal consumption.

- Public program costs would depend on the extent of such a program. Assuming a 100 percent program and 100 MGY plant, annual net subsidies (gross subsidy less income tax) of $3.2 (1977 dollars) billion would be expected in 1985 and nearly $4.3 billion (1977 dollars) by 2000. This estimate does not reflect expected increases in ethanol production costs stemming from increased grain prices and decreased DDG prices.

- Other impacts would be expected on balance of payments, consumer prices, and other items. Of particular note would be the impacts felt by the engineering, equipment manufacturing, and construction industries if a rapid large scale program were pursured. For example, a $4.4 billion dollar construction program would have to be completed to meet a 1985 goal of 100 percent replacement. Even the $6.5 billion required by 2000 would be significant.

Summary of Study Findings

The results of this study indicate that:

- Gasohol can be burned in unmodified internal combustion engines.
- Ethanol production uses more energy than it produces. The efficiency ranges from 49 to 86 percent, depending upon the method of calculation
- The competitive selling price of ethanol would have to be about $.41 per gallon in 1977 dollars. A more thorough analysis than that permitted here may reveal additional benefits that could be definitively credited to gasohol; however, such a study may also indicate additional costs.
- Estimated plant investment for grain ethanol plants range from $1.56 per gallon for a 10 million gallon per year plant down to $.97 per gallon for a 100 MGY plant.
- Estimated costs of production based on conventional financing and historical grain and distillers dried grain prices are $1.35 per gallon for a 20 MGY plant and $1.16 per gallon for a 100 MGY plant.
- Costs of production exceed by three to five times the competitive selling price of ethanol, a ratio that makes ethanol economically infeasible without subsidies.
- Subsidies of about $.94 per gallon of ethanol for a 20 MGY plant and $.75 per gallon for a 100 MGY plant would be required as investment incentives.
- A subsidized regional program with full 100 percent replacement of gasoline by gasohol for the seventeen state study area, would require production of 4.8 billion gallons of ethanol in 1985 and 6.5 billion gallons by 2000.

- A program of this magnitude would increase grain prices, decrease distillers dried grain prices, cause major dislocations in soybean production and processing, and raise ethanol production costs.

- Program costs for a full 100 percent replacement of gasoline by gasohol in the region would involve annual net subsidy costs of about $3.2 billion (1977 dollars) in 1985 and nearly $4.3 billion (1977 dollars) by 2000.

I. REPORT ORGANIZATION

The report is organized into nine chapters. Five chapters, Chapters II through VI, develop the data required to carry out the feasibility analysis which is reported in Chapter VII and establish the plant size-location criteria for Chapter VIII. Chapter IX summarizes various available information on the impacts of developing a gasohol industry.

Chapter II deals with technical characteristics and related performance parameters concerning gasohol and draws conclusions regarding imputed price of ethanol. Chapter III deals with the general characteristics of ethanol and the production technology and includes some of the basic process operations and equipment required for grain and non-grain inputs. In Chapter IV, the physical aspects of ethanol production and the input and output of raw materials and of energy are discussed. Chapter V deals with the establishment of market prices for raw materials and by-products. In Chapter VI the cost estimates for various plant configurations regarding investment and annual operating cost are provided. In Chapter VII, the Financial Analysis, all these inputs are drawn together into a cohesive unit to examine the economic feasibility of gasohol under varying raw material and by-product prices, energy costs, financing schemes, and incentive possibilities. Chapter VIII deals with plant size and location issues, with a major concern being to establish reasonable plant size according to the characteristics of the relationships of the plant relative to the supplies or the markets. Finally, Chapter IX addresses the domestic and international impacts of a gasohol system vis-a-vis their variations in the extent and developmental timing of a gasohol program. An extensive Bibliography of related material and an Appendix containing supplementary materials conclude the report.

II. GASOHOL: TECHNICAL CHARACTERISTICS AND COST OF ETHANOL

For purposes of this report, gasohol is defined as a motor fuel consisting of ten percent agriculturally derived anhydrous ethanol [1] and 90 percent unleaded gasoline. Consideration of the use of ethanol as a motor fuel extender dates from the early 1900's. Surges of interest in ethanol as a fuel extender have occurred periodically, as, for example, during the depression of the 1930's when grains were very low priced and during World War II when disruption of petroleum supplies threatened the war effort. Today, the interest is intensified by both a surplus of low-priced grains and an increasing dependence on imported crude oil.

In considering the use of gasohol, both the economic and technical issues involved in its use and production must be examined. Although the principal focus of this report is the economic feasibility of producing and marketing gasohol, certain technical aspects must be considered in the economic analysis. The technical feasibility of using gasohol as a motor fuel in present-day unmodified internal combustion engines is generally accepted, although some of the technical issues are not fully resolved as indicated in the following discussion; however, the purpose of this chapter is to derive the competitive price of ethanol.

A. Methodology

The cost of gasohol is essentially the weighted average of the costs of the two components - ethanol and gasoline:

Gasohol cost per gallon = 0.10 (cost per gallon ethanol) +
0.90 (cost per gallon of gasoline)

However, gasohol has certain distinctive technical characteristics relative to gasoline which must be considered in determining the value of gasohol to the consumer. These factors include:

- fuel economy
- octane number
- exhaust emissions
- driveability
- corrosion of parts
- safety and toxicity

[1] See Appendix II-1 for chemical and physical properties of ethanol.

These technical characteristics and the production aspects of ethanol contribute to distribution, marketing and user costs that are unique to gasohol. Thus, the general cost equation for gasohol shown above can be expanded to be:

$$\text{Gasohol Selling Price} = 0.10\begin{bmatrix}\text{ethanol price,} & & \text{transportation,}\\ \text{f.o.b. plant} & + & \text{handling and}\\ & & \text{dealer markup}\end{bmatrix} + 0.90\begin{bmatrix}\text{gasoline price,} & & \text{transportation,}\\ \text{refinery} & + & \text{handling and}\\ \text{gate} & & \text{dealer markup}\end{bmatrix} \pm \text{value adjustment factors for gasohol} + \text{fuel tax}$$

To date there is, however, no straight forward, universal formula that can be used to express cost differences between the use of gasoline and the use of gasohol. Following is a discussion of the principal technical cost factors that must be considered.

B. Value Adjustments for Gasohol Characteristics

A primary consideration which must enter into gasohol price comparisons is the type of gasohol that is to be used. Two basic types of gasohol are possible: (1) gasohol of the same octane number as regular no-lead gasoline and (2) gasohol having an octane number greater than regular, unleaded gasoline.

1. Ethanol Plus Special Base Gasoline

Gasohol having the same octane number as regular, unleaded gasoline is produced by blending ethanol with a specially-produced low-octane gasoline. The use of ethanol as a gasoline blender would affect the costs associated with petroleum-refining operations and the investment pattern of the refining industry. Since the gasoline used for blending would be of lower octane number than regular unleaded gasoline, it may be anticipated that there would be a decrease in the cost of production; however, two factors would tend to moderate these savings. Currently this gasoline would be produced in small quantities for which a premium price would be required. Over a longer period of time, the effects on the refinery industry of producing 10 percent less gasoline would need to be considered also. 1/

In order to quantify these effects for this study, a linear programming of the U.S. refining industry was constructed. 2/ The model was calibrated to forecast for the year 1985 in order to allow for investment savings which would accompany the use of alcohol in motor fuels in significant quantities.

1/ Farmland Industries, private communications, April 1978.

2/ Bonner & Moore Associates, Inc. A Formula for Estimating Refining Cost Changes Associated with Motor Fuel Reformulation, Draft, Jan. 13, 1978.

Results of this linear programming model were then utilized to develop a set of empirical equations from which to estimate the cost effects of various changes which the blending of alcohol and gasoline would bring to the refining industry's processing requirements.

The equations include factors expressing the operating and investment cost changes which would accompany:

(1) a reduced gasoline volume
(2) a reduced base gasoline octane quality (ethanol's characteristics would compensate for this), and
(3) a requirement for reduced Vapor Lock Index (VLI) since the addition of alcohol would require the refiner's base gasoline output to accommodate the addition of a component which results in an increased vapor pressure.

The first two factors represent savings at the refinery while the third represents, in general, an increase in cost since relatively less expensive butanes would probably be replaced with relatively higher-priced less-volatile components. These equations then were utilized in developing the cost savings at the refinery inherent in using ethanol as a blending agent.

However, the model incorporated, also, the projected refinery product distribution and quality forecasts for 1985. Inherent in these projections is the assumption that the spread of 40-45 percent between crude oil and gasoline costs is at a peak today. By 1985, that value will probably be lowered to 35-40 percent. Thus, although the resulting equations would give results valid for projected 1985 refinery operations, the results would not be valid for 1977 conditions; therefore, no quantitative use was possible for this study. The equations would be valid under the assumptions only for a future time when lowered motor fuel octane requirements are projected. 1/

A refinery model which incorporates current refinery conditions would be needed in order to ascertain the 1977 cost savings at the refinery of producing a base gasoline especially for blending with ethanol.

2. Ethanol Plus Unleaded Gasoline

Gasohol produced by blending ethanol with regular unleaded gasoline would have an octane number greater than that of the base gasoline, and the degree of its enhancement would depend on the octane number of the gasoline. The exact road octane number enhancement--the enhancement of concern for the gasohol cost adjustment--is open to question and will be discussed below.

Experimental work of interest to this study, has been conducted using an ethanol-gasoline motor fuel produced by blending 10 percent alcohol with 90 percent regular gasoline, both leaded and unleaded. Thus, for the initial phase of the program, a cost of gasohol based on a 10 percent blend of ethanol in

1/ Dixon, J. Bonner & Moore Associates, Inc., private communication, June 1978.

regular unleaded gasoline seems appropriate. The discussion of the various technical factors and the related cost adjustment which follows is based on data obtained with this blend, one which has an octane number higher than that of regular unleaded gasoline.

The technical effects of adding ethanol to unleaded gasoline are summarized below under the assumption that gasohol would be used in unmodified automobile engines, although modifications are and have been considered. Engine power and economy are dependent on the characteristics of the engine used. The use of ethanol will increase the antiknock quality so that engines having higher compression ratios may be used resulting in greater engine efficiencies. Too, the use of alcohol may allow the use of other fuels such as jet fuels in spark-ignition engines.

If EPA mandated fuel economy standards of 27.5 mpg by 1985 are to be attained, then major changes must occur if engines similar to the present day engines are to be retained. Even at best, however, the fuel economy of 5 percent that has been claimed for gasohol is not enough to achieve the rapid increases in fuel economy required in the near future.

Although proposals have been considered that employ ethanol in diesel engines and as a neat (100% ethanol) fuel, the limitations of the present study require examination only of gasohol as a substitute motor vehicle fuel in unmodified engines. Section h below briefly discussed the status of fuel and engine modifications.

a. Fuel Economy

Results of fuel economy tests associated with the use of gasohol are contradictory. In the Nebraska 2 million mile road test, average fuel economy of gasohol was reported to be on the order of 3-4 percent greater than that of gasoline, and to be temperature dependent. 1/ More recently, Scheller reported that at temperatures below about 67°F, gasohol-fueled vehicles obtained more miles per gallon than control vehicles using unleaded gasoline. At 45°F, for example, gasohol cars obtained about 5.3 percent greater fuel economy. At an ambient temperature of 67°F, fuel economy miles per gallon was the same for gasohol and gasoline and above that temperature the fuel economy of gasohol was less than that of gasoline. 2/ Potentially, this could be an important factor as currently more gasoline is consumed in the summer than in the winter.

In carefully controlled dynamometer tests run at the Department of Energy's Bartlesville Energy Research Center (BERC), at a test temperature of 75°F, no significant difference in fuel economy was found, either when testing cars used in the Nebraska test or when testing a 1975, 1976 or 1977 car. The federal test procedure "composite" volumetric (miles per gallon) fuel economy showed no significant difference in fuel economy between gasohol with ½(RON+MON)=91

1/ Scheller, William A., and Brian J. Mohr. "Nebraska 2 Million Mile Gasohol Road Test Program -- Progress Reports, Apr. 2, 1975, July 2, 1975; Oct. 2, 1975; Jan. 31, 1977.

2/ Scheller, William A. "Texts on Unleaded Gasoline Containing 10% Ethanol--Nebraska's Gasohol," Presented at the International Symposium on Alcohol Fuel Technology--Methanol and Ethanol, Wolfsburg, Federal Republic of Germany, November 12-14, 1977.

and the base fuel with ½(RON+MON)=87.5; however, highway fuel economy suggested a slight decrease of approximately 2 percent in fuel economy associated with gasohol compared to the base fuel.

In addition, BERC reported that the fuel energy economy data (miles per 100,000 BTU) suggested a slight improvement in fuel energy economy associated with gasohol compared to base fuel. The improvement in fuel energy economy associated with gasohol appeared to be consistent in each phase of the test cycle; however, the differences are generally only 2-3 percent. Previous data generated at BERC using a control vehicle suggested that for triplicate tests from a single vehicle fuel economy differences less than ± 5 percent are not statistically significant.

It should be emphasized that in tests performed to date, the unequal octane character of gasohol compared to that of the unleaded fuel which was used both for testing and mixing has not been considered; however, it is recognized that (1) an increase in fuel economy is likely using gasohol if changes in engine parameters are made to take advantage of higher octane quality of gasohol compared to that of the base fuel or (2) a decrease in refinery costs for base fuels may result with gasohol due to the fact that new base fuels of lower octane quality than present base fuels could be required. 1/

The change in fuel economy associated with the addition of alcohol to gasoline is reported to be dependent on the original carburetor setting since alcohol, which contains oxygen, has the effect of leaning out the mixture. 2/ Differences then in fuel economy were explained as being due to differences in the initial carburetor setting: if the initial setting is rich (as was the case for pre-1969 cars) the fuel economy is indeed improved; if less rich, fuel economy is about the same; if set lean, then the mixture becomes too lean and misfiring occurs. So in order to have optimum fuel economy, proper adjustment of the carburetor specific to the fuel being burned is needed. This information points out inherent difficulties in comparing the results of performance experiments run at different times on different engines, with unknown carburetor settings. Test conditions are critical.

Due to the nature of the available fuel economy data, discussed above, it was determined that no definitive fuel economy adjustment could be made to the cost of gasohol.

1/ U.S. Department of Energy, Bartlesville Energy Research Center. Interim Report "Gasohol" Test Vehicles, August 1977, and more recent BERC test emission/fuel economy data, communication from Jerry R. Allsup, BERC, January 1978.

2/ Brinkman, N. D., N. E. Gallopoulos and M. W. Jackson. "Exhaust Emissions, Fuel Economy, and Driveability of Vehicles Fueled with Alcohol-Gasoline Blends," Paper 750120, Society of Automotive Engineers, February 1975.

b. Exhaust Emissions

The exhaust emissions of gasoline-powered motor vehicles containing unburned and partially burned hydrocarbons, other organic compounds such as aldehydes, carbon monoxide, nitrogen oxides and compounds of lead and other elements that are contained in the fuels, additives and lubricating oils, have been of environmental concern for a number of years. 1/ The concentrations of hydrocarbons, carbon monoxide and nitrogen oxides in the emissions of newer automobiles have been subjected to EPA regulations. Exhaust emissions have been reduced in automobiles manufactured since 1975 with changes in design, use of unleaded gasoline, and the addition of catalytic convertors.

For cars using gasohol, the vehicle exhaust emissions of unburned hydrocarbons and nitorgen oxides are essentially the same for cars using gasoline. With gasohol, carbon monoxide emissions are reduced by as much as 30 percent. Aldehyde emissions would increase, but the amounts are expected to be small and readily handled by the catalytic converter. A small amount of unburned ethanol would be expected but this too should be handled by the catalytic converter. Cars burning gasohol, then, would still require catalytic converters in order to meet federal emission standards. 2/ Since it is apparent that gasohol use would not eliminate the catalytic converter, no gasohol cost adjustment could be made on the basis of a possible decrease in exhaust emission.

c. Octane Number

Gasoline is sold in several different quality levels of grades--regular and premium leaded, and regular and premium unleaded--defined primarily in terms of octane number and specifically for certain types of engines and emission controls. The Antiknock Index, the sum of the research octane number plus the motor octane number divided by two, ½(R+M) averaged as follows for summer 1976: 3/

Regular, leaded	88.2
Premium, leaded	95.2
Regular, unleaded	89.6
Premium, unleaded	93.0

1/ American Chemical Society, Cleaning Our Environment, The Chemical Basis for Action, 1969.

2/ Allsup, Dr. J., DOE-BERC, Bartlesville, OK, personal communication, March 1978.

3/ National Petroleum News Factbook Issue, McGraw Hill, New York, 1977.

Small adjustments in octane number are made for season of year and geographic locations by adjusting the mixture of the hydrocarbons in the gasoline. In addition to the gasolines of the above octane numbers, the development of the blending pump allowed gasoline having intermediate octane numbers to be sold economically, 1/ although this practice has decreased greatly.

The increase in octane number of blended ethanol and gasoline has received much attention. However, the determination of road octane number in the vehicle is not as straightforward as some published results would seem to indicate.

Data published in 1971 reported that for 10 percent ethanol in regular leaded gasoline, the increase in research octane number was 3.9, the increase in motor octane number was 1.9, and the increase in road octane number was 1.4 at moderate speeds and 0.2 at high speed (greater than 60 mph) 2/ Other results indicate a larger research octane number increase of 3 to 8 depending on the octane number of the base gasoline. 3/

It has been pointed out that recent model-year cars require fuels of high motor octane number rather than high research octane number. Thus, the road octane number of gasohol would be only slightly higher than that of the base gasoline. 4/

The question of the extent to which road octane number enhancement would affect gasohol costs remains to be determined quantitatively. The potential driveability, power, and fuel economy of a given engine is realized only when its gasoline antiknock quality is adequate. 5/

d. Vapor Pressure

Adding ethanol to a hydrocarbon such as gasoline causes an increase in vapor pressure and depresses the boiling temperature over the range of approximately 110-210°F, with the greater difference being near 150°F. 6/ Studies with gasoline have shown that both the vapor pressure and the fraction distilled below about 160°F govern the tendency to vapor lock. Addition of ethanol to gasoline, then, would probably increase vapor locking. 7/

1/ Allvine, Fred C., and James M. Patterson. The Marketing of Gasoline, Bloomington: Indiana University Press, 1972.

2/ American Petroleum Institute. "Are There Substitutes for Lead Antiknocks," San Francisco, 1971.

3/ Dimitroff, Ed, Southwest Research Institute, Consultant to DPRA, Mar. 2, 1978.

4/ Brinkman et al., op. cit.

5/ American Society for Testing and Materials. Significance of Tests for Petroleum Products, Tallahassee, Fla.: American Society for Testing and Materials, January 1977.

6/ Brinkman, et al., op. cit. Table 2.

7/ American Petroleum Institute. Alcohols, A Technical Assessment of Their Application as Fuels, Publication No. 4261, July 1976.

No increased tendency for vapor lock, however, was reported by Scheller in the Nebraska road test. 1/ One method of adjusting the base gasoline so that the resulting gasohol has the same vapor-locking tendency would be to reduce selectivity of hydrocarbons, e.g. butanes or pentanes, of the gasoline. If this is done, ethanol could be considered in part as a substitute for light hydrocarbon components rather than an extender of gasoline. 2/

e. Corrosion

Corrosion and engine degradation problems are of concern in vehicles using alcohol-gasoline blends. For example, copper and brass corrosion and plastics gauge float degradation have been reported in cars using methanol-gasoline fuels. 3/

Little evidence of corrosion due to a 10 percent methanol in gasoline blends was found in the high mileage-short time test conducted by Mobile Research and Development Company; however, there is concern about possible corrosion in a family auto where mileage is accumulated over a 10 year or so period. 4/

Any problems associated with the use of ethanol-gasoline blends would be expected to be less severe than those found for methanol-gasoline fuels. No corrosion attributable to the use of gasohol was identified in the Nebraska Road Test. Thus, no adjustment to the cost of gasohol for corrosion appear to be warranted, although longer run tests should be done to conclusively resolve this issue.

f. Driveability

Driveability is commonly rated at idle during acceleration and under cruise conditions as a car is driven through a prescribed cycle which is repeated several times until the performance of the car stabilizes. Demerits for such malfunctions as hesitation, stumble, surge, idle roughness and backfire in any phase of the cycle are assigned. The final driveability rating is a composite of all the assigned demerits, weighted for importance.

Brinkman et al., 5/ and others 6/ working primarily with methanol-gasoline blends have concluded that deterioration in driveability may be attributed to the leaning effect of the alcohol.

1/ Scheller, op. cit.

2/ Wise, John J. Statement by Vice President for Planning of Mobil Research and Development Corporation before the Senate Appropriations Committee, United States Senate, Jan. 31, 1978.

3/ American Petroleum Institute, op. cit.

4/ Koehl, Dr. W. Mobile Research and Development Corp., private communication, Jan. 18, 1978.

5/ Brinkman et al., op. cit.

6/ American Petroleum Institute, op. cit.

Similar deteriorations are found whether the leaning is caused by the addition of alcohol to the gasoline or by mechanical adjustment of the carburetor. Thus, if gasohol is to be used in unmodified engines, it would be anticipated that any deterioration in driveability would be dependent on initial carburetor setting. If the carburetor is calibrated for lean operation, then, at intermediate temperatures, driveability would deteriorate; on the other hand, cars with carburetors calibrated rich--pre-emission control cars--would not show a significant deterioration in driveability.

No problems with starting, hesitation, stalling or backfiring were reported in the Nebraska 2 Million Mile Road Test. 1/ The effects of gasohol on driveability at various temperatures has not received sufficient quantitative attention to date. No adjustment to the cost of gasohol will, therefore, be made for driveability factors.

g. Volume Increase

A volume increase, over and above that of the sum of the volume of the two components, results when gasoline and ethanol are mixed. For gasohol, the volume change is 100.23 percent. Even though this volume change is small, it is significant as gasoline is sold by volume not weight and refineries keep track of thousandths of a cent per gallon since the volume of sales is so large.

For the prices of gasoline and ethanol encountered in this study, this savings amounts to $0.001 per gallon of gasohol.

h. Fuel and Engine Modifications

Possibilities have been proposed which would include changes in fuel used, engine changes and the use of 100 percent alcohol fuel (neat).

The most promising engine currently being investigated which could achieve the mandated fuel economy is the diesel; thus, a major shift to diesel power may be anticipated. Ethanol can be used in diesel engines if separate injections are employed. From work done by Volvo on operating ethanol in diesel engines and diesel fuel injectors, it appears that the relative amounts of alcohol and diesel fuel depend on speed and load requirements. 2/ Some questions still must be answered before diesel engines

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1/ Scheller, op. cit.

2/ Panchapakesan, N. R., K. V. Gopalakrishnan, and B. S. Murthy. "Factors That Improve the Performance of an Ethanol-Diesel Oil Dual-Fuel Engine," Proceedings of International Symposium on Alcohol Fuel Technology--Methanol and Ethanol, Wolfsburg, Germany, Nov. 21-23, 1977.

can be recommended for general use, however. Current EPA emissions regulations can be met reasonably well; however, there are no standards currently for particulate matter, definitely a problem with diesels. Also, if diesel powered cars and trucks become a reality, they would necessitate major refining changes. With present stock and refinery methods, 30 percent of crude oil can be converted to diesel fuel; if a higher percentage of diesel is obtained, efficiency is lowered.

Another proposal would modify engines to accomodate such fuels as neat alcohol. If this were done, the advantageous properties of fuel alcohol could be realized. Although the heat content per volume is lower for alcohol than for gasolines, thermal efficiency is potentially better with alcohols because higher compression engines may be used 1/. Other engines being discussed include gas turbine, and the rotary engine.

i. Impacts on Gasohol Value

The lack of conclusive (both contradictory evidence and absence of data) technical data on gasohol performance limits precise estimates of the value of gasohol relative to gasoline.

In view of the available technical evidence, the following conclusions were reached with respect to the economics of gasohol use and value impacts when gasohol is used in unmodified engines:

- gasohol would not eliminate the need for emission control systems being used for gasoline powered engines
- There is insufficient evidence to allow definitive cost adjustments for fuel economy, octane enhancement, and vapor lock.
- there is a volume increase of 0.23 percent upon mixing ethanol with gasoline.

The result of these conclusions is that the volume increase is the only cost impact ($.001 per gallon of gasohol), which can be included with certainty.

The subsequent analysis was based on the assumption that regular unleaded gasoline would be used as a base. As previously indicated, changes in the base gasoline with reference to octane quality, vapor lock index, and initially for the production of a small quantity of specialized product, may reflect some incremental cost impacts. Additional investigation (fuel performance research and refinery model) should be undertaken to determine cost differences between gasohol and gasoline. It is the contractor's tentative observation that the adjustment, primarily based on the octane enhancing qualities of ethanol, may be in the range of $.015 per gallon of gasohol.

However, this estimate is considered to be tenuous and thus insufficient on which to conduct the subsequent financial analysis, except in terms of a sensitivity impact.

1/ American Petroleum Institute, op. cit.

C. Cost Adjustments for Gasohol Distribution

Since ethanol and gasohol have properties such as vapor pressure, density and flammability which are similar to those of gasoline, the distribution of gasohol could at some point merge into the existing gasoline distribution system. 1/ There are certain problems associated with the storage and transportation of ethanol and gasohol stemming from technical characteristics regarding water sensitivity, safety and toxicity.

1. Water Sensitivity

Anhydrous ethanol is miscible in all proportions with all but a very few gasolines; however, ethanol is hydroscopic, and the miscibility of aqueous ethanol in fuels is limited. A small amount of water can cause a separation of ethanol-gasoline blends into two layers, a water-alcohol phase and a gasoline phase. Water tolerance in the mixture is temperature dependent; the water tolerance level of a 10 percent ethanol blend is less than 0.2 percent at 0°F and increases to approximately 0.4 percent at 90°F. 2/

Thus, if separation of gasohol is to be prevented, the water level must not exceed about 0.4 percent. As the water level in existing pipelines and barges exceeds this on occasion, the use of these facilities for transporting anhydrous ethanol and gasohol is generally precluded. Various emulsifying agents are known which improve the water tolerance somewhat and, indeed, some of the ethanol denaturants (e.g. isopropyl alcohol) may serve to make the system more water tolerant, thus permitting the use of pipelines and barges as transportation modes. Additional work is required to determine the extent to which pipelines and barges could be used for gasohol transportation.

For this reason, it is concluded that particularly during the initial stages of a gasohol program that the points within the ditribution system of gasoline where the ethanol could be blended with the base gasoline include: (1) the refinery as trucks are being loaded; (2) the pipeline terminal or bulk blending facility as trucks are being loaded; and (3) the retail station by means of a blending pump.

In each of the above cases, ethanol storage facilities would be required at the blending site. The estimated cost for a storage tank varying in size from a minimum of 20,000 to 100,000 barrels is $6 per barrel, or $.143 per gallon, which includes site preparation, the tank and the needed lines. Routine maintenance for one more tank at a pipeline terminal is minimal--an occasional painting. The life of the tank is long. Tanks put in place in the 1930's are still in use. 3/ These facilities would need to incorporate some system such as special vents for keeping the ethanol dry.

1/ See Appendix II-2 for a discussion of the gasoline refinery distribution system.

2/ American Petroleum Institute, op. cit.

3/ Hennessey, John. Williams Pipeline Co., Tulsa, Oklahoma, private communication, May 1978.

In addition to the ethanol storage tank, gasohol storage tanks would need to be dry and kept essentially free of moisture by some mechanism such as the use of special vents. The cost of this requirement is expected to be minimal.

2. Safety and Toxicity

Both gasoline and ethanol are highly flammable and the sale and handling of each requires adherence to statutory safety regulations. The toxicity hazards for ethanol and gasoline are similar. (See Appendix II-3)

In general, ethanol and gasoline require similar precautions as far as flammability is concerned; however, ethanol presents a more serious explosion hazard when flammability limits and vapor pressures are considered. The flammability limits are 4.3-19 volume percent, which corresponds to a temperature range of somewhat greater than 10°C (50°F) to somewhat less than 50°C (122°F). 1/ Gasoline vapors, on the other hand, are too rich to ignite, having a concentration in saturated air at 68°F of 25-50 volume percent, well outside the flammability limits of 1.4-7.6 volume percent.

While a potential safety problem is present for ethanol, no conclusive evidence was found to support an estimate of an additional storage cost allowance for safety features. This issue has not received much attention to date and is considered to be an unresolved issue.

3. Impacts on Distribution Costs

The transportation, storage, handling and dealer markup costs for gasoline, ethanol and gasohol, due to their properties, would be similar - with the exception of the additional cost for maintaining essentially moisture-free ethanol and/or gasohol storage. The incremental distribution costs associated with gasohol appear to be small under the distribution system considered herein. It should be noted that this area of the economics of gasohol has received little attention, with the result that firm cost estimates are not available, and additional work should be done in this area to confirm the conclusion.

D. Price of Gasoline

Since the cost of gasohol is determined primarily by the price of gasoline, the price of gasoline is an important consideration in assessing the comparative market potential of the motor vehicle fuels.

1/ See Appendix II-1.

1. Retail Price of Gasoline

The retail price of gasoline varies by grade of gasoline and by the type of service station (Table II-1). In December, 1977, the average selling price of regular gasoline at full-service major-brand stations, including an average tax of $.125 per gallon, was $.644 per gallon; at independent stations the price was $.584 per gallon. The variation in price between the four grades is not uniform among the types of stations; however, in all cases the price roughly parallels the octane number of the gasoline.

The annual average retail price of regular motor gasoline for 1967-76 in both current and constant dollars is shown in Figure II-1. 1/ In current dollars, the price of gasoline rose from $.332 per gallon in 1967 to $.587 per gallon in 1976. If these prices are deflated by the inflation rate experienced in the United States during these years (as measured by the Bureau of Labor Statistics' Consumer Price Index), the price of gasoline (in constant 1967 dollars) was $.332 per gallon in 1967, rose to a peak of $.358 per gallon in 1974 at the time of the oil embargo, and dropped to $.349 in 1975 and $.344 in 1976. The constant dollar price of gasoline has remained fairly steady. In 1976, the retail price of regular gasoline was only $.012 cents per gallon higher than in 1967, in constant 1967 dollars.

2. Retail Gasoline Price Projections

The forecast for domestic petroleum liquids supply and price made by the Energy Information Administration of DOE 2/ was based on numerous assumptions. The most critical of these were the assumed path of future world oil prices and its effect on domestic price regulations and other government policies, the extent and quality of the domestic resource base, and the forecast of growth of the U.S. economy. Six scenarios were developed: five assumed world oil prices constant in real terms -- i.e., imported oil prices would just keep pace with domestic inflation; one assumed a high price of imported fuel.

These estimates assumed that the composite price controls scheduled under the Energy Policy and Conservation Act would be extended throughout the forecast period.

The projected real gasoline price made under the six scenarios for 1985 vary from $.714 to $.722 under the assumption of a constant real price of crude oil in 1985 (Table II-2). If a high import price of crude is assumed, the projected price is $.787 per gallon (including excise tax). By comparison, in 1975, the retail price was $.675 per gallon. In 1990, the retail price of gasoline is projected to vary from $.723 to .743 per gallon with a jump to $.912 with high import prices of crude, in 1977 dollars.

1/ Table II-3 presents numerical retail price series. It is from a different source and varies slightly from Figure II-1.

2/ U.S. Department of Energy, "Projections of Energy Supply and Demand and Their Impacts," Annual Report to Congress, Vol. II, July 1977.

Table II-1. Average gasoline selling prices and margins for major and indenendent retail dealers, including tax - December, 1977

	Full Service			Self Service		
	Major	Independent	National average	Major	Independent	National average
	(cents per gallon, including tax)					
Regular						
Selling price	.644	.584	.633	.591	.558	.582
Margin	.093	.070	.090	.041	.045	.042
Premium						
Selling price	.699	.635	.691	.669	.616	.658
Margin	.104	.091	.102	.074	.073	.074
Unleaded (regular)						
Selling price	.681	.620	.672	.648	.598	.636
Margin	.102	.081	.099	.069	.059	.067
Unleaded (premium)						
Selling price	.716	.636	.706	NA	NA	NA
Margin	NA	NA	NA	NA	NA	NA

Source: Lundberg Survey, Inc., as reprinted in U.S. Department of Energy, EIA, Monthly Energy Review, March 1978.

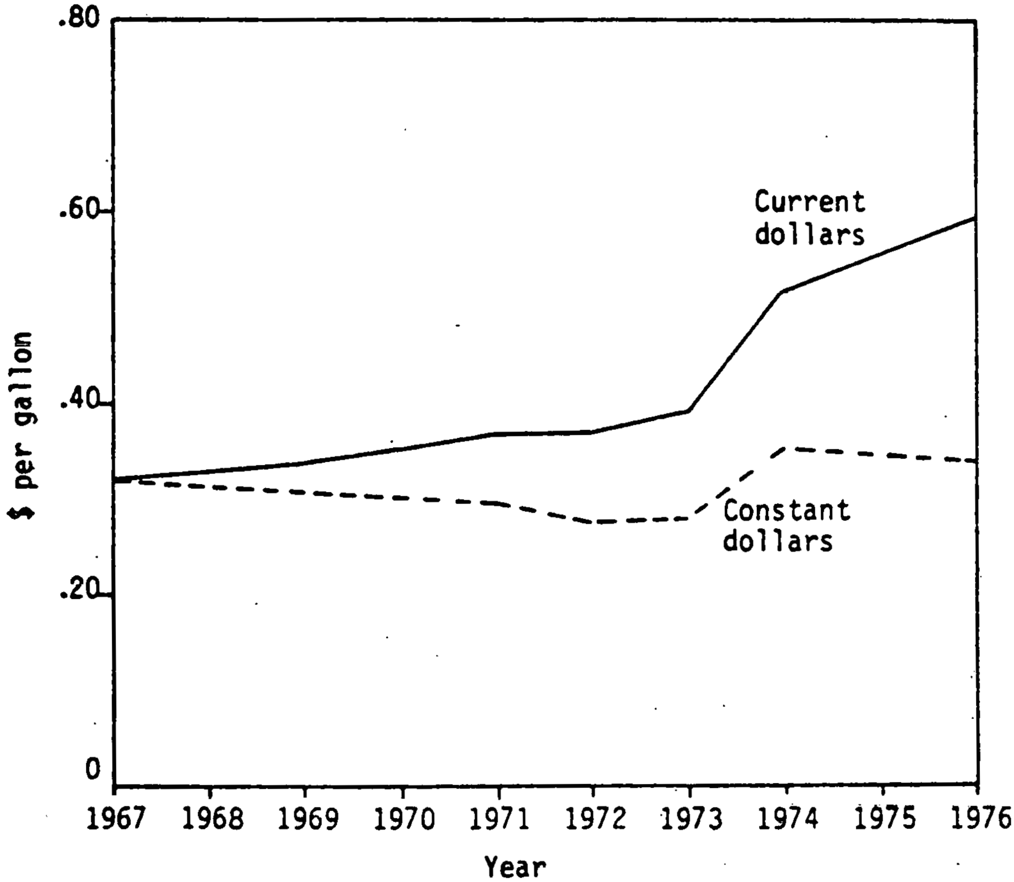

Figure II-1. Retail price of motor gasoline in current and constant dollars.

Source: Federal Energy Administration, Office of Energy Information and Analysis, Monthly Energy Review, July 1977.

Table II-2. Projected retail gasoline prices including taxes, 1985 and 1990 (1977 dollars)

Scenario	A	B	C	D	E	F
Demand	High	High	Med	Low	Low	High Crude oil import price
Supply of domestic oil and gas	High	Low	Med	High	Low	
1985						
$/gal	.716	.722	.717	.714	.719	.787
Annual price growth rates, percent	1.0	1.1	1.0	0.9	1.0	1.9
1990						
$/gal	.732	.743	.739	.723	.738	.912
Annual price growth rates, percent	0.4	0.6	0.7	0.3	0.5	3.0

Source: Derived from U.S. Department of Energy, Energy Information Administration, "Projections of Energy Supply and Demand and Their Impacts," Annual Report to Congress, Vol. II, 1977.

The retail price of gasoline is in essence composed of the sum of refinery gate price of gasoline, plus transportation and terminalling, dealer markup and fuel taxes.

3. Refinery Gate Gasoline Price

The refinery gate price for gasoline has, in general, paralled the price of crude oil. 1/ In 1965, the average refinery gate price of gasoline was $.1152 per gallon (Table II-3). This price gradually increased (about $.03 per gallon of gasoline) through 1973. In 1974, when the Arab Oil Embargo occurred, prices of both crude oil and the refinery gate price of gasoline nearly doubled. By 1976, the average refinery gate price of gasoline reached $.3382 per gallon (Table II-3).

4. Transportation and Terminalling

The wholesale prices of gasoline, as represented by the dealer tank wagon price or dealer purchase price, parallel the prices of gasoline at the refinery gate. Transportation and other costs associated with moving the gasoline from the refinery gate to the retail dealer may be estimated by the difference between the two prices. This difference is approximately $.05 per gallon and has varied little in the period from 1950 to the present (Talbe II-3).

5. Dealer Margins

Various data series and dealer configurations yield slightly different dealer margins, although on the average, the dealer markup is about $.08 to $.09 per gallon (Table II-3). The dealer margins at major brand stations and independent stations were $.093 and $.070, respectively in December 1977 (Table II-1). The margins at self-service stations were considerably lower at $.041 for the major and $.045 per gallon for the independent. Dealer margins on regular gasoline at full service stations have varied little in the period from 1974 to 1977 as shown in the data below. 2/

Year	Average dealer margin ($/gal)
1974	.097
1975	.084
1976	.078
1977	.083

1/ See Appendix II-4 for brief background on crude oil prices.

2/ Lundberg Survey, Inc. as reprinted in U.S. Department of Energy, EIA, *Monthly Energy Review*, March 1978.

Table II-3. Average prices, and imputed margins for regular grade gasoline in the United States, 1965 to 1976.

Year	Gasoline refinery gate 1/	Dealer tank wagon	Service station: Without fuel tax	Service station: With fuel tax	Transportation and terminalling	Dealer margin	Fuel taxes
	($/gal)						
1965	.1152	.1538	.2070	.3115	.0386	.0532	.1045
1966	.1159	.1583	.2157	.3208	.0424	.0574	.1051
1967	.1184	.1631	.2255	.3316	.0447	.0624	.1061
1968	.1155	.1651	.2293	.3371	.0496	.0642	.1078
1969	.1180	.1711	.2385	.3484	.0531	.0674	.1099
1970	.1230	.1768	.2455	.3569	.0538	.0687	.1114
1971	.1270	.1811	.2520	.3643	.0541	.0709	.1123
1972	.1270	.1772	.2446	.3613	.0502	.0674	.1167
1973	.1472	.1948	.2688	.3882	.0476	.0740	.1194
1974	.2553	.3053	.4041	.5241	.0500	.0988	.1200
1975	.3027	.3578	.4545	.5722	.0551	.0967	.1177
1976	.3382	.3899	.4744	.5947	.0517	.0845	.1203

1/ Average of 8 refinery markets.

Source: National Petroleum News Factbook Issue, McGraw Hill, New York, 1977.

In fact, for some time the dealer margin has remained essentially unchanged. For example, in 1969, Platt's Oilgram Price Service reported an average dealer margin of $0.08 per gallon for full service stations.

6. Taxes

Taxes specific to gasoline are collected at the time of retail sale. Refunds and tax credits, however, for non-highway use was authorized by the "Excise Tax Reduction Act of 1965."

In 1977, rates varied from $.05 to .095 cents per gallon for the High Plains and Midwestern states specifically included (see Table II-4) in the present study. In addition, the federal motor fuel tax is 4 cents per gallon. Nationally, the current fuel tax averages $.125 per gallon. 1/

The motor fuel taxes constitute quite varied proprotions of the total state tax revenues in the states included in this study. In South Dakota, these taxes were 19 percent of the total tax revenues, in Nebraska, 17 percent and in Wisconsin, only 7 percent. Most of these 17 states (except Nebraska, Oklahoma, Wisconsin, Illinois and Indiana) constitutionally prohibit diversion of the motor fuel tax to non-highway uses.

E. Marketing

Gasohol is being sold as a motor fuel in a few areas today utilizing the familiar type of service stations. Gasohol has been marketed in Illinois since November 21, 1977. Currently, there are 33 stations throughout the state selling gasohol at the same selling price as premium no-lead. A total of 300,000 gallons of gasohol were sold by the end of the first six months of operation. 2/

Gasohol has been sold in Nebraska on a regular basis since February 21, 1978. 3/ At the present time, there are four service stations selling gasohol, two of which sell it on a regular basis. The other two, located in central Nebraska, are involved in a 90-day test sale. For the period

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1/ Lundberg Survey Inc., as reported in the U.S. Department of Energy, EIA Monthly Energy Review, March 1978, reported the average fuel tax as follows:

Year	$/gal
1974	.122
1975	.122
1976	.125
1977	.125

2/ Mavis, Al, conservation coordinator, Illinois Department of Agriculture, private communication, Jan. 20, 1978.

3/ Fricke, C. R., Administrator, Nebraska Gasohol Committee, Lincoln, Nebraska, private communication, July 1978.

Table II-4. State fuel tax rates and revenues

State	1977 gasoline tax rate	1976 state motor fuel tax revenues	Motor fuel taxes as percent of total tax revenues in 1976
	($/gal)	($000)	
Colorado	.0700	99,179	10
Illinois	.0750	390,287	8
Indiana	.0800	248,743	13
Iowa	.0700	126,893	11
Kansas	.0800	98,770	12
Michigan	.0900	404,965	11
Minnesota	.0900	189,603	9
Missouri	.0700	196,648	14
Montana*	.0800	41,245	15
Nebraska*	.0950	84,007	17
North Dakota*	.0800	26,843	9
Ohio	.0700	375,949	11
Oklahoma	.0658	117,256	12
South Dakota	.0800	35,854	19
Texas	.0500	427,285	11
Wisconsin	.0700	161,975	7
Wyoming	.0800	22,730	12

Source: 1977 National Petroleum News Factbook Issue, Mc Graw Hill, New York.

from March through June, 36,000 gallon of gasohol were sold at three outlets. The first 20 million gallons of gasohol sold each year in Nebraska is exempt from five cents per gallon of the excise tax.

To date no extensive consumer acceptance studies have been completed, but consumer acceptance is assumed to be a function of both performance and selling price. In an effort to learn if gasohol is popular enough to sustain a permanent market, the Iowa Development Commission is coordinating an in-depth market research project which began June 15, 1978. 1/ Based on the premise that when testing a new product, it must be competitively priced with similar products on the market or consumers will not purchase it at all, gasohol is being sold at five Iowa towns at a price comparable to gasoline (Based on current market prices, the IDC concluded that gasohol should sell about 10-12 cents per gallon higher than no-lead fuels).

Current marketing information would indicate that purchasers of motor vehicle fuel are (1) willing to serve themselves and forego some of the services normally accorded them at full service stations provided the price is lower, (2) willing to pay more for a higher octane motor fuel if their vehicles perform better--as evidenced by increased sales of premium no-lead, and (3) willing to support brand loyalty.

If these and other features which entice consumers to a specific brand of motor fuel or to a specific retail outlet can be exploited, the market potential for gasohol as a motor vehicle fuel could be compatible with the present day market for motor fuel.

Definitive data on octane number and other performance properties of gasohol would be required by the intelligent purchasers, but if the consumers feel they are obtaining proper value for the price, the average consumer is probably little concerned about the original source of the fuel. The key question revolves around performance and the consumer's perception of performance. At present, the answers are not clear-cut.

F. Gasohol and Imputed Ethanol Prices

This chapter's preceding discussions of the unique characteristics of gasohol's nature, distribution, marketing, and pricing were presented as considerations which are germane to this study's estimates of gasohol costs, for if gasohol is to be competitive with gasoline as a motor fuel, its retail price including cost adjustment factors should be equivalent to that of gasoline to complete the analysis of gasohol price, the price (cost) of ethanol must be considered. From the preceding discussion, it is clear that gasoline price is an important cost component of gasohol. Furthermore, it

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1/ "Iowa to Sell Gasohol to Consumers in Research Test," Feedstuffs, June 12, 1978.

can be assumed, excepting institutional constraints, that gasoline prices (costs) will be determined by factors external to an ethanol industry.

Given the working conclusions and assumptions, the required ethanol price (cost) can be obtained by rearranging the formula given at the beginning of the chapter as follows:

$$\text{Ethanol price f.o.b. plant} = 10\left[\text{gasohol selling price} - .90\left(\text{gasoline price, refinery gate} + \text{transportation, terminalling and dealer markup}\right) - .10\left(\text{ethanol transportation, and handling cost and dealer markup}\right) + \text{gasohol value adjustment} - \text{fuel taxes}\right]$$

The retail price of regular unleaded gasoline is about \$.52 per gallon exclusive of fuel tax in 1977 dollars. This is a refinery gate price of \$.40 per gallon plus \$.05 per gallon for transportation and terminalling and \$.07 per gallon dealer margin. It was concluded that the transportation, handling and dealer margin for ethanol would be similar to gasoline, i.e. about \$.12 per gallon. A value adjustment of \$.001 per gallon of gasohol was estimated for the volume increase.

Excluding fuel taxes and substituting into the equation a required f.o.b. plant price for ethanol of \$.41 1/ per gallon is obtained. Assuming different refinery gate prices and holding other costs constant, a range of required ethanol prices can be obtained as shown in Table II-5. When refinery gate gasoline prices vary from \$.35 to 1.00 per gallon, ethanol prices vary from \$.36 to \$1.01 per gallon. Considering the gasoline price projections shown in Table II-2, the refinery gate price under the constant dollar world crude price scenarios would be in the order of \$.45 per gallon in 1985 and \$.47 per gallon in 1990 which would make ethanol equivalent to \$.46 and \$.48 per gallon, respectively. Under a scenario that constant dollar world crude prices will increase, the refinery gate price of gasoline would be about \$.50 in 1985 and \$.60 in 1990. The equivalent ethanol price would be \$.51 and \$.61 respectively. These values (1977 dollars) must be considered as rough approximations since the transportation and dealer margins may increase from recent relationships.

The fact that no adjustment was made for octane number enhancement merits further explanation. The exact value of the octane number enhancement depends on the octane number of the blending gasoline. Gasohol with an octane number greater than the regular no-lead produced by blending ethanol with regular no-lead gasoline, might command a price greater than of regular no-lead gasoline, if the consumer desires a gasoline with that octane rating.

1/ $\$.41 = 10[\$.52 - .9(\$.52) - .10(\$.12) + \$.001]$

Table II-5. Required ethanol price (cost), f.o.b. plant as a function of refinery gate gasoline price.

Gasoline price refinery gate	Ethanol price f.o.b. plant
($/gal)	($/gal)
.35	.36
.40	.41
.45	.46
.50	.51
.55	.56
.60	.61
.65	.66
.70	.71
.75	.76

Source: DPRA estimate

Price differences between the two qualities of unleaded fuel vary, but not directly with the octane number difference. For example, at one full-service station, premium no-lead with a minimum octane number of 94 sells for \$.739 while regular no-lead with a minimum octane number of 88 sells for \$.709 or \$.005 per octane number. At another full-service station, the difference in cost of the two grades is \$.04 per gallon while the difference in octane number is 5, giving \$.008 per octane number. Ethanol does increase the octane number of the fuel and the associated value would be in the range of the difference in price between regular no-lead and premium no-lead. For example, if experimentally, the octane number increase were shown to be two then the cost adjustment would be on the order of \$.016 to \$.010 per gallon of gasohol or \$.16 to \$.10 per gallon of ethanol. No adjustment, however, was made in these gasohol costs for octane enhancement as no definitive data on either the octane enhancement or the value of an octane number were available.

In the initial phases of gasohol production, the slightly higher cost of the currently mass-produced, unleaded gasoline must be weighted carefully against that for the specially-blended base with less expensive components produced as a special batch in small quantities. Whether, indeed, a higher price for gasohol would be justified awaits both consumer acceptance and the results of carefully controlled experiments to determine the actual road octane number enhancement, driveability in the particular climatic conditions, corrosion over the long term, and other questions related to the particular characteristics and consumer acceptance of gasohol.

III. ETHANOL: GENERAL CHARACTERISTICS AND PRODUCTION TECHNOLOGY

This chapter presents a general discussion of ethanol production technology as a background to the study's primary concern--discussing the economic feasibility of ethanol production and gasohol utilization. The current technology of the fermentation process using grains and other raw materials is well-known and understood.

Later sections of the chapter briefly discusses the potential technological developments germane to ethanol production.

A. Ethanol Production

Ethanol is but one form of generic alcohol, a family of compounds that are the hydroxol derivatives of hydrocarbons. Each alcohol is distinguished by its carbinol group, and ethanol--(C_2H_5OH)--is a two-carbon member of the generic family of alcohols. Ethanol is used in some forms as an industrial solvent and in others as the alcoholic basis of a variety of beverages and foodstuffs.

In its most familiar use, beverage alcohol is a form of ethanol with flavors and colorations that are actually impurities from the grain and fermentation process, and are enhanced by aging. Whiskey is an example of this beverage form. Neutral spirits, ethanol with all impurities removed except water, is a chemically pure form familiar as beverage vodka.

Ethanol is also frequently used as an industrial solvent and is a constituent of paints, shellacs, lacquers, various medical compounds, tinctures, and toilet preparations. Among the various chemicals that can be derived using ethanol are: anesthetic and glycol ethers, various esters, acetates, and chlorethane.

The other use of ethanol, and the chief concern of this study, is as a constituent of gasohol for use in internal combustion engines.

Ethanol may be produced from agricultural products (any carbohydrate) through fermentation or from petroleum products through chemical synthesis. This investigation is confined to ethanol derived from agricultural products.

Ethanol derived from starch-bearing feedstocks (grains, starch, potatoes) is produced in essentially a two-stage process. In the first, starch is converted through hydrolysis to sugar enzymatically by diastase in sprouting grain (malt) or with fungal amylase. 1/

Starch + water	Enzyme	Sugar
$(C_6H_{10}O_5)_n + nH_2O$	-------->	$nC_6H_{12}O_6$

In the second stage, the resultant sugar composition is converted to ethanol and carbon dioxide through fermentation.

Sugar	Yeast	Ethanol	Carbon Dioxide
$C_6H_{12}O_6$	-------->	$2C_2H_5OH$	$+ 2CO_2$

For those agricultural products (sugar beets, sugar cane, molasses) yielding the necessary sugars directly, the first stage is unnecessary.

Sugar may also be a conversion product of cellulose, the pulp of all biomass (e.g., corn stalks, wheat, straw, wood). Technically, the cellulose of biomass may be converted into sugars by acid or enzymatic hydrolysis and could, thus, make available an additional source of the sugars necessary for fermentation; however, such resources are not commercially attractive at the present time. 2/

Because ethanol is soluble in both water and gasoline, ethanol must be processed and distilled to remove the water when ethanol is used to produce gasohol. The distillation process, possible because ethanol and water have differing boiling points, is achieved through a two-stage process. The first results in 95 percent ethyl alcohol and 5 percent water (190 proof alcohol). The second distillation produces the 200 proof anhydrous ethanol required for gasohol.

To assure compliance with revenue levies (taxes) and consumer use, ethanol used for other than beverage purposes is denatured through the addition of various and, commonly, toxic substances.

1/ Scheller, W. A. "The Production of Ethanol by the Fermentation of Grain," Presented at the International Symposium on Alcohol Fuel Technology, Wolfsbury, Federal Republic of Germany, Nov. 12-4, 1977.

2/ Lipinsky, E. S. et al. Battelle-Columbus Laboratories. Systems Study of Fuels from Sugar Cane, Sweet Sorghum, and Sugar Beets, Vol. III, sponsored by ERDA, December 1976.

B. Process Operations and Equipment for Grains

An ethanol plant's operations and equipment will vary for the different raw materials to be processed. Those converting the starches and sugars from grains are generally compatible and are schematically presented in Figure III-1. An important exception is wheat. Due to the high gluten content, the processing of straight wheat produces excessive foaming which requires certain process modifications. However, wheat can be blended with corn or grain sorghum up to 20 to 25 percent, without special foaming problems. Thus, the reference to grain used below assumes that wheat is blended into corn or grain sorghum. The process now in use and described below is a batch process.

1. Enzyme and Yeast Propagation

Each processing plant must develop and maintain adequate stores of uncontaminated fungal amylase and yeasts. The plant must provide development, growing, and controlled maintenance areas for such cultures sufficient to the plant's economically viable fermentation production.

2. Grinding and Cooking

Conveyors, grinders, and properly-sized holding tanks are necessary to move and grind processing grains. The grains are ground to expose their starch molecules, mixed with water (30-40 gallons per bushel) and cooked to convert their starch to sugar through hydrolysis. The pH and the temperature of the mixture must be controlled.

3. Fermentation

The fermentation reaction, a 48-hour process, takes place in individual tanks arranged in batteries. The number of tanks required depend upon a plant's designed production capacity, but obviously they must be sufficient to maintain the 48-hour operation and to allow stand-down capacity for tank loading, unloading, cleaning, and sterilization necessary for continuous and cyclical processing operations.

As the mash is charged into a fermentation tank, the yeast is added to commence the fermentation process. The process heat must be drawn off to maintain the mash temperature at the 32^{o} C required for yeast operations. The carbon dioxide produced during fermentation may be discharged into the atomsphere or dried and compressed into marketable forms when feasible.

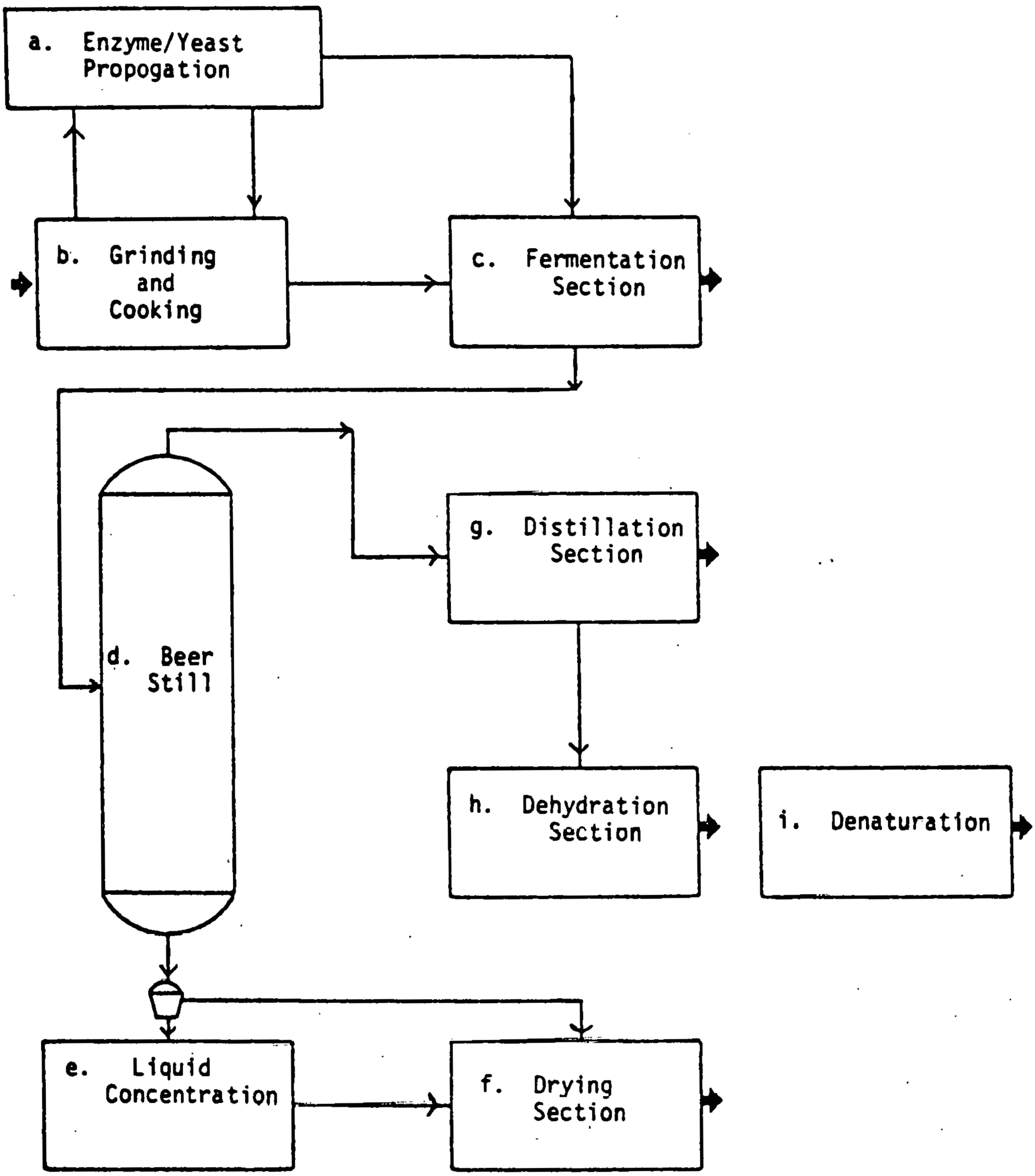

Figure III-1. Block flow diagram grain fermentation process.

Source: Scheller, W. A. "The Production of Ethanol by the Fermentation of Grain," Presented at the International Symposium on Alcohol Fuel Technology, Wolfsburg, Federal Republic of Germany, Nov. 12-4, 1977.

4. Beer Still Distillation

The fermented mash, containing about 12 percent alcohol in water and the spent grain are charged into the beer still where initial distillation takes place. The alcohol, now concentrated to 50 percent in water vapors, boils off the top and is condensed, while the spent grains consisting of both dissolved and undissolved solids of protein, fiber, yeast, and water are discharged at the bottom of the still and centrifugally separated into liquids and solids.

5. Liquid Concentration

The centrifuge-solubles are reduced in volume about 50 percent in multiple effect evaporators. They are then pumped to the driers and remixed with the centrifuge-discharged solids for drying.

6. Drying

In order for a plant to produce, store, and ship a uniform product of distillers dried grain, driers reduce the moisture content of the mixture of solid spent-grain and concentrated solubles to 10 percent. The resultant product with a specified analysis is marketed as high protein feed additives.

7. Distillation

The beer-still distillates of condensed vapors of 50 percent (100 proof) alcohol in water, are introduced into one or more distillation columns to remove the aldehydes and fusil oil and to concentrate the alcohol to 95 percent (190 proof). 1/ The aldehydes and fusel oil can be stored for possible sale or may be used as process boiler fuel.

8. Dehydration

To produce anhydrous ethanol, 200 proof, requires the removal of the remaining water by an extractive distillation process. Benzene or other suitable material is added to the 190 proof alcohol to form a ternary mixture that will break the azeotrope of ethanol and water and allow the anhydrous ethanol to be separated for storage. The benzene is then recycled into the dehydration process.

9. Denaturation

The ethanol produced for industrial consumption, including fuels, must be denatured to assure compliance with the regulations of the Bureau of Alcohol, Tobacco, and Firearms. One such formula is: "To every 100 gallons of ethyl

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1/ Industry contacts suggest that aldehydes and fusil oils should be removed from fuel grade ethanol. However, the need for removal is questioned by some researchers. Thus, this issue is unresolved.

alcohol (ethanol) of not less than 160° proof add: 4.0 gallons of methyl isobutyl ketone; and 1.0 gallon of either kerosene, deodorized kerosene, or gasoline." 1/

C. Process Operations and Equipment for Non-Grains

The processes required for production of ethanol from non-grain raw materials vary from the grain process. The major difference relates to the front-end preparation of these materials. Rather than describe the complete processes and equipment, the differences from the basic grain process will be highlighted for each non-grain raw material in the following discussion.

1. Process and Equipment for Potato Fermentation

Rather than describe the complete process and equipment used in a plant that would process potatoes as a starch source instead of grain, highlighted only are those aspects that are different from those of a grain fermentation plant. The major difference is the storage. Potatoes are stored in a controlled environment -- "potato cellar" (cool and dark); grain is stored in steel bins or piled on the ground. The grinding and cooking processes preparatory to fermentation vary only slightly from those for grain processing because the size and moisture content of the potato.

The fermentation and distillation operations and equipment are the same for both plants with but one exception. The yield of alcohol from fermentation will be about 7 percent maximum and, thus, there will be more water to remove by distillation.

The recovery of potato pulp is simpler than the recovery of distillers dried grain; however, since the protein content of potato pulp is too low to justify expensive drying operations, potato pulp is processed and sold to area feedlots in its wet form.

2. Process and Equipment for Sugar Beet Fermentation

Sugar beets processing is a combined beet sugar and fermentation process. All of the operations that are characteristic of a beet sugar plant except for the crystallation of sugar are found in the beet sugar fermentation plant. The equipment and processing necessary to the storing, slicing, defusion and concentration of raw juice to thick juice are necessary, and beet pulp recovery and drying operations and equipment are required. In addition, all the processing and equipment required for fermentation, distillation, dehydration and denaturation are needed.

1/ Bureau of Alcohol, Tobacco and Firearms. Formulas for Denatured Alcohol and Rum, Section 212, Title 27, April 1977, TD 6634, 28 FR1038.

3. Process and Equipment for Starch and Molasses Fermentation

Starch and molasses fermentation processing is simpler than that for all other products discussed. Storage is simplified because both starch and molasses are concentrated. Since pulp and fiberous material are separated in a prior process, the need for grinding is eliminated and the preparation for starch fermentation requires only the hydrolysis and heating operation. Molasses needs only dilution with water before its charging into the fermentation. Vats from the fermentation step on the starch and molasses plants are similar to grain plants with the exception of the process pulp recovery. In the case of starch, there is only a small volume of effluent from the beer still to be treated -- no drying of stillage and no recovery of saleable protein feed.

D. Potential Ethanol Production Technology

Since this study examines ethanol production under current technologies, the future economics of the industry which will doubtless reflect the effects of still-to-be-determined technologies are not considered. This section, then, but briefly catalogues potential technological innovations in ethanol production.

Future technological advancements will center principally on raw material source and treatment developments, improved micro organisms, and more efficient processing techniques and equipment. The first is the most significant.

1. Raw Materials

As noted earlier, ethanol production relies upon the conversion of starches and sugars into ethanol. Future developments will concern materials with increased starch yields, with more directly accessible sugars, and with varied sugar sources. Research directed toward genetic improvements in vegetable, grain, and sugar beet varieties to increase their potential starch and sugar yields may be expected to promote efficiencies.

A most promising development in the search for new materials is that reflected in the work of Dr. George T. Tsao of Purdue University 1/ which centers principally upon his attempts to break down the cellulose waste in such diverse sources as corn stalks, sugar cane bagasse, sawmill residues, small tree trunks, and industrial wastes and urban trash. A cost will be realized in the gathering of such materials, but their obvious availability and their potential low-cost for glucose sugar recovery makes their potential use of interest.

1/ Tsao, George T. "Utilization of Grain and Crop Residues for the Production of Fuel and Chemicals," Purdue University, West Lafayette, Ind., undated.

2. Improved Micro-Organisms

A technically limiting factor in ethanol production is the inability of currently-used yeasts to sustain fermentation in mash concentrations of greater than 12 percent alcohol content. New strains may be capable of propogation with greater alcohol tolerance. Their introduction would allow a more efficient production process with higher alcohol yields and correspondingly less water removal requirements in the distillation process. Published data on new strain developments are not available. There are reports of proprietary research in this area, but there is no conclusive evidence available regarding the likelihood of a breakthrough.

3. Equipment and Process Developments

a. Continuous Fermentation

The most widely discussed development in equipment technology concerns that for developing continuous fermentation. The process has been used to ferment wine grapes and sugar syrups and molasses, but there are no documented data of its application in grain fermentation. At best, the development would reduce fermentation from approximately 48 hours to as few as seven or eight hours and would result in lower inventory of materials and fermentation equipment capital investment costs. The process, however, would not greatly reduce energy consumption or other operating costs. What gains are possible with continuous fermentation may come at the expense of somewhat lower alcohol yields than attained with batch fermentation.

Two European firms, Vogelbush of Austria 1/ and BMA 2/ of Germany claim to have fermentation processes and equipment which result in significant savings in energy and operating costs, but these are proprietary and no published cost data supporting these contentions are available. Each firm designed and built installations in many parts of the world and these plants produce from 1 to 15 million gallons of ethanol per year.

b. Vacuum Fermentation

A promising development being investigated is vacuum fermentation. 3/ This process requires the co-development of continuous fermentation under vacuum and a mutation of the temperature-insensitive microorganisms to allow the resultant alcohol vapors to be drawn off the fermentators continuously. The process would replace the mash column with a fractionation column, a potential energy savings advancement.

1/ Vogelbusch Gesellschaft mbH Vienna, Austria, reoresented in the United States by Bohler Bros of America, 1625 W. Belt North,Houston, TX 77043, personal communication, 1978.

2/ Braunschweigische Maschenembauanstalt(BMA) Braunschweig, West Germany, represented in U.S. by Silver Engineering Works, Inc., 3309 Balke St., Denver, Colorado 80205, personal communication, 1978.

3/ Colorado Gasohol Task Force. Production and Marketing of Alcohol Motor Fuels from Colorado Agricultural Commodities: A Tentative Description, Jan. 31, 1978.

c. Dehydration Operations

Several investigations are being conducted that involve the concentration of ethanol through dehydration processes. Such still require considerable further work before they are cost effective. A number of these are listed below.

The solvent extraction of ethanol is being investigated as a new technique. 1/ Alcohol in aqueous solution is fed into a column with a counter current of gasoline. The process depends upon the solubility of alcohol and gasoline and the insolubility of water in gasoline to draw off a product containing only gasoline and alcohol. This procedure, if successful at a high transfer rate, would eliminate the need for distillation columns and their high energy requirements.

Crystallization extraction is a technique which utilizes the fact that the latent energy of freezing water is less than the latent heat of vaporization. The controlled freezing of the alcohol-water solution may be a more energy efficient method of concentrating the alcohol product than is distillation.

The fluidized rectification of alcohol reported in a recent Russian work 2/ indicates that a two-fold productivity increase may be realized with fluidized-bed columns as compared to conventional fixed-plate columns with bubble-cap trays or columns with fixed packings.

The use of molecular sieves or reverse osmosis to separate alcohol from water is under investigation also. Currently, the low production rate and high pressures required for the process are limiting factors. A similar technique using an ion exchange with a zeolite process is described within another Russian work. 3/

1/ Colorado Gasohol Task Force. Production and Marketing of Alcohol Motor Fuels from Colorado Agricultural Commodities: A Tentative Description, USDA, Jan. 31, 1978.

2/ Gelperin, N. I., et al., "Rectifying capacity of columns with fluidized packing," Khim, Prom. (Moscow), v. 47, no. 1, 1971.

3/ Andronikashvili, T. G. et al., "1966 Preparation of Absolute Ethyl Alcohol by Zeolite," Lavod. Lab, V. 32, No. 10, p. 1211, as reported by the Colorado Gasohol Task Force in Production and Marketing of Alcohol Motor Fuels from Colorado Agricultural Commodities: A Tentative Description, Jan. 31, 1978.

IV. ETHANOL: INPUT-OUTPUT RELATIONSHIPS OF RAW MATERIALS AND ENERGY

One consequential aspect of ethanol production is the relationships between its production inputs and the mass and energy content of the products of that production. This chapter estimates these relationships.

A. Raw Material Input and Product Output Relationships

As previously indicated, this study focuses on those major crops and food processing by-products that are produced in a seventeen state Cornbelt and Great Plains area and used as raw materilas in the production of ethanol. Four primary items are produced from the fermentation of these raw materials: ethanol, distillers by-product, carbon dioxide, and water.

Table IV-1 summarizes the input-output relationships for each of the raw materials. Differences in unit measurements of and the water, starch, and sugar contents of the raw materials result in a wide range of output yields.

1. Ethanol

Corn, grain sorghum, and wheat yield 2.6 gallons of ethanol per bushel. Due to the difference in its nominal weight per bushel, the percentage yield of wheat is slightly less--28.7 percent--than the 30.7 percent for corn and grain sorghum. The percent yield of ethanol from potatoes and sugar beets, high water content products, is quite low at 9.4 and 6.7 percent respectively. Molasses yields 22.6 percent of its weight in ethanol and starch has the highest yield at 39.6 percent.

Precise estimates of the impact of raw material quality differences on ethanol yield are not available. Industry consultants suggest that sample grade and damaged grains have marginally lower ethanol yields. Doubtless, their specific yields, because they depend on the degree and kind of grain damage, would be batch specific.

2. Distillers By-product

The percentage yield of distillers by-product from corn and grain sorghum is, at 30 percent, similar to their ethanol yield. Wheat yields a higher percent of distillers by-product than it does ethanol--34 percent to 28.7 percent. Sugar beets and starch have relatively low yields at 13.2 and 14 percent respectively. Distillers by-product from molasses and potatoes are assumed to be sold in the local area only, at 75 percent moisture.

Table IV-1. Input-output relationships for converting selected raw materials to ethanol.

Item	Corn	Grain sorghum	Wheat	Potatoes	Sugar beets	Molasses	Starch
Input							
Unit	bu	bu	bu	cwt	ton	gal	lb
Norminal wieght per unit	56	56	60	100	2,000	11.7	1.0
Moisture content in percent	13	13	13	78	75	23	10
Output (yield) per nominal unit in percent							
Ethanol	30.7	30.7	28.7	9.4	6.7	22.6	39.6
Distillers by-product	30.0	30.0	34.4	14.8 1/	13.2	133.3 2/	14.0
Carbon dioxide	29.3	29.3	27.3	8.9	6.4	21.6	37.8
Water	10.0	10.0	9.6	66.9	73.7	--	8.6
Total	100.0	100.0	100.0	100.0	100.0		100.0
Output (yield) per nominal unit in nominal weight (lbs)							
Ethanol	17.2	17.2	17.2	9.4	134	2.6	.4
Distillers by-product (10 percent moisture)	16.8	16.8	20.7	14.8 1/	264	15.6 2/	.1
Carbon dioxide	16.4	16.4	16.4	8.9	128	2.5	.4
Water	5.6	5.6	5.7	66.9	1,474	--	.1
Total	56.0	56.0	60.0	100.0	2,000		1.0
Output (yield) per nominal unit in gallons							
Ethanol	2.6	2.6	2.6	1.4	20.3	.4	.06

1/ 75% moisture
2/ 75% moisture includes water added during processing

Source: DPRA estimate derived from:

Battelle-Columbus Laboratories. Systems Study of Fuels from Sugar Cane, Sweet Sorghum, and Sugar Beets, Volume III, Columbus, Ohio, December 1976.

Reilly, Peter J. "Report on Corn Alcohol as a Fuel Additive," Iowa Farm Bureau Federation Energy Conference, Des Moines, Iowa, Oct. 20, 1977.

National Academy of Science, Nutrient Requirements of Beef Cattle, No. 4, 5th revised edition, 1976.

3. Carbon Dioxide

Carbon dioxide yields are approximately equal to the product's ethanol yields. The grain products yield just about 30 percent; starch yields 37.8 percent; potatoes and sugar beets yield 8.9 and 6.4 percent respectively.

4. Water

Water represents the fourth item of output. All products yield roughly 10 percent water, except potatoes and sugar beets which yield approximately 70 percent.

B. Output Quality

The ethanol, carbon dioxide, and water outputs are approximately the same for each raw material. However, the quality of the distillers by-products varies widely and depends on the raw material and on the processing steps employed. Because of their protein content, distillers by-products are used primarily as a high protein livestock feed, and their protein content is a primary indication of their quality (they also have a net energy content). Distillers dried grain have a 29 to 30 (dry weight basis) percentage of total protein. Their digestible protein content is about 23 percent (moisture-free basis). 1/

Potato and sugar beet stillages have a total protein content of about 10 percent (4.5 percent digestible) on a dry weight basis. The total protein content of molasses stillage is about 20 percent (12.0 percent digestible dry weight basis). Starch stillage has essentially no protein content. Because of their relatively high protein content, the distillers by-products from grains are considered competitive, as a high protein feedstuff, to soybean meal which has a 44 percent digestible protein content (dry weight basis).

C. Energy Input-Output Relationships

The energy relationships considered here for an ethanol production facility have been considered in terms of the energy in, plant energy requirements and the caloric content of raw materials, and energy out, the caloric content of the products. Even with this narrow definition, several possible methods for determining the energy relationship are possible. A more extensive energy relationship may be determined, but in every case, the system under consideration must be very carefully defined.

1/ National Academy of Sciences, op. cit.

1. Plant Energy Sources

The ethanol production plants were projected to depend upon coal as their energy source. As could be expected, various other sources (briefly described below) of energy are feasible, but such sources are not to be expected in the near future as major energy sources.

a. Coal

Midwest coal supplies are located in Kansas, Missouri, Illinois, and Wyoming. Since coal transportation is costly, plant operating costs will be reflective of such expenses and will vary by location. In North Dakota and Montana, lignite coals are available. These coals have caloric contents of 7,000 - 8,000 Btu/lb. Costs are related to the caloric and the sulfur content of each coal type. This study's cost calculations were based on those for low sulfur Wyoming ("cowboy") coals having a heat content of 10,500 Btu per pound.

b. Other Energy Sources

As energy sources, solar and biomass are still considered inapplicable for general use. However, one "solar-assist" (as opposed to a total solar energy input) design1/ for ethanol production proposed in Colorado, features a variety of innovations. According to this report, when applied to small plants, solar energy for beer still dilute alcohol evaporation and spent grain drying seems feasible. No proposed designs, however, offer technological and costing data applicable to this study's purposes.

In biomass source energy application, agricultural products and cropping residues themselves are utilized for process boiler energy. Eventually, it is believed, both the economic incentive (as fossil fuel prices increase) and the necessary technology will be available to allow the collection, compaction, and transportation of crop field residues--straw, stover, celluose waste, etc.--at an economically acceptable level. Such residues frequently contain about 7,000 Btu per pound dry matter and presently are estimated to cost approximately $35 to $45 per ton dried, 2/ ($2.50 - $3.00 per million Btu) or about double the current price of coal.

c. Cogeneration Energy

A third possible energy source is provided by cogeneration energy systems. In practice steam energy generated to operate one plant unit, is conserved and reapplied to operate another unit in the manufacturing process. The system is employed in electric utility operations, in sugar refineries, and in wet corn milling processing plants. The system, however, requires specific plant design characteristics and to be feasible the system necessitates exacting planning and it must be incorporated into initial plant designs.

1/ Domestic Technology Institute. Executive Summary and Support Materials of the Integrated Solar Food and Ethanol Fuel Production System, U.S. Department of Commerce, 1977.

2/ Battelle Columbus Laboratories, Systems Studies of Fuels from Sugar Cane, Sweet Sorghum, Sugar Beets, and Corn. Volume IV, Columbus, Ohio, March 1977.

2. Energy Balance

This study's determination of the energy balance for ethanol production was estimated in a number of different ways. Unfortunately, no generally accepted energy accounting scheme has evolved to account for both the energy and feed value consequent to the production of ethanol. Two primary approaches are presented below. One is based on the heat content of the inputs and outputs, and the second is based on the energy inputs and the heat content of the outputs. A third alternative, an allocated input energy approach, is also discussed. All energy values are reported in terms of energy per gallon of ethanol produced.

a. Heat Content of Inputs and Outputs Approach

This approach assigns caloric values to the raw material input, the direct process energy, and the ethanol and distillers by-product outputs.

1. Caloric content of corn, ethanol and distillers by-products - There is general agreement1/ concerning the caloric content of corn, ethanol, and distillers dried grain (DDG). Specifically these contents are as follows:

	Btu per gallon of ethanol
Corn (337,000 Btu/bu)	145,000
Ethanol	84,000
DDG	50,000

2. Process energy - The process energy value required for a fermentation ethanol plant was estimated from various published data2/ and then judged reasonable by industry consultants. Further, this value for process energy is currently being attained in one, perhaps, exemplary plant. The total process energy of 131,000 Btu per gallon of ethanol produced for a plant producing both ethanol and distillers dried grain with 10 percent moisture may be allocated as follows:

1/ Sources include:

Cray, Cloud L., Jr., Midwest Solvents Corporation, Gasohol Seminar, Rio De Janerio, Brazil, September 1977.

Stone and Webster Engineering Corporation. "Preliminary Economic Evaluation of Nebraska Grain Alcohol Plant," Agricultural Products Industrial Utilization Committee, State of Nebraska, December 1976.

Corcoran, W.P., A.T. Brackett and F. Lindsey. Indiana Grain Fermentation Alcohol Plant, Indianapolis Center for Advanced Research, 1976.

2/ Sources include:

Stone and Webster Engineering Corporation, op. cit.

Reilly, Peter J. "Report on Corn Alcohol as a Fuel Additive," Iowa Farm Bureau Federation Energy Conference, Des Moines, Iowa, Oct. 20, 1977.

Cray, Cloud L., Jr., op. cit.

Corcoran, W.P., op. cit.

	Energy (1,000 Btu/gal ethanol)
Cooking	9
Fermentation	0
Distillation	52
Feed recovery	42
Miscellaneous	23
Electricity	5
	131

3. Energy Balance - Under the heat content approach, then, an energy loss of 142,000 Btu per gallon of ethanol is calculated as shown below:

	Energy (1,000 Btu)
Inputs	
Corn	145
Process energy	131
Total	276
Outputs	
Ethanol	84
Distillers dried grain	50
Total	134
Energy loss	142

b. Energy Inputs Approach

The second approach for estimating the energy balance is to compare the energy inputs for the production, the harvesting, and the transporting of corn and for process energy to the value of the energy output.

1. Corn input energy - The total direct energy inputs required to produce, harvest, and transport corn to the country elevator and to produce the required agricultural chemicals for corn production is estimated to average 106,000 Btu in the United States (Table IV-2). This varies by location: the Illinois estimate is 94,000 Btu per bushel; the Nebraska estimate is 176,000 Btu.

The above estimate excludes invested energy in durable production items such as farm equipment and farm structures and the energy retained by crop residues. While it is clear that the latter could be utilized as a process energy fuel the collecting and transporting of the residues require additional direct energy input as well as the equipment's invested energy. In addition, the removal of the crop residues, particularly on a continuous basis, would also involve the removal of plant nutrients from the soil and these would have to be replaced by invested fertilizer energy. Potential changes in soil structure and economic rates could be expected to affect energy rates as well.

Obviously, the exclusion of crop residue energy value from this analysis is not intended to suggest that crop residues cannot be used as an energy source; rather, their exclusion suggests that careful and extensive accounting and research--beyond the scope of this study--on the long term effects of crop residue removal is needed before confidently including these values in the energy balance.

Table IV-2. Estimated energy used in corn production, selected states, 1974

State	Gasoline	Diesel fuel	Fuel oil	LP gas	Natural gas	Electricity	Invested energy	Total	Crop yield per acre	Energy used for ton of crop field weight 1/	Energy used per bushel of crop field weight
	-----------------------------			1000 Btu's per acre				-----------------------------	(tons)	(1000 Btu)	(1000 Btu)
Corn Grain											
Illinois	1,432	549	--	997	14	142	4,509	7,734	2.32	3,334	94
Iowa	1,385	670	1	732	20	120	3,878	6,806	2.24	3,038	85
Nebraska	975	2,401	--	1,667	753	1,293	4,845	11,933	1.90	6,281	176
Texas	1,176	1,259	--	398	5,865	1,456	3,845	13,999	2.58	5,426	152
United States Ave.	1,209	946	22	782	390	320	3,935	7,604	2.00	3,802	106

1/ 15.5% moisture
Source: Battelle Columbus Laboratories, op. cit.

Similarly, the accounting for the energy invested in durable production goods does represent an energy requirement; however, if this line of reasoning is pursued, energy accounting for all energy sources and processes should include indirect invested energy so that comparable measures are developed.

For these reasons, the contractor has chosen to exclude these items from the input energy balance.

2. Energy balance - Utilizing the process energy developed above, an energy balance may be determined as follows:

	Energy (1,000 Btu/gal ethanol)
Inputs	
Corn production	41
Process energy	131
Total	172
Outputs	
Ethanol	84
Distillers dried grain	50
Total	134
Energy loss	38

c. Allocated Input Energy Approach

An alternative approach would be to allocate the input energy to the produced ethanol and distillers by-product. The energy required for distillation is charged to ethanol, and the energy required for drying is considered a DDG input. The remainder of the input energy would be allocated on the basis of the relative DDG to corn value1/ of .41 a value, which takes into consideration the net energy, the digestible protein content, and the fact that only the starch portion of the grain is utilized in ethanol production. This value suggests that, on a dry weight basis, an allocation of 41 percent of the corn production energy and the remainder of the process energy should be allocated to DDG and 59 percent should be allocated to ethanol.

The energy balance, then, based on the values obtained above, are as follows:

	Ethanol (1,000 Btu/ gal ethanol)	DDG (1,000 Btu/ gal ethanol)
Inputs		
Corn production and harvesting	24	17
Process energy	74	57
Total	98	74
Outputs		
Ethanol	84	
DDG		50
Total	84	50
Energy loss	14	24

1/ See Appendix IV-1

D. Efficiency of Ethanol Production

A measure of the energy efficiency of ethanol production may be obtained by calculating the ratio of the output energy to that of the input energy, i.e.,

$$\text{Efficiency} = \frac{\text{Output Energy}}{\text{Input Energy}} \times 100$$

Utilizing the heat content approach in which output energy was determined to be 134,000 Btu and input energy, 276,000 Btu, yields an efficiency of 49 percent. An energy efficiency of 78 percent was calculated for the energy inputs approach from the values of 134,000 Btu for outputs and 172,000 Btu for inputs. An energy efficiency for both ethanol and distillers dried grains may be calculated from the energy values obtained by the allocated input energy approach. Efficiencies of 86 percent (84/98) were calculated for ethanol and 68 percent (50/74) for distillers dried grains.

Under all three approaches, then, the conversion of process and corn grain energies into ethanol and lower-hydrocarbon livestock feed results in a net energy loss. Although the calculations depicted corn grain conversion specifically, an energy loss would be consequent to the use of other raw materials as well.

V. ETHANOL: RAW MATERIAL COSTS AND BY-PRODUCT CREDITS

Raw materials considered for ethanol production in this study include corn, grain sorghum, wheat, sugar beets, beet molasses and starch. The by-products resulting from ethanol production from these raw materials include atmospheric carbon dioxide and, respectively, corn distillers dried grain, sorghum distillers dried grain, wheat distillers dried grain, potato distillers by-product, sugar beet distillers by-product, molasses stillage, and starch stillage.

A. Raw Material and By-Product Prices

The raw material and by-product prices paid and received by ethanol producers can be expected to vary considerably over an expected plant life of twenty or more years, for reasons summarized by Heady (1976): "...U.S. agriculture may be faced with considerable instability. In years of large world crop shortfalls, as in 1972 and 1975, demand for U.S. exports may 'leap-frog' with sharp rises in farm commodity and food prices. In normal world supply conditions, our own (U.S.) supply capacity may dampen farm prices and incomes for domestic producers."1/ Indeed, 1977 and 1978 are examples of years in which depressed grain prices and incomes for domestic producers followed the surge of high prices just two to three years earlier.

It was not the purpose of this study to forecast raw material and by-product prices. (Price sensitivity analyses were conducted and are reported in Chapter VII.) This study does, however, estimate a reasonable base or average price level for raw materials and by-products around which the fluctuations in price can be expected. To do this, the contractor analyzed raw material and by-product prices at various U.S. locations for the last ten to fifteen years, and cash prices from leading U.S. grain-belt grain and by-product markets, representing exchanges among volume commodity traders for domestic as well as foreign use, were tabulated. Each consequent price series was converted to 1977 dollars based on the GNP implicit price deflator (1977 = 100), and the average price over the period in terms of 1977 dollars was computed.

Given the excess supply capacity of U.S. grain producers, the average real price represents a cost of production estimate below which supply will normally decrease and above which supply will normally increase. Average prices in terms of 1977 dollars provide a point estimate of future commodity prices in real terms, free of inflation and cyclical price movements.

1/ Heady, Earl O., "U.S. Supply Situation for Food and Fiber and the Role of Irrigated Agriculture," in The TAMU Centennial Year Water for Texas Conference: Water for Food and Fiber Production, Texas Water Resources Institute, Texas A&M University, College Station, 1976.

Leading grain-belt grain market prices are a reasonably good indicator of delivered raw material costs to grain ethanol producers, and since grain ethanol plants are expected to be raw material oriented, the grain-belt market prices are a close proxy for basing raw material prices. The relationship cannot be exact, however, because difference between leading market destination and ethanol plant destination prices among producing areas often do not reflect merely freight differentials, but rather they result from a complex of local demand and day-to-day operating conditions, freight costs, and other items.1/ Secondary price data for local markets are not routinely published, but local prices will generally be slightly lower than leading markets.

1. Raw Material Prices (See Table V-1)

This study's base corn price of $2.50 per bushel reflects the per bushel #2 yellow corn average prices at Kansas City, Chicago and Omaha cash markets which have averaged $2.46, $2.48 and $2.45, respectively. Number 3 yellow corn averaged $2.38 and $2.33 per bushel at Chicago and Minneapolis.

The base grain sorghum price of $2.30 per bushel ($4.11/cwt) was based on #2 yellow sorghum prices at Kansas City and Fort Worth which averaged $2.30 and $2.59 per bushel ($4.11 and $4.62 per cwt), respectively.

The base wheat price of $3.35 per bushel is based on average cash prices for Kansas City hard red winter, Chicago soft red winter, and St. Louis soft red winter -- $3.35, $3.08 and $3.03, respectively.

The study's base potato prices reflect the New York market, season average prices received by farmers and the judgements of potato market consultants. In terms of 1977 dollars, the average New York market price, over the period 1964 to 1976, was $6.22 per cwt. Comparable prices received by farmers in the U.S. averaged $4.13 per cwt. Potato industry contacts reported that in 1977, cull potatoes were readily available at $1.00 per cwt delivered to potato processing plants. Thus, this study's analyses used a delivered price of $1 per cwt ($20 per ton) for cull potatoes.

Sugar beet prices received by farmers in terms of 1977 dollars were found to average $25.72 per ton, excluding payments under the Sugar Act. Average Colorado beet molasses prices were $61.34 per ton or $0.36 per gallon in 1977 dollars.

Corn starch price data are not available. Previous analyses2/ performed by DPRA indicate that corn starch and corn value are interrelated: when corn is priced at $2.50 per bushel, the cost of starch will be $0.08 per pound.

1/ Davis, Leroy and Lowell Hall, "Spatial Price Differentials for Corn Among Illinois Country Elevators," American Journal of Agricultural Economics, Vol. 5, No. 1, February 1974

2/ Development Planning and Research Associates, Inc., Supplementary Economic Impact Analysis of the Wet Corn Milling Industry, U.S. Environmental Protection Agency, Contract No. 68-01-3855, Task 1, October 1977.

Table V-1. Base raw material and by-product prices in 1977 dollars.

Item	Price
Raw material	
Corn	$2.50/bu
Grain Sorghum	$2.30/bu
Wheat	$3.35/bu
Potatoes	$20/T
Sugar beets	$26/T
Beet molasses	$.36/gal
Starch	$.08/lb
By-product	
Corn distillers dried grain	$110/T
Sorghum distillers dried grain	$110/T
Wheat distillers dried grain	$110/T
Potato distillers by-product	$6/T
Sugar beet distillers by-product	$93/T
Molasses stillage	$15/T
Starch stillage	0
CO_2 (atm)	0

Source: See Appendix V-1 and V-2 for base data

2. By-product Prices

A distillers dried grain base price of $110 per ton for corn, sorghum, and wheat distillers dried grain was estimated (Table V-1). This price was based on the average prices for corn distillers dried grains at Cincinnati which ranged from $89.56 to $139.22 per ton and averaged $110 per ton in terms of 1977 dollars over the 1962-1976 period. Typically, distillers dried grain at Cincinnati trades in the range of 60-85 percent of soybean meal (44% protein) at Decatur. Distillers dried grains have a total protein content of about 27 percent which makes them a substitute high protein feed for certain livestock, principally beef and dairy cattle.

The following distillers dried grain price forecasting equation has been estimated by Wisner and Gidel (1977)1/:

$$DDG_p = 3,3325 - 0.022227\ (DDG_s) + 0.265566\ (SBM_p) + 0.148753\ (C_p) + 0.518949\ (EC_n)$$

$$(-3.21) \qquad (12.81) \qquad (2.92) \qquad (1.98)$$

where: DDG_p = Distillers dried grain price in dollars per ton at Cincinnati

DDG_s = U.S. distillers dried grains supply in thousands of tons

SBM_p = Price of 44% protein soybean meal in dollars per ton at Decatur

C_p = Corn price in cents per bushel

EC_n = Cattle numbers in five major European protein feed importing countries

This equation indicates an elastic demand for distillers dried grains: a given percentage increase in supply could be sold with a lesser percent decrease in price. The equation also shows a direct price relationship between distillers dried grain and 1) soybean meal, 2) corn prices, and 3) cattle numbers in five major European protein feed importing countries. It is important to note that the above statistically estimated price forecasting equation is based on historic data with distillers dried grain representing but a small fraction (less than 2 percent) of the high protein feed sources available in the U.S. If distillers dried production increased so that it represented a significant proportion of total high protein feeds available, then the demand-price relationship would become price inelastic: a large percentage price decrease would be required to clear the market. Under such conditions by-product credits to net ethanol production costs would decrease and the price and production of substitute feeds such as soybean meal would also decrease. The price impact of increased distillers dried grain production would depend largely on the extent and timing of an ethanol industry growth. The larger the industry, the greater the related price impacts. Price data were not found specifically for wheat and grain sorghum distillers dried grains. It may be possible that slight price differences can result when nutrient contents vary among the by-products of different raw material grains.

1/ Wisner, R.N. and J.O. Gidel, "Economic Aspects of Using Grain Alcohol as a Motor Fuel, With Emphasis on By-product Feed Markets." Iowa State University, Economic Report Series No. 9, Appendix IV, June 1977.

A distillers beet pulp or sugar beet distillers by-product price base of $93 per ton was estimated. Price determinations for beet pulp (molasses) were based on Los Angeles cash market prices and on informal interviews with sugar beet industry consultants. It is assumed that distillers and sugar processors beet pulp are of equal dollar value. Industry contacts suggest that Midwest sugar processor's beet pulp is contracted between beet processors and feeders. Prices received by processors are established at about 80-90 percent of the value of #2 corn or at about 100 percent of the value of grain sorghum. In terms of 1977 prices, this would range from about $4.25 to $4.75 per cwt or $85 to $95 per ton. Los Angeles beet pulp (molasses) ranged from $74 to $118 per ton and averaged $93 per ton over the period 1965-1975 (in 1977 dollars).

Major market potato pulp price quotes are not available. Processors interviewed indicated that prices in the neighborhood of $5 to $7 per ton (in terms of 1977 dollars) for 75 percent moisture potato pulp were reasonable. The lower protein content and higher moisture content of potato pulp cause its price per ton to be much lower than that for corn, wheat, sorghum distillers dried grains, or distillers sugar beet pulp.

Molasses stillage is not currently produced in the United States. However, in Europe, wet (75 percent moisture) molasses stillage is sold on a very localized basis (as is potato pulp). Based on protein content, molasses stillage might have a value in the vicinity of $15 to $20 per ton if produced.

Starch stillage was judged to be a plant effluent with no markets. Thus the by-product price for starch stillage was estimated to be zero. Exception may exist where local specialized demands for starch stillage constituents (e.g., spent yeast and unused sugar) exist.

Low pressure carbon dioxide was also determined to have no or very low value. Compressed carbon dioxide is of value as a gas in fire extinguishers and as a solid for dry ice. This value for dry ice will depend on special local conditions. Furthermore the value of CO_2 is marginal compared to compression costs. No by-product credit for carbon dioxide is, therefore, used in this study's analyses.

B. Net Raw Material Cost

Raw material costs and by-product credits for ethanol production resulting from the use of corn, wheat, grain sorghum, cull potatoes, sugar beets, starch and molasses were computed in terms of 1977 dollars. These estimates are based on (1) the raw material and by-product prices discussed above and (2) the conversion factors for ethanol production from these raw materials presented previously in Chapter IV. These data are summarized in Table V-2.

As shown in Table V-2 raw material costs per gallon of ethanol for the various scources are: corn, $.96; grain sorghum, $.88; wheat, $1.29; cull potatoes, $.69; sugar beets, $1.28; starch, $1.20; and molasses, $1.00.

Table V-2. Net raw material cost in 1977 dollars

Item	Units	Corn	Grain Sorghum	Wheat	Cull Potatoes	Sugar beets	Starch	Molasses
Raw material price	dollars	2.50/bu	2.30/bu	3.35/bu	20/T	26/T	.08/#	.36/gal
Conversion	gal ethanol	2.6/bu	2.6/bu	2.6/bu	28.8/T	20.3/T	.06	.4/gal
Unit raw material cost	$/gal ethanol	.96	.88	1.29	.69	1.28	1.20	1.00
By-product price	dollars	110/T	110/T	110/T	6/T[1/]	93/T	0	$15/T
Conversion	lbs by-product	16.8/bu	16.8/bu	20.7/bu	296#/T	264#/T		15.6/gal[1/]
Unit by-product credit	$/gal ethanol	.36	.36	.44	.03	.60	0	0.12
Net raw material cost	$/gal ethanol	.60	.52	.85	.66	.68	1.20	1.12

1/ Potato and potato distillers by-product @ 75 percent moisture.

Source: DPRA estimate

By-product credits per gallon of ethanol are derived from the various by-product prices and conversion rates as follows: corn, $.36; grain sorghum, $.36; wheat, $.44; cull potatoes, $.03; sugar beets, $.60; molasses, $12; and starch $0.00.

Net raw material costs (raw material cost less by-product credit) per gallon of ethanol are estimated as: corn, $.60; grain sorghum, $.52; wheat, $.85; cull potatoes, $.66; sugar beets, $.68; starch, $1.20; and molasses, $1.12. Grain sorghum has the least net raw material cost among these raw materials given the stated price levels and conversion ratios. In order of net raw material cost these raw materials are: grain sorghum, corn, cull potatoes, sugar beets, wheat molasses, and starch.

Combinations of grain types and grades ranging in price from $2 to $4.50 per bushel, in terms of 1977 dollars, and yielding distillers dried grains at approximately 16.8 pounds per bushel can be evaluated in the context of the net raw material cost sensitivity estimates shown in Table V-3. For example, if the cost of grain is $2.50 per bushel and the by-product price is $110 per ton, then the net grain material cost is $.60 per gallon of ethanol. And if, then, a mixture of grain grades were used whose average cost was $2 per bushel and whose ethanol and by-product yields were similar, the net raw material cost would decrease $.19 per gallon to $.41 per gallon of ethanol. Similarly, by-product price changes can be evaluated in terms of their affect on net raw material cost. By way of comparison, the value of ethanol for gasohol in terms of 1977 dollars was estimated to be $.41 per gallon of ethanol in Chapter II. In general, net raw material costs (excluding all other plant costs) exceed $.41 per gallon over most combinations of plausible grain and by-product prices.

C. Price and Availability of Sample Grade Raw Material Grains

Because lower grade, less expensive grains would improve the economic feasibility of ethanol production, sample grade grains have been suggested as relatively inexpensive raw material source for ethanol production. This study therefore determined the extent to which ethanol producers can depend on the availability of less expensive, low and sample grade raw materials by examining data related to raw material availability by grade, including two USDA survey results, one for grains and the other for potatoes in the Red River Valley, and by consulting with industry contacts.

1. Grains

The results of the USDA Federal Grain Inspection Service examinations of grain carloads two months following harvest are summarized in Table IV-4 for corn, hard red winter wheat and grain sorghum. According to these data, sample grade inspections vary considerably by year ranging from 4.1 to 11.1 percent of all inspections of corn, 0.8 to 1.7 percent for HRW wheat, and 2.8 to 13.3 percent for grain sorghum for the 1974-76 crop years.1/ Additional state data are

1/ U.S. Department of Agriculture, Federal Grain Inspection Service, 1976 Crop Quality Report, 1977.

Table V-3. Net grain cost 1/ (grain cost less by-product credit) per gallon of ethanol as a function of grain and distillers dried grain prices

Cost of grain ($/bu)	By-product credit ($/Ton DDG) 50	70	90	110	130
	($/gal)				
2.00	.61	.54	.48	.41	.35
2.50	.80	.73	.67	.60	.54
3.00	.99	.92	.86	.79	.73
3.50	1.19	1.12	1.06	.99	.93
4.00	1.38	1.31	1.25	1.18	1.12
4.50	1.57	1.50	1.44	1.37	1.31

1/ Based on 2.6 gallon ethanol and 16.8 lbs. distillers dried grain per bushel of grain.

Source: DPRA estimate

contained in Appendix V-3. Review of this data reveals considerable variation by location, condition often attributed to weather influences during harvesting, especially for fall harvested corn and sorghum.

Price data for grades below #3 corn including sample grade were not available but would generally be less than $2.30 per bushel. According to Dr. Floyd Niernberger, USDA Grain Marketing Research Center, Manhattan, Kansas,1/ the value and disposition of sample grade depends on its location, quantity and quality. Sample grade grain on farms is usually disposed of on the farm, generally by blending with livestock feed, or by blending with higher quality grain for the cash market. Low quality grain on farms generally results due to storage and in small quantities within a larger batch of grain.

After grain has entered marketing channels, it is handled according to the rules of the grain market exchange. Buyers may discount the price or refuse to accept out-of-position grain, grain that does not meet contract specifications when delivered. Some smaller brokerage firms find buyers for out-of-position grain. If no buyer is found the seller may have no alternative other than to discard the grain.

Generally, the availability of sample grade grain is too infrequent and geographically dispersed to provide a reliable raw material source. Further, grain marketing channels tend to blend batches of highly perishable, low quality grain with much larger volumes of higher-valued grain without losing the latter's higher grade. Such blending increases the market value of the lower quality grain and avoids the special separation costs in handling.

The perishability, randomness, and dispersion associated with the occurrence of sample grade grain lots and the tendency to blend small batches of it with higher grades result in little incentive to incur the special separation and transportation charges to channel low quality grain into ethanol production.

2. Potatoes

Potato stock quality information presented in Table V-5 is based on survey results reported by the USDA, Economics, Statistics, and Cooperative Service in the Red River Valley of North Dakota and Minnesota. Samples of process potatoes were selected in 1977-78 at harvest and again after storage. Based on all samples, the percent of culls at harvest ranged from 6-8 percent. Culls after storage ranged from 13-21 percent. Furthermore, communication with industry sources revealed that fields can be re-harvested for culls at a delivered price to a local processor for about $1 per cwt. On the basis of this information, the cost of cull potatoes was based at $1 per hundredweight.

1/ Personal communication, November 1977.

Table V-4. Percent of inspection receipts 2 months following harvest, all inspections.

CORN

	U. S. Grade							Special Grades and Classes			
	No 1	No 2	No 3	No 4	No 5	Sample grade	Total	Weevily	Yellow	White	Mixed
% 1976 crop year	5.6	34.4	26.7	18.0	11.2	4.1	100.0	0.9	99.0	0.9	0.1
% 1975 crop year	5.2	37.9	27.2	16.4	8.9	4.4	100.0	1.4	99.1	0.9	0.0
% 1974 crop year	3.2	23.0	27.2	21.5	14.0	11.1	100.0	1.6	99.4	0.6	0.0

Based on samples from Alabama, Illinois, Indiana, Iowa, Kansas, Kentucky, Maryland, Minnesota, Missouri, Nebraska, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia and Wisconsin.

HARD RED WINTER WHEAT

	U. S. Grades										Special Grades			Subclasses		
	No 1 heavy	No 1	No 2 heavy	No 2	No 3 heavy	No 3	No 4	No 5	Sample grade	Total	Tough	Weevily	Garlicky	Dark hard winter	Hard winter	Yellow hard winter
% 1976 crop year	25.3	29.3	6.7	26.3	1.1	6.4	1.9	1.3	1.7	100.0	13.0	0.2	0.0	15.2	58.4	26.4
% 1975 crop year	28.4	39.6	4.7	19.7	0.8	4.0	1.3	0.7	0.8	100.0	11.1	0.1	0.0	18.4	47.0	34.6
% 1974 crop year	26.3	18.8	12.7	29.7	1.5	7.1	2.0	0.9	1.0	100.0	3.6	0.1	0.0	5.2	93.1	1.7

Based on samples from California, Colorado, Idaho, Illinois, Kansas, Missouri, Montana, Nebraska, Oklahoma, Oregon, Texas, Utah and Washington.

SORGHUM

	U.S. Grade						Special Grades and Classes			
	No 1	No 2	No 3	No 4	Sample grade	Total	Weevily	Yellow	White	Other
% 1976 crop year	10.0	51.6	23.1	12.5	2.8	100.0	[illegible]	99.8	0.0	0.2
% 1975 crop year	9.5	55.3	21.7	10.6	2.9	100.0	0.4	99.9	0.0	0.1
% 1974 crop year	2.6	30.3	26.7	27.0	13.3	100.0	1.4	100.0	0.0	0.0

Based on samples from California, Colorado, Kansas, Missouri, Nebraska, Oklahoma and Texas.

Source: USDA Federal Grain Inspection Service, 1976 Crop Quality Reports, 1977.

Table V-5. Potato stocks quality survey, Red River Valley, 1977-78 average grade of potatoes

Type	No 1 including B's: At harvest	No 1 including B's: After storage	No 2: At harvest	No 2: After storage	Culls: At harvest	Culls: After storage	No 1 B's after storage 1/	Weight loss
	(%)							
			Samples recovered before April 1, 1978 2/					
White	87	75	7	11	6	14	6	5
Russet	86	76	6	11	8	13	7	4
			Samples recovered before April 1, 1977 2/					
White	86	65	8	14	6	21	9	5
Russet	84	71	9	11	7	18	6	4
			All samples 1976-77 storage season-final					
White	87	68	7	14	6	18	9	7
Russet	85	70	8	12	7	18	6	8

1/ No. 1 B's are potatoes that meet the U.S. No 1 grade but do not meet minimum size standards for the area: red and white varieties - 1½ - 2¼ inches in diameter and russet varieties - under 2 inches in diameter or less than 4 ounces.

2/ Matched samples, quality at harvest compared with quality after storage.

Source: Crop Reporting Board, ESCS, USDA, Potato Stocks April 11, 1978.

VI. ETHANOL: PLANT INVESTMENT AND OPERATING COSTS

This chapter presents estimates of ethanol production plant investment, raw material costs and other operating costs. These estimates provide the basic financial input to carry out the subsequent financial analysis of ethanol production. This chapter does not consider financial parameters such as depreciation policies, income taxes, capital sources, capital costs and related

A. Methodology

In accordance with the terms of reference for this study, cost estimates were synthesized from previously reported cost estimates and direct contacts with on-going ethanol plants. Most of the cost estimates to date have been for grain ethanol plants producing about 20 million gallons per annum; thus, the estimated costs for larger and smaller plants and non-grain ethanol plants were made with engineering estimating techniques. It should be recognized that estimates for grain ethanol plants below and above the 20 million gallon size are reconaissance grade estimates and that specific engineering studies should be undertaken to validate and refine these cost estimates. Cost estimates for non-grain ethanol plants were estimated in a similar fashion and are, therefore, subject to the same limitations.

All cost estimates were made on the basis of December, 1977 dollars. Engineering News Record indices and the GNP Implicit Deflator were used for converting to 1977 dollars.

B. Estimated Plant Investment

This section presents estimated investment requirements for ethanol plants. First, the investment and details of a 20 million gallon grain ethanol plant, 1/ representing the most commonly quoted plant are shown and discussed. Secondly, estimates for a range of grain ethanol plant sizes (10 million to 120 million gallons) are presented. These estimates are then compared with investment estimates made by other investigators. Finally, investment estimates are presented for non-grain ethanol plants.

1/ It was assumed that wheat would be restricted to 20 to 25 percent of the grain input due to the foaming problems associated with converting wheat to ethanol.

1. Estimated Investment for a 20 Million Gallon Grain Ethanol Plant

The investment cost of a 20 million gallon grain ethanol plant is $31.3 million or $1.56 per gallon of ethanol capacity. This estimate includes land, site preparation, buildings and equipment, but excludes working capital. Within these broad categories about 1 percent is for land, 7 percent for site preparation, 14 percent for buildings, and 78 percent for equipment (see Table VI-1). Thus, equipment represents the largest investment category for a grain ethanol plant.

To further illustrate the investment components of a grain ethanol plant the investment categories were subdivided into major components including plant site, office and laboratory, maintenance shop, steam plant, water system, alcohol plant, grain storage, feed drying and storage, and alcohol storage. As shown in Table VI-1, the major investment components are the steam plant, the alcohol plant, and the dehydrator feed drying and storage. These three components account for 81 percent of total investment.

A brief discussion of the investment components follows.

a. Plant Site

About 80 acres of land would be required for a 20 million gallon plant. The site would require preparation including grading, internal roads, railroad siding, effluent treatment ponds, lighting, fencing, and foundation grading for the buildings and equipment. Land was estimated at $3,125 per acre. Total site development was estimated at $2,150,000. It should be recognized that land values and site preparation costs will be location dependent and could vary up or down depending on the specific location of a plant.

b. Office and Laboratory

A separate office and laboratory building would be expected. This building would include the space and equipment for the administration, marketing, and technical functions of the company and the latter would encompass quality control, safety, health and environmental regulatory monitoring functions and the testing procedures imposed by the ATF Bureau of the U.S. Treasury. Building costs were estimated at $400,000 and equipment costs, at $80,000.

c. Maintenance Shop

A small maintenance headquarters and shop would be necessary to house and maintain the rolling stock, loaders, pumps, motors, valves and other equipment of the plant. The building was estimated at $100,000 and its equipment at $50,000.

Table VI-1. Estimated investment for 20 million gallon grain ethanol plant in 1977 dollars

Component	Investment category: Land	Site preparation	Building	Equipment	Total
	------------------------	------------------------	$000	------------------------	------------------------
Plant site	250	2,150			2,400
Office and laboratory			400	80	480
Maintenance shop			100	50	150
Steam plant			130	9,200	9,330
Water system			250	70	320
Alcohol plant			700	9,100	9,800
Grain storage			400	80	480
Feed drying and storage			120	6,000	6,120
Alcohol storage			2,200	20	2,220
Total	250	2,150	4,300	24,600	31,300

Source: DPRA estimate.

d. Steam Plant

The steam plant would be comprised of a boiler, cooling tower, generator water process equipment, and coal storage and handling. It was assumed that the boiler would generate high pressure steam to drive turbines for electricity generation and that the exhaust from this generation low pressure steam would be used for space heating and product processing. The building housing the boiler and boiler controls was estimated at $130,000 and the equipment at $9.2 million. If a different fuel source were used and/or electricity were purchased rather than generated, these costs would change; however, such would result, also, in different operating costs. Detailed engineering cost studies would be required to determine such specific costs.

e. Water System

The water system was assumed to include a well, pumps, motors, water tower, and piping to all water-use points for cooling and for processing water as well as for boiler water. Structures for the water system were estimated to cost $250,000 and equipment, $70,000. Water requirements were estimated at 2 million gallons per day. The actual investment would depend upon specific locations: for example, if water were purchased, investments would be reduced and operating costs would be increased.

f. Alcohol Plant

The producing unit's alcohol plant includes equipment for mash preparation, yeast propagation, fermentation, distillation, and dehydration of the alcohol. This component, representing one-third of total investment was estimated at $700,000 for the building and related items and $9,100,000 for process equipment.

g. Grain Storage

Equipment and space for up to thirty days of grain storage was assumed. In-plant storage of two-thirds of the grain is provided; one-third is stored outside. The loading, unloading, weighing, and conveying equipment was estimated at $80,000 and the structure at $400,000.

h. Feed Drying and Storage

The drying of the distilled dried grains with solubles on a continuous basis and the storing or directly loading the production trucks or rail cars will require an estimated $6,120,000 total investment. Of this total $120,000 is designated for building and $6,000,000 for equipment.

i. Alcohol Storage

It was assumed that ethanol storage equal to thirty days production (approximately 1,667,000 gallons) would be required on the plant site. The storage security, and denaturing facilities were estimated at $2,200,000 for storage and buildings and $20,000 for equipment.

2. Estimated Investment by Size of Grain Ethanol Plant

As previously noted, the 20 million gallon plant is the common reported size. To estimate the investment requirements for other plant sizes, the estimating function

$$\frac{\text{Investment A}}{\text{Investment B}} = \left[\frac{\text{Size A}}{\text{Size B}}\right]^{N}$$

was utilized. The important variable is the scaling factor, N, which reflects economies of size. An examination of the few investment estimates of plants other than 20 million gallons, direct industry contacts, and a literature review 1/ yielded a scale factor of 0.71.

Utilizing the estimate for the 20 million gallon plant, investment estimates were calculated for a range of plants from 10 million gallons to 120 million gallons using the above expression. The estimates of investment are shown in Figure VI-1. A 10 million gallon plant was estimated to have a per gallon investment of $1.91. This compares with the $1.56 per gallon for the 20 million gallon plant. For the 120 million gallon size plant, a per gallon investment of $.93 was estimated.

Figure VI-1 demonstrates the expected economies of size reflected in the estimating equation; however, few engineering cost studies, particularly of larger plants, are available. Engineering studies should be done to refine and confirm these estimates.

3. Comparison of Grain Ethanol Plant Investment Estimates

Five original sources of investment estimates for grain ethanol plants are available. Since they were estimated at differing times, it was necessary to convert them to 1977 dollars for comparison purposes. DPRA estimates of investment are lower than those made by Cray, Miller and Indiana and higher than those of Stone and Webster and Scheller (Table VI-2). The Stone and Webster report notes that its investment costs are "Order of Magnitude" estimates and are subject to a variation of ±30 percent. None of the other studies specifically identify an investment cost range.

The contractor has relied to a great degree on industry consultants who reviewed all of the cost studies and also on its own estimates. Furthermore, the DPRA estimate is reconnaissance level estimate of ±25 percent.

4. Estimated Investment for Non-grain Ethanol Plants

Although few investment estimate data are available for non-grain ethanol plants, data for comparable industry processes are applicable. Certain components of the non-grain ethanol system are similar to those for grain

1/ Popper, Herbert. Modern Cost Engineering Techniques, New York: McGraw-Hill, 1970.

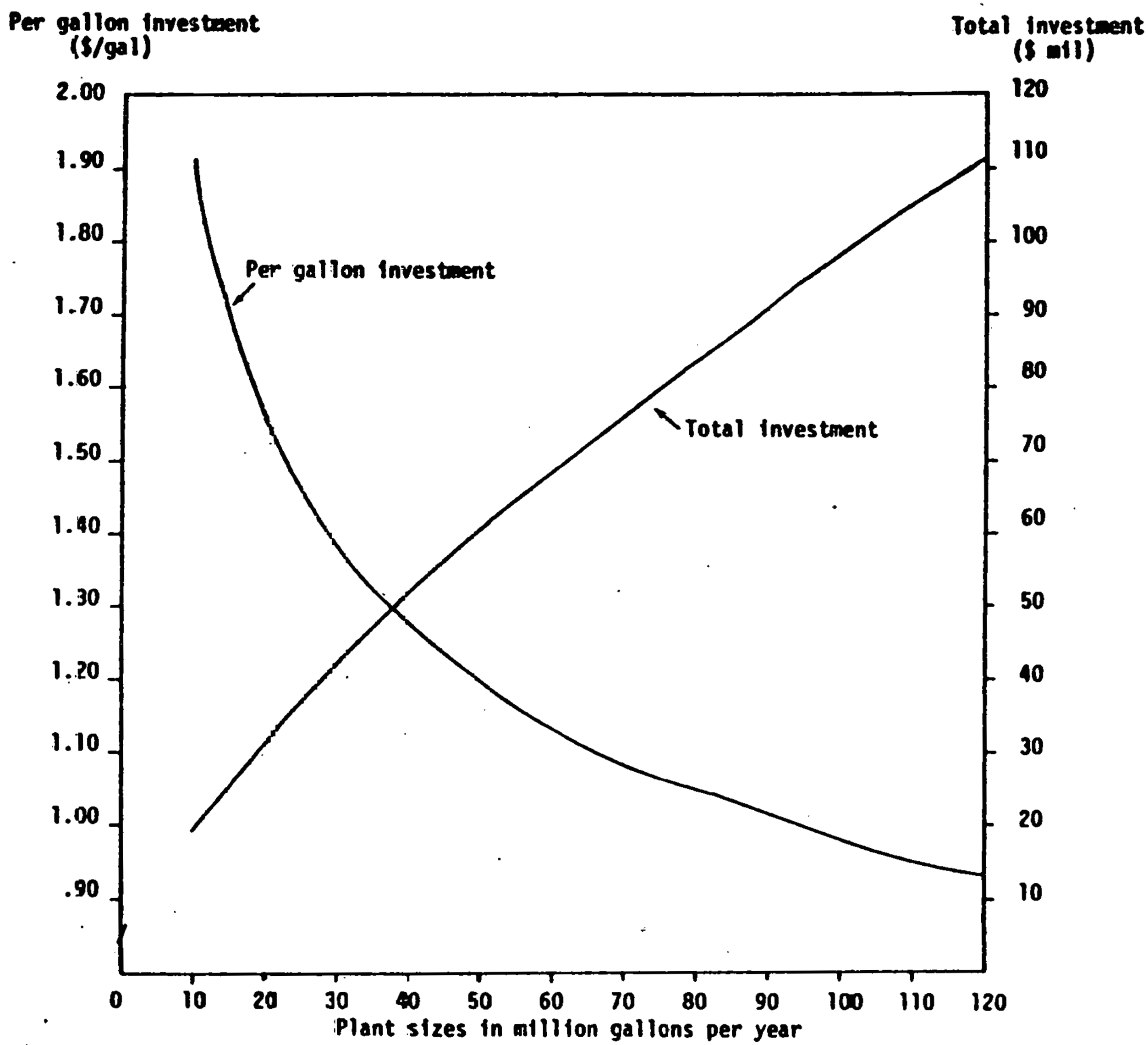

Figure VI-1. Estimated investment for grain ethanol plants by size of plant

Table VI-2. Comparison of per gallon investment for grain ethanol plants in 1977 dollars

Plant size (million gallon per year)	Source	Reported estimate ($/gal)	DPRA ($/gal)
15	Cray 1/	2.23	1.70
16.3	Miller 2/	1.80	1.66
19	Indiana 3/	1.67	1.58
20	Stone and Webster 4/	1.24	1.56
20	Scheller 5/	1.35*	1.56
35	Scheller 5/	1.11*	1.33
70	Scheller 5/	.88*	1.08
100	Scheller 5/	.75*	.98

*Includes working capital

Source: Derived by DPRA and adjusted to December 1977 dollars. See Appendix VI-1 for original data.

1/ Cray, Cloud L., Jr. Midwest Solvents Corporation, Gasohol Seminar, Rio de Janerio, Brazil, September 1977.

2/ Miller, Dwight L. "Fuel Alcohol from Wheat," Proceedings of Seventh National Conference on Wheat Utilization Research, USDA, ARS, 1972.

3/ Corcoran, W. P., A. T. Brackett and F. Lindsey. Indiana Grain Fermentation Alcohol Plant, Indianapolis Center for Advanced Research, 1976.

4/ Stone and Webster Engineering Corporation. "Preliminary Economic Evaluation of Nebraska Grain Alcohol Plant," Agricultural Products Industrial Utilization Committee, State of Nebraska, December 1976.

5/ Scheller, William A. "Cost of Producing Grain Alcohol," Working paper, undated.

ethanol. In other instances, certain front-end processing equipment in non-grain ethanol plants is similar to that used in plants processing the same raw materials into different products, i.e., sugar beets into beet sugar. Thus, estimates for these different procedures can provide estimation data.

In determining a reasonable plant size, it was assumed that the size of potato and sugar beet ethanol plants would be similar to that for existing plants processing these raw materials. A starch and beet molasses plant of 10 million gallons was, therefore, assumed representative.

a. Potato Ethanol Plant

A 7.2 million gallon potato ethanol plant was estimated. This plant would require 250,000 tons of potatoes per year, a requirement equivalent to that for a very large plant currently processing potatoes in frozen potato products. 1/ It was assumed that storage and front end processing components of a current frozen potato plant would be similar to the requirements for a potato ethanol plant. The fermentation requirements would be similar to those for grain ethanol production; thus, these cost relationships were used.

Based on this approach, it was estimated that investment would be $27.4 million (Table VI-3). The factory yard and potato storage would be a significant component, representing 30 percent of the total.

Currently operating plants might be converted to fermentation production at a lower cost considering the lower value of sunk investment; however, such conversions would occur on a plant by plant basis and would require specific conversion studies.

b. Sugar Beet Ethanol Plant

A sugar beet ethanol plant would combine the front-end processing and storage characteristics of a sugar beet processing plant with the fermentation and distillation processing of an alcohol plant. The plant size chosen, 4,000 tons of beets sliced per day, represents a large beet plant in the Colorado, Nebraska, and Kansas area and would produce 9.7 millions of ethanol annually. 2/

Because sugar beets have a short processing season (120 days), plant economics would require the double processing of some raw juices into storage and some into production. The raw juices for storage would be concentrated to 90 percent, cooled, later diluted, and fermented for ethanol production.

1/ DPRA, Economic Impact of Water Pollution Controls on Selected Food Vegetable Industries. Vol. IV, The Fruits and Vegetable Industry. National Commission on Water Quality, Washington, D.C., November 1975.

2/ DPRA, Economic Impact of Proposed Effluent Limitation Guidelines on Beet Sugar Industry, Environmental Protection Agency, Washington, D.C. August 1973.

Table VI-3. Estimated investment for a 7.2 million gallon potato ethanol plant in 1977 dollars

Component	Land	Site preparation	Building	Equipment	Total
	Category				
	($000)				
Factory yard and potato storage	400	500	3,000	4,000	7,900
Office, laboratory and maintenance			400	100	500
Steam and processing plant			5,500	12,600	18,100
Alcohol storage	___	___	800	100	900
Total	400	500	9,700	16,800	27,400

Source: DPRA estimate

Taking these characteristics and factors into account, it was estimated that a 9.7 million gallon sugar beet ethanol plant would require an investment of $34.7 million (Table VI-4). Of this total, 40 percent of the investment would be for factory yard and remote station handling and storage.

This estimate assumes new investment. Considering the likelihood of sugar beet plant closures, it may be possible to convert an old plant and utilize inplace facilities. This would require specific plant by plant engineering and cost studies.

c. Starch Ethanol Plant

The starch ethanol plant was sized at 10 million gallons per year. It was assumed that this plant would be located adjacent to an existing corn wet milling or wheat wet milling plant. The estimated investment for a starch ethanol plant is $11 million (Table VI-5) assuming a separate, stand-alone plant. If the fermentation and distillation functions were added to an existing starch processing plant, certain duplicated facilities could be eliminated and the investment could be reduced to $8,579,000.

In a starch plant, since all raw material is hydrolyzed into sugar and fermented, no residue pulp is dried. The non-alcohol effluent from the beer still would require waste treatment facilities either on site or by connection to a municipal treatment plant.

d. Beet Molasses Ethanol Plant

A 10 million gallon beet molasses ethanol plant was estimated and it differs from a beet plant by requiring less investment for raw material storage and for preparation equipment. No investment costs for residue pulp drying facilities are required.

On a stand alone basis, it is estimated that investment would be $11.4 (Table VI-6). If this unit could be integrated with a beet sugar plant, the elimination of duplicate facilities would reduce the estimated cost to $9.2 million.

5. Comparison of Investment by Type of Plant

A comparison of the estimated investment by type of plant indicates that the investment per gallon for starch and molasses plants is lower than that for grain plants: $1.09 - $1.14 vs $1.89 per gallon for grain plants. Potato and sugar beet plants at $3.80 and $3.58 per gallon respectively are significantly greater in cost than are grain plants (Table VI-7).

Table VI-4. Estimated investment for a 9.7 million gallon sugar beet ethanol plant in 1977 dollars

Component	Category				
	Land	Site preparation	Building	Equipment	Total
	($000)				
Factory yard	400	1,000	2,000	6,000	9,400
Remote stations	600			4,000	4,600
Office, laboratory and maintenance			400	100	500
Processing plant			5,500	12,600	18,100
Juice storage			800	100	900
Alcohol storage			1,100	100	1,200
Total	1,000	1,000	9,800	22,900	34,700

Source: DPRA estimate

Table VI-5. Estimated investment for a 10 million gallon starch ethanol plant in 1977 dollars

Component	Land	Site preparation	Building	Equipment	Total
	($000)				
Plant site	140	1,000			1,140
Starch storage			140	50	190
Office and laboratory			300	60	360
Maintenance shop			60	40	100
Steam plant			80	3,000	3,080
Water system			90	20	110
Alcohol plant			300	4,000	4,300
Effluent treatment				500	500
Alcohol storage			1,200	20	1,220
Total	140	1,000	2,170	7,690	11,000

Source: DPRA estimate

Table VI-6. Estimated investment for a 10 million gallon beet molasses ethanol plant in 1977 dollars

Component	Category				
	Land	Site preparation	Building	Equipment	Total
	($000)				
Land	140	1,000			1,140
Storage - raw material			500	90	590
Office and laboratory			300	60	360
Maintenance shop			60	40	100
Water system			90	20	110
Steam plant			80	3,000	3,080
Alcohol plant			300	4,000	4,300
Effluent treatment				500	500
Alcohol storage			1,200	20	1,220
Total	140	1,000	2,530	7,730	11,400

Source: DPRA estimate

Table VI-7. Comparative investment for ethanol plants by type of raw material in 1977 dollars

	Units	Grain	Potatoes	Sugarbeets	Starch	Molasses
Annual production	(mil gal)	10.0	7.2	9.7	10.0	10.0
Investment						
Land	($1,000)	200	400	1,000	140	140
Site	($1,000)	1,600	500	1,000	1,000	1,000
Building	($1,000)	2,300	9,700	9,800	2,170	2,530
Equipment	($1,000)	14,800	16,800	22,900	7,690	7,730
Total	($1,000)	18,900	27,400	34,700	11,000	11,400
Investment per gallon	($/gal)	1.89	3.80	3.58	1.09	1.14

Source: DPRA estimate

C. Estimated Operating Costs

Section C presents the estimated operating costs for ethanol plants. As was true for investment costs, most of the existing estimates are for 20 million gallon per year grain ethanol plants. Estimates for this study were first made for the 20 million gallon per year ethanol plant and then modified for the other plant sizes. Estimates for the non-grain ethanol plants were made from a combination of the applicable operating costs of existing plants and from the fermentation costs as developed (and adjusted) for the grain ethanol plants.

Operating costs include direct and indirect costs. Direct costs include fuel, labor and other supplies. Indirect costs include plant overhead, administration and marketing. Costs such as income taxes, depreciation, and interest are excluded from this discussion and are considered in the subsequent financial analysis.

1. Estimated Operating Costs for Grain Ethanol Plants

The operating costs of seven sizes of grain ethanol plants ranging from 10 million gallons per year to 120 million gallons per year are shown in Table VI-8. These costs are displayed in detail for both direct and indirect costs.

a. Direct Costs

The direct costs are estimated for fuel, labor and other costs exclusive of raw material costs. Raw material costs are major and were discussed in Chapter V.

1. Fuel - It was assumed that coal would be the primary source of energy. The fuel costs are based on Western type coal with a caloric content of 10,500 Btu per pound and a delivered price at the plant of $30 per ton. Coal with this heat content and this price results in a unit fuel cost of $1.43 per million Btu. From the previously described energy balance (Chapter IV), an energy equivalent of 131,000 Btu per gallon of ethanol was estimated for grain ethanol production. This converts to cost-per-gallon of ethanol of $.187. The type of processing (batch) used for costing is not expected to have economies of size in unit fuel costs; thus, the unit fuel cost was assumed to be the same for all sizes of grain ethanol plants.

2. Labor - Although ethanol plants are capital intensive, they have significant labor costs. To estimate costs, a direct labor budget was prepared for a 10, 20, and 40 million gallon plant. It was assumed that these plants would operate on a near-continuous basis of 330 days per year and would require three regular shifts and one swing shift to maintain an average 40 hour work week per employee. A base wage rate of $7 per hour was considered to be a representative rate as of December, 1977 (based on current wage scales

Table VI-8. Estimated operating costs for grain ethanol production by size of plant in 1977 dollars

Cost	Plant size (mil gal per year) 10	20	40	60	80	100	120
	($/gal)						
Direct costs							
Fuel	.187	.187	.187	.187	.187	.187	.187
Labor	.091	.057	.043	.038	.035	.033	.032
Other	.008	.008	.008	.008	.008	.008	.008
Total	.286	.252	.238	.233	.230	.228	.227
Indirect							
Plant overhead	.086	.063	.048	.044	.042	.040	.039
Administration	.042	.030	.022	.020	.019	.018	.018
Marketing	.024	.018	.014	.013	.012	.012	.011
Total	.152	.111	.084	.077	.073	.070	.068
Total direct and indirect	.438	.363	.322	.310	.303	.298	.295

Source: DPRA estimate.

of similar industries) and a similarly representative shift differential of $.50 per hour is also included. A 25 percent fringe benefit package was added to the base wage rate.

Based on the direct labor budget, the estimated direct labor costs of $.091, $.057 and $.043 per gallon of ethanol were estimated for the 10, 20 and 40 million gallon plant, respectively (Appendix VI-2). As shown, economies of size are present for direct labor. These relationships were used to establish a direct labor cost function which was used to estimate the direct labor costs for the larger plants. For example, the per gallon direct labor cost for a 120 million gallon plant was estimated to be $.032. It is noted that this estimate should be considered as a reconnaissance grade estimate and that detailed engineering studies are required to refine and validate these cost estimates, particularly for the larger plant sizes.

3. Other - The costs of chemicals and other supplies directly associated with ethanol production were based on estimates for a 20 million gallon plant. It was assumed that the per gallon cost would be constant for all plant sizes. The estimate of other direct costs was $.008 per gallon ($160,000 per year for a 20 million gallon plant).

b. Indirect Costs

1. Plant overhead - The largest cost element of plant overhead is that for indirect labor which includes plant supervisors, maintenance personnel, technicians and other support employees for plant operation. To estimate indirect labor, indirect labor budgets were prepared for the 10, 20, and 40 million gallon plant sizes. Wage rates used were representative of similar positions in comparable processing industries. A 25 percent fringe benefit package was added to the base wage rate.

Based on the indirect budgets, per gallon costs of $.058, $.040 and $.031 were estimated for the 10, 20 and 40 million gallon plants respectively (Appendix VI-3). This relationship was converted to a cost function which was extended to estimate indirect labor costs for the larger plant sizes. This resulted in an estimated cost for indirect labor of $.024 for 120 million gallon plant.

The other elements of plant overhead are repairs, maintenance, insurance, general supplies and related items. Those costs were estimated at $.028, $.023 and $.018 per gallon for the 10, 20, and 40 million gallon plants respectively. For the 120 million gallon plant, the other indirect costs were estimated at $.015 per gallon.

2. Administration - Administrative costs include company management, supporting staff, property taxes, office supplies, legal and professional fees, and communications. The labor component was estimated with labor budgets as previously described for direct and indirect plant overhead labor (Appendix VI-4).

The labor component was estimated at $.011, $.007 and $.005 per gallon for the 10, 20, and 40 million. By determining a function of these labor costs, a cost of $.004 was estimated for the 120 million gallon plant.

3. Marketing - Marketing costs are those for the selling and distributing of the products of the ethanol plant (ethanol and distillers dried grains) to a wide variety of customers. These costs cover the marketing payroll, office expenses, and promotion and advertising costs. The labor costs of marketing were estimated as previously described and are detailed in Appendix VI-5. These labor costs on a per gallon basis for the 10, 20, and 40 million gallon plants are $.011, $.009 and $.006 respectively. For the largest plant, 120 million gallons, the cost is $.00- per gallon.

The expenses for travel, communication, promotion and office expense make up the other marketing costs which are included in total marketing costs in Table VI-9.

c. Comparison of DPRA Estimates with Reported Estimates

As indicated under the discussion of investment costs, independent cost estimates are available. Unfortunately, however, the estimates have not been made on a consistent basis in assigning direct and indirect expenses. Based on the contractor's review of these studies, it was concluded that direct costs, fuel, labor, and other direct expenses were most readily comparable although not precisely. The reported direct costs were adjusted to 1977 dollars for comparison purposes.

As shown in Table VI-9, the contractor's estimate is higher than Miller's and lower than the other estimates. Scheller 1/ estimated direct and indirect conversion costs at $.32 (1977 dollars) per gallon compared to DPRA's $.25 estimate. The Indiana study 2/ estimated indirect costs at $.118 per gallon. This compares to the DPRA estimate of $.111 per gallon. The total direct and indirect costs in the Indiana study were $.389 (in 1977 dollars) per gallon compared to DPRA's estimate of $.363 per gallon.

The various differences in cost assignment and formats make comparisons difficult. However, it is the contractor's judgment that their estimated operating costs are reasonable and comparable to other estimates.

2. Estimated Operating Costs of Non-Grain Ethanol Plants

Operating costs for non-grain ethanol plants were estimated by synthesizing the applicable costs from existing processing plants with the costs estimated for the applicable ethanol components.

1/ Scheller, William A. "Cost of Producing Grain Alcohol," Working paper, undated.

2/ Corcoran, W. P., A. T. Brackett and F. Lindsey. Indiana Grain Fermentation Alcohol Plant, Indianapolis Center for Advanced Research, 1976.

Table VI-9. Comparison of estimated direct and indirect operating costs in 1977 dollars

Plant size	Source	Reported estimated	DPRA
(mil gal per year)		($/gal)	($/gal)
15	Midwest Solvents	.315	.264
16.7	Miller	.230	.259
19	Indiana	.271	.252
20	Stone & Webster	.304	.252

Source: See Appendix Table VI-6 for original data.

a. Potato Ethanol Plant Operating Costs

The operating costs of a potato ethanol plant are similar to those costs described for the grain ethanol plant with two exceptions. Fuel costs are higher due to the lower alcohol yields of potatoes and more water to be removed from ethanol. Too, more energy is required for potato storage. Offsetting some of the energy increase is the savings due to not drying potato pulp. Marketing costs are less for potato plants because of the limited values and local market for wet pulp.

b. Sugar Beet Ethanol Plant Operating Costs

Operating costs for sugar beet ethanol plants are not significantly different from those for grain or potato plants. A higher fuel cost is estimated for beet plants than for grain plants because of double processing of the thick storage juices. Marketing costs are estimated to be somewhat lower for beet plants than for grain plants.

c. Starch and Molasses Ethanol Plant Operating Costs

Plants processing either starch or molasses have significantly lower operating costs than do grain plants. There may be a slight cost advantage to a molasses plant compared to a starch plant, but no data delineating this difference were found. The contractor believes the cost differential is minimal and, therefore, both plants were estimated to have the same costs. Starch and molasses plants have lower costs for labor, fuel, and all indirect costs than do grain plants.

d. Comparative Ethanol Plant Operating Costs by Raw Material

Table VI-10 compares different operating costs for different raw material types. Clearly, the starch or molasses ethanol plants have the lowest direct and indirect costs. Because the costs shown are costs per gallon, the reader should be cautioned that the plants compared are not identical size plants and some differences are due to economies of scale rather than to raw material characteristics only.

The real effect of raw material costs will be more apparent in the following Financial Analysis (Chapter VII) where raw material costs and capital recovery costs are fully evaluated and the effect of by-product credit for each plant is shown.

Table VI-10. Comparative ethanol plant operating costs by raw material

Raw material	Unit	Grain	Potatoes	Sugar beets	Starch or molasses
Annual production	(mil gal)	10	7.2	9.7	10
Direct costs					
Labor	($/gal)	.091	.071	.066	.066
Fuel and energy	($/gal)	.187	.245	.233	.127
Other	($/gal)	.008	.008	.009	.005
Total	($/gal)	.286	.324	.308	.198
Indirect costs					
Plant overhead	($/gal)	.086	.096	.089	.064
Administration	($/gal)	.042	.047	.044	.031
Marketing	($/gal)	.024	.013	.012	.009
Total	($/gal)	.152	.156	.145	.104
Total	($/gal)	.438	.480	.453	.302

Source: DPRA estimate

VII. FINANCIAL ANALYSIS OF ETHANOL PRODUCTION

This chapter presents the financial analysis of ethanol production. The analysis brings together the data and information on competitive ethanol prices, raw material prices, by-product prices, plant investment and operating cost estimates presented in the preceding chapters and the various additional financial elements--cost of capital, income tax, working capital, sustaining capital, inflation--needed to undertake the financial analysis.

The focus of this analysis, in line with the Terms of Reference, is from the point of view of the firm, that is, investors will make investment decisions that will increase their wealth.

A. Methodology

A typical investment will require an initial capital outlay or perhaps investment outlays over a multiple year construction period. These investment outlays will typically return cash at one or more times in the future. There is a time value associated with money in that $1 received today is not worth the $1 received one or more years from now due to the interest that can be earned on money invested today.

Thus a method is needed to compare cash flows occurring at different times. The common approach to this is discounted cash flow analysis. 1/ This procedure converts all cash flows to a lump sum occurring at a single point in time. The present time is the most frequently used point, thus future cash flows are discounted to present value.

The suitable discount rate to be used is the "cost of capital" for the firm (investors), that is the foregone opportunity of future cash benefits, had the firm invested in a alternative venture. If the project cannot produce discounted returns greater than its capital costs, it will be unattractive to the firm. Put another way, the discounted returns must exceed the capital costs if the investors wealth is to be increased.

In general, the decision rule is that an investment will be attractive to the investor if the expected return, discounted at the cost of capital, exceeds the investment cost, also discounted at the cost of capital. Another way of expressing the feasibility criteria is:

1/ Other methods of evaluating investment proposals are used although they are considered inferior since they do not consider the timing of the cash flows. These methods include accounting rate of return, payback method and other techniques.

(Total present value of future cash flows) -

(Total present value of investment) $\geq$ 0

The difference between the sum of the discounted future cash flows (benefits) and the sum of the discounted investment costs is commonly called the "net present value." Thus the feasibility criteria can also be referred to as

Net present value $\geq$ 0

In more specific terms the general discounted cash flow model can be expressed as

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+R)^t} - I_0$$

where

C_t = the expected projected cash flow in year t

I_0 = the investment (assumed to be made at t = o)

T = the economic lifetime of the project

R = the cost of capital

Obviously the above expression is highly simplified and many elements are included and the timing patterns of cash flow and investment are in practice complex. The following discussion briefly describes the elements.

1. Cost of Capital

One of the key factors is the cost of capital (discount rate). Two primary approaches may be used--(1) the weighted cost of capital which combines both the cost of debt and equity into one weighted cost and (2) the cost of equity. When properly done both approaches lead to the same decision. For this study the cost of equity approach was used.

The cost of capital concept is a complex one involving the real cost of capital, inflation premium and risk premiums. For purposes of this study a nominal cost of equity of 15 percent was used as a base. This relatively high value was used, to reflect a risk premium that would be associated with new investment areas such as fuel grade ethanol. It is noted that indeed investors may require a higher return due to their perception of risk associated with ethanol production. On the other hand, if the risk could be reduced, the cost of equity might be lower. To examine these possibilities, sensitivity analyses of the cost of equity were examined.

2. Operating Cash Flow

Operating cash flows, under the cost of equity approach, are defined as revenues less raw material expense, operating and maintenance expense, interest expense, income taxes, principal payment. Noncash items such as depreciation and amortization are exluded, except as they affect income taxes.

The computation of income taxes are complex with the many convention types such as depreciation, carryforward and carryback provisions, investment credit provisions and other tax provisions. It is also noted that direct incentives such as direct subsidy payments would also be included in the cash flow.

3. Investment

Investment outlays include those costs required to construct the plant. For purposes of DCF analysis, these costs are taken in the year they are expected to be incurred. For large projects such ethanol plants, construction will normally occur over three or more years. A three year construction period was assumed in the following analyses with approximately one-third of the investment (in constant 1977 dollars) being incurred in each year.

Since the plant may have some value at the end of the analysis period, (items such as land, buildings), terminal value is often taken in the last year of the analysis. This value is essentially a negative investment and thus offsets initial investment. However, this value is discounted, thus in present value terms,its worth is less than the initial outlays for these items.

Since the equity approach was used, debt proceeds were taken as cash inflows. 1/ Thus the investment outlays represent only the equity portion.

a. Net Working Capital

In addition to the basic investment outlays for plant, a net working capital will also be required to finance on-going operations. Working capital will vary depending upon inventory prices, accounts payable and receivable maturities. For this analysis, working capital was estimated as a function of annual raw material throughput and revenues from distillers dried grain. For example, the working capital for grain plants was estimated as 16 percent of distillers by-product revenues plus $.43 per bushel of grain. For example, the working capital investment was estimated at $5.0 million for 20 million gallon ethanol plant and $25.8 million (1977 dollars) for a 100 million gallon plant under base conditions of $2.50 per bushel of grain and $110 per ton DDG. This investment was assumed to be made during the year the plant was placed in service which corresponds to the fourth year, following the three year construction period.

1/ Principal repayment and interest charges are cash outflow elements of the operating cash flow.

b. Sustaining Capital

Sustaining capital (sometimes called replacement capital) encompasses all outlays required to maintain the plant and excludes outlays for plant betterments, modernization and expansion. These outlays were assumed to begin in the sixth year following the placing of the plant in services. The annual outlay was estimated at 2.2 percent of the building investment and 5.9 percent of equipment investment. For purposes of income tax computations, sustaining capital was divided into an expense portion and depreciable portion. This division was based on IRS tax guidelines.

4. Inflation

Another important factor, not previously mentioned, is inflation. Inflation increases items such as investment revenues and operating expenses. For purposes of this analysis, costs were estimated in 1977 dollars. Those estimates were then inflated over time, so that the analysis was done using nominal dollars. Because inflation would not increase fixed interest, principal repayments and depreciation charges, these cost elements were not inflated.

5. Display of Results

With inflation, prices and costs will vary each year of the analysis. In order to facilitate presentation and understanding of the results, the nominal prices and costs were converted back to real terms ($1977) and assuming a constant real price. 1/

Traditionally, net present value or the present values of components of the net present value are reported in total lump sums for the period of analysis. Again, to facilitate display and understanding, the results were converted to equivalent costs per gallon of ethanol.

For purpose of display, in this chapter, certain cost items were aggregated from those shown in Chapter VI. Direct costs are shown as energy and other direct costs. Indirect costs are displayed as one item. The aggregate per gallon values will agree with those shown in Chapter VI subject to rounding error.

For purposes of this report, interest expense, principal repayment, return on equity capital and return on equity capital and income taxes were aggregated to one value called "capital recovery." (Appendix VII-1 contains the breakdown of capital recovery for selected situations.) Raw material costs and by-product credits per gallon were simply the prices of the items in bushels, tons, etc. times the appropriate conversion factors.

1/ This assumption is not considered to be restrictive in that average real present value price (cost) produced by discounted cash flow analysis is equivalent under a variety of assumptions regarding prices and inflation combinations.

6. Computation

Because of the numerous computations involved in discounted cash flow analysis and the variety of financial questions of interest, the above described DCF model was programmed on a computer. While the actual model was somewhat more complex than the brief description given herein, the underlying principals are pertinent.

It is noted that much of the complexity involves computation of income taxes and that an interative procedure was developed so that an ethanol price, f.o.b. plant, that would make the NPV equal to zero including tax effects, could be solved for. This iterative procedure also was used to investigate various incentives.

While the results are reported as production costs, it should be recognized that if the ethanol plant could realize a price equal to the production cost, the investor could retire the debt, recover his investment and realize a return on equity equal to the stated cost of equity capital. In other words, the stated production cost may be viewed as a full cost.

B. Analyses Performed

A number of financial analyses were performed to test the impact of different raw material prices by product prices, energy costs, leverage and debt costs, various tax incentives, various investment estimates and various direct payment and grant schemes.

1. Plants Analyzed

Eleven different plant configurations were analyzed as follows:

Plant type	Size (mil gal ethanol/yr)
. grain (corn, wheat, or sorghum)	10 to 120
. sugar beet	9.7
. potato	7.2
. starch	10
. molasses (beet)	10

The reader is referred to Chapter VI for a detailed description of these plant configurations.

2. Bases of Analyses

In order to place the various analyses in perspective, a set of base cases were established. These base cases were based on the contractors approximation of representative prices and costs and conventional financing terms. In addition, a number of other assumptions (depreciation method, types of loans, etc.) were inputed into the financial model. These base parameters are summarized in Table VII-1.

As a point of reference, key base parameters are $2.50 per bushel grain price, $110 per ton distillers dried grain price, 15 percent cost of equity, 10 percent interest rate, 30 percent debt financing and 6 percent annual inflation rate. For all analyses, a 20 year direct reduction loan and sum of the year digit depreciation were assumed. Interim construction financing in proportion to the yearly investment outlays was assumed for all cases involving debt financing.

To determine the impact of 10 kay variables, sensitivity analyses were performed. These analyses were done on the 20 and 100 MGY grain plant. In each sensitivity analysis, only one or two parameters were varied. All other variables were held constant.

In addition to the sensitivity analyses, various types of incentives (direct payments, construction grants and fuel tax exemptions) were examined.

C. Base Condition Results

Total costs of ethanol production assuming the required 15 percent return on equity investment and income tax effects were estimated for grain plants ranging from 10 to 120 million gallons annual throughput and for non-grain ethanol plants of approximately 10 million gallons annual throughput. Comparison of estimated ethanol production costs under a business as usual situation with the ethanol selling price, indicates that production costs are about three to five times greater. Also, cost comparisons among types of plants show that grain ethanol plants are generally lower cost.

1. Feasibility under Base Conditions

Total estimated production of ethanol under baseline conditions ranged from a low of 1.16 per gallon of ethanol (Table VII-2) for a 120 million gallon grain plant to a high of $2.02 per gallon (Table VII-3) of ethanol for a potato ethanol plant. As developed in Chapter II, ethanol for blending with regular non-leaded gasoline would have to be priced for about $.41 per gallon to make gasohol competitive with gasoline. Under these cost relationships,

Table VII-1. Description of parameters used in analyses

Item	Unit	Base	Sensitivity values					
Inflation rate	pct	6						
Cost of equity	pct	15	10	15	20			
Interest rate 1/	pct	10	5	7	9	10	11	
Debt ratio	pct	30	30	50	70	90		
Loan type	--	Direct reduction						
Loan term	years	20						
Depreciation method	--	Sum of years digit						
Income tax rate	pct	50						
Investment tax credit								
(Percent of qualified investment)	pct	10	30	50				
Limit percent of tax liability	pct	0	50	100				
Grain price	$/bu	2.50	2.00	2.50	3.00	3.50	4.00	4.50
Distillers dried grain price	$/ton	110.00	50.00	70.00	90.00	110.00	130.00	150.00
Sugar beet price	$/ton	26.00						
Distillers dried beet pulp price	$/ton	93.00						
Potato price	$/ton	20.00						
Distillers potato pulp price	$/ton	6.00						
Starch price	$/lb	.08						
Molasses price	$/gal	.36						
Molasses stillage	$/ton	15.00						
Energy price	$/MBtu	1.43	1.07	1.43	1.79			
Total investment	pct of base	--	75	125				
Construction period	years	3						

1/ Includes interim financing

Table VII-2. Total cost of grain ethanol production by plant size under base conditions in 1977 dollars

Cost	Ethanol plant size (million gallon) 10	20	40	60	80	100	120
	($/gal)						
Energy	.19	.19	.19	.19	.19	.19	.19
Other direct	.10	.07	.05	.05	.04	.04	.04
Indirect	.15	.11	.08	.08	.07	.07	.07
Capital recovery	.46	.38	.32	.29	.27	.26	.25
Raw material	.96	.96	.96	.96	.96	.96	.96
By-product credit	-.36	-.36	-.36	-.36	-.36	-.36	-.36
Total	1.50	1.35	1.24	1.21	1.17	1.16	1.15

Source: DPRA estimate

Table VII-3. Total cost of ethanol production for different raw materials under base conditions in 1977 dollars

Cost	Grain 1/	Potato 2/	Sugar beet 3/	Starch 1/	Molasses 1/
	($/gal)				
Energy	.19	.25	.23	.13	.13
Other direct	.10	.08	.08	.07	.07
Indirect	.15	.16	.16	.10	.10
Capital recovery	.46	.87	.83	.28	.28
Raw material	.96	.69	1.28	1.20	.97
By-product credit	-.36	-.03	-.60	.00	-.12
Total	1.50	2.02	1.97	1.78	1.43

1/ 10 million gallons per year

2/ 7.2 million gallons per year

3/ 9.7 million gallons per year

Source: DPRA estimate

estimated ethanol production costs are about three to five times greater than the expected competitive selling price. Thus it is concluded that under base conditions, representative for "business as usual" situation, the production of fuel grade ethanol is not financially feasible.

2. Grain Ethanol

Referring to Table VII-2, the range of total costs for grain based ethanol is $1.50 for a small plant down to $1.15 for a large 120 million gallon plant. (This assumes $2.50 per bushel grain input and $110 per ton DDG.) Clearly, economies of size are present under the estimated cost structure.

The single largest cost component is raw material at $.96 per gallon. Capital recovery is the second largest cost component anging from $.46 per gallon for the small plant down to $.25 per gallon for the large plant. The by-product credit of $.36 per gallon is also a major item of total cost. This cost structure suggests that these are critical parameters.

A more comprehensive analyses of plant size, including assembly and distribution costs, is contained in Chapter VIII. It was concluded that a large ethanol plant (about 100 million gallons) was in the optimal range in terms of the estimated cost situation. It was also concluded that a 20 million gallon plant could represent a reasonable size unit for an initial project for a limited gasohol program. Thus, subsequent analyses will present both the 20 and 100 MGY plant sizes.

3. Non-Grain Ethanol

The financial analyses suggest that non-grain ethanol plants, excepting molasses, are higher cost sources of ethanol than grain plants. In the case of potatoes and sugar beets, the high cost of the plants (capital recovery of over $.80 per gallon), is a major source of cost. In the case of sugar beets, raw material costs are very high at $1.28 per gallon ($26.00 per ton of beets). In the case of the starch, the absence of a by-product credit is a major causal factor. Also, in the case of the starch plant, the raw material costs are high at $1.20 per gallon ($.08 per pound of starch). The molasses plant, with total estimated costs of $1.43 per gallon, is slightly lower cost than the comparable sized grain plant. This estimate assumes a by-product credit of $.12 per gallon of molasses. As discussed in Chapter V, molasses stillage is not currently produced in the United States. Thus the estimate of the by-product cost is indicative based on its relative protein content. However, relative to grain, it would appear to offer potential and should receive further attention if a regional program is pursued.

While the other non-grain sources do not appear to be attractive raw materials for ethanol, it should be noted that there may be special situations for which these raw materials may warrant additional consideration. For example, if an existing beet sugar plant could be purchased cheaply and ethanol equipment added, the costs might be significantly reduced. Another possibility might be low cost sugar beets. These possibilities would require specific investigations and analyses.

The remainder of the analysis will focus upon grain ethanol production.

D. Production Cost Sensitivity

Four major cost components - investment, grain price, distillers dried grain price and energy - were varied to investigate the impact on ethanol production costs. Results are presented for the 20 and 100 million gallon per year grain plants.

1. Investment Cost

The investment impact was measured by ranging the base investment ±25 percent. A 25 percent investment change caused about a 6 percent change ($1.35 ± $.08) in the cost per gallon of ethanol for the 20 MGY plant and a 4 percent ($1.16 ± $.05) for the 100 MGY plant. This suggests that a relatively wide variance in investment will not substantially impact total production costs.

2. Grain and Distillers Dried Grain Prices

The effect of raw material and by-product prices on ethanol production cost is shown in Table VII-4 and Table VII-5 for the 20 and 100 MGY plants, respectively. Grain prices were varied from $2.00 to $4.50 per bushel and can be interpreted as average corn, wheat and/or sorghum per bushel prices, f.o.b. plant. Similarly, distillers dried grain prices were varied from $50 to $150 per ton and can be interpreted as average corn, wheat, and/or sorghum distillers dried grain prices f.o.b. plant. Within the ranges of the analyses, ethanol cost ranged from a low for $1.03 ($.84) 1/ per gallon with $2.00 per bushel grain and $150 per ton DDG to a high of $2.31 (2.13) 1/ per gallon with $4.50 grain and $50 DDG. This shows a $1.00 per bushel change in the cost of grain translates into about a $.38 to $.39 per gallon change in the ethanol production cost. Similarly a $20 per ton change in the by-product price translates into about a $.06 to $.07 per gallon change in the ethanol cost of production.

From this analysis it can be seen that prices of raw materials and by-product items are very important. As discussed in Chapter IX, it is expected that under a large gasohol program, grain prices will increase to some degree, while distillers dried grain prices would fall relative to historical levels.

3. Direct Energy Cost

Direct energy costs were varied by ±25 percent from the base price of $1.43 per MBtu. With all other costs held constant, a 25 percent change in direct energy costs would change ethanol production costs by about 4 percent. It would appear that a relatively large change in direct energy cost would result in a relatively small change in the cost of ethanol production.

1/ ( ) refers to 100 MGY plant

Table VII-4. Cost of ethanol as a function of grain price and distillers dried grain price for a base 20 MGY plant in 1977 dollars

Price of grain	Distillers dried grain ($/ton)					
	50	70	90	110	130	150
($/bu)	($/gal)					
2.00	1.35	1.28	1.22	1.16	1.10	1.03
2.50	1.54	1.48	1.42	1.35	1.29	1.23
3.00	1.73	1.67	1.61	1.54	1.48	1.42
3.50	1.92	1.86	1.80	1.74	1.67	1.61
4.00	2.12	2.05	1.99	1.93	1.87	1.80
4.50	2.31	2.25	2.18	2.12	2.06	2.00

Source: DPRA estimate

Table VII-5. Cost of ethanol as a function of grain price and distillers dried grain price for a base 100 MGY plant in 1977 dollars

Price of grain	Distillers dried grain ($/ton)					
	50	70	90	110	130	150
($/bu)	($/gal)					
2.00	1.17	1.10	1.04	.97	.91	.84
2.50	1.36	1.29	1.23	1.16	1.10	1.03
3.00	1.55	1.[illegible]	1.42	1.35	1.29	1.22
3.50	1.75	1.68	1.62	1.55	1.49	1.42
4.00	1.94	1.87	1.81	1.74	1.68	1.61
4.50	2.13	2.06	2.00	1.93	1.87	1.80

Source: DPRA estimate

This analysis assumes all other costs remain constant and the analysis is designed to test the impact of a range input energy cost from the standpoint of estimating error. If, in fact, overall energy costs increased, it would be expected that other production costs would also rise. This issue will be discussed later in this chapter.

E. Incentives for Ethanol Production

Based on the preceding analyses, it was concluded that the production of fuel grade ethanol is not financially feasible. This raises the question of what incentives would be required to create a feasible situation.

Governmental incentives (actions taken to stimulate production and/or use of a good or service) have been and are being used in the United States.

The types of incentives may be divided into eight major types [1/] as follows:

1) Exemption from taxation, or reduction of existing taxes.

2) Disbursements in which the Federal Government distributes money without requiring anything in return.

3) Governmental requirements backed by criminal or civil sanction.

4) Traditional government services provided through a nongovernmental entity without direct change (i.e., regulating interstate and foreign commerce and providing inland waterways).

5) Nontraditional government services such as exploration, research development and demonstration of new technology.

6) Market activity under conditions similar to those faced by non-governmental producers or consumers.

7) Creation or prohibition of organizations that carry out actions.

8) Collection of fees for the delivery of a governmental service or good not directly related to the cost of providing that good or service.

1/ Battelle-Pacific Northwest Laboratories, An Analysis of Federal Incentives Used to Stimulate Energy Production, U.S. Department of Energy, March 1978.

1. Incentives for Current Energy Development and Production

Production of current forms of energy in the United States has resulted from simulation through a variety of complex technical, economic, legal, institutional and political forces. An important factor in this complex of forces has been the Federal Government operating through a series of Federal incentives designed to stimulate energy development and production.

a. Costs of Incentives

A recent estimate places the costs of federal incentives for energy at $123-$133 (Appendix VII-2) billion, beginning in 1918. This breakdown of energy form indicates that about 60 percent of the total has gone to oil energy, 13 percent to nuclear, 12 percent to natural gas, 10 percent to hydro-electric and 5 percent to coal.

Eighty-five percent ($65.7 billion) of the incentives for oil energy went to simulate petroleum refining and transportation and 1 percent to research and development (Appendix VII-2).

The cost of federal incentives for oil in 1976 amounted to $11.1 billion - nearly 14 percent of the estimated historical total (Appendix VII-3). Clearly, incentives for oil are rising.

b. Types of Incentives

Taxation and disbursements are the two major types of energy incentives, representing 44 and 27 percent of the total costs of energy incentives respectively (Appendix VII-4). In the case of oil, these two types of incentives have historically accounted for 53 and 39 percent of the incentive costs for oil (Appendix VII-4). It should be noted that in 1976, the situation in oil had shifted substantially with disbursements accounting for 84 percent of the total and taxation 12 percent (Appendix VII-3). This has resulted in large measure to the fixing of old crude oil prices substantially below that of new and stripper oil.

The cost by type of incentive provides some indication of the type incentive and, thus policy tools, which are commonly used. Clearly, taxation and disbursements are the primary tools which the U.S. has historically relied upon.

From this brief analysis, two conclusions can be stated-- (1) higher and longer run social goals have been and are extensively pursued through incentives to encourage energy development and production, and (2) taxation and disbursements have been the major incentives used.

The following discussion considers financing, investment and direct tax credits and direct payments.

2. Financing

A large number of financing schemes could be developed including conventional bank financing, government loans, industrial revenue bonds and leasing. Additionally a variety of repayment (i.e., direct reduction, constant repayment, ballon repayments) schemes might be available. In this instance, it would appear that bond financing and leasing are not viable options, considering the risk involved with new ventures and markets. Consequently these sources were not analyzed.

The impact of interest rates, leverage and cost of equity capital were analyzed as representative of the impact of differing financing conditions. All analyses are based on a 20-year direct reduction loan.

a. Interest Rate and Leverage

With a constant cost of equity at 15 percent, Tables VII-6 and 7 present the impact of interest rates and leverage. With a given debt ratio, the changes in interest rate did not materially change total production costs. The difference between 5 percent interest and 11 percent interest was $.01 per gallon for 30 percent leverage and $.07 ($.04) 1/ per gallon at 90 percent leverage.

The impact of leverage is much more pronounced. At a 5 percent interest rate, the increase of leverage from 30 percent to 90 percent reduces ethanol price by $.18 per gallon. At 11 percent interest the difference is $.13 ($.15) 1/ per gallon.

b. Cost of Equity

The above analysis assumed a 15 percent cost of equity. Without loan guarantees, the 15 percent may be low, thus a 20 percent cost of equity was examined. Assuming 30 percent leverage, the cost of ethanol was increased to $1.50 ($1.27) 1/ from the base of $1.35 ($1.16) 1/ per gallon.

On the other hand, if loan guarantees were available, cost of equity might be reduced. A 5 percentage point reduction (10 percent cost of equity) would reduce the cost per gallon to $1.23 ($1.08) 1/, a reduction of $.12 ($.08) 1/ per gallon.

c. Interest Rate, Leverage and Cost of Equity

Tables VII-6 and 7 assumed a 15 percent cost of equity capital. Assuming that through loan guarantees or other factors, that the cost of equity was 10 percent, and that as a result of the guarantee, 90 percent leverage could

1/ ( ) refers to 100 MGY plant.

Table VII-6. Cost of ethanol as a function of interest rate and debt ratio for a base 20 million gallon grain plant

Interest rate	Debt (pct)			
	30	50	70	90
	($/gal)			
5	1.34	1.29	1.23	1.16
7	1.34	1.30	1.24	1.18
9	1.35	1.30	1.26	1.20
10	1.35	1.31	1.27	1.22
11	1.35	1.31	1.27	1.23

Source: DPRA estimate

Table VII-7. Cost of ethanol as a function of interest rate and debt ratio for a base 100 million gallon grain plant

Interest rate	Debt (pct)			
	30	50	70	90
	($/gal)			
5	1.16	1.12	1.08	0.98
7	1.16	1.13	1.09	0.99
9	1.16	1.13	1.10	1.00
10	1.16	1.14	1.11	1.01
11	1.17	1.14	1.11	1.02

Source: DPRA estimate

be obtained, the effect would be to reduce the cost of ethanol by about $.07 per gallon. Thus, at a 7 percent interest rate, 90 percent leverage and 10 percent cost of equity, ethanol cost would be about $1.16 ($1.03) per gallon.

In all situations, however, it appears that regardless of financing, the cost of ethanol would not fall below $1.00 per gallon including the 100 MGY plant,assuming $2.50 per bushel grain and $110 per ton DDG.

3. Income Tax Credits

A variety of tax incentives are available such as accelerated depreciation methods, investment tax credit and rapid amortization. Various proposals are currently being considered for direct tax credits in connection with shale oil production. For this study accelerated depreciation (SOYD) was assumed throughout. Investment tax credits and direct income tax credits were investigated.

a. Investment Tax Credit

The base analysis included allowances for the existing investment tax credit provisions of 10 percent, 7 year carryforward and limit of 50 percent of the income tax over $25,000. Raising the percentage of qualified investment to 30 and 50 percent only reduced the cost by $.03 ($.01) 1/ and $.04 ($.02) 1/ per gallon respectively from the base (Tables VII-8 and 9). It is noted that under a 50 percent tax credit the year carry forward would impact the 20 MGY plant by about $.01 per gallon.

The conclusion drawn from this analysis is that investment tax credit is not a powerful incentive.

b. Income Tax Credit

A direct tax credit is another tax incentive that might be considered. However, at full costs of production, a full tax credit would only reduce the cost by $.13 (to $1.22 per gallon) per gallon for a 20 MGY grain plant. For the 100 MGY plant, the reduction of a full tax credit would be $.09 (to 1.06 per gallon) per gallon. Thus a full tax credit would not significantly reduce full ethanol production costs (see Appendix VII-1 for tax estimates).

4. Direct Construction Grants

One approach would be to provide direct government construction grants. Two situations are presented. The first represents a conventional situation, with 30 percent leverage, 10 percent interest and a 15 percent cost of equity. The second illustration assumes 90 percent leverage, a 7 percent interest rate and a 10 percent cost of equity. The second situation might represent some type of low interest government loan participation.

Table VII-8. Cost of ethanol as a function of investment tax credit and limit for a base 20 MGY grain ethanol plant in 1977 dollars

Percent of qualified investment	Percent of tax limit: 50, 7 year carryforward	50, 20 year carryforward	100, 7 year carryforward	100, 20 year carryforward
	($/gal)			
10	1.35	1.35	1.35	1.35
30	1.32	1.32	1.32	1.32
50	1.32	1.31	1.32	1.31

Source: DPRA estimate

Table VII-9. Cost of ethanol as a function of investment tax credit and limit for a base 100 MGY grain ethanol plant in 1977 dollars

Percent of qualified investment	Percent of tax limit: 50, 7 year carryforward	50, 20 year carryforward	100, 7 year carryforward	100, 20 year carryforward
	($/gal)			
10	1.16	1.16	1.16	1.16
30	1.15	1.15	1.15	1.15
50	1.14	1.14	1.14	1.14

Source: DPRA estimate

As shown in Table VII-10, a 100 percent construction grant would yield a cost of $1.06 per gallon and $.98 per gallon respectively for a 20 MGY and 100 MGY plant under conventional financing. Under government financing with a 100 percent grant, the ethanol costs would be only slightly less at $1.04 and $.96 per gallon for the 20 MGY and 100 MGY plants respectively. The small difference in cost between the two 100 percent schemes results from the assumption that working capital is financed through equity. Lesser grants would increase ethanol costs. The ethanol costs are substantially above the $.41 per gallon competitive requirement and suggests that an incentive program based on grants alone would not be sufficient to attract investment to fuel ethanol production.

5. Subsidies

As suggested, subsidies either through direct payments or fuel tax exemptions would be required to support the production of fuel grade ethanol made from grains. The extent of the subsidy would be the difference between the cost of ethanol production and the expected competitive selling price which was estimated to be $.41 in 1977 dollars. This estimate, as indicated in Chapter II, may ultimately be determined to differ slightly, thus the required subsidies have been computed for a range of $.39 to $.43 per gallon of ethanol for the 20 MGY and 100 MGY plant and under two financing schemes.

Based on these specifications, it is concluded that the direct subsidy without any other type of governmental incentive would be about $.94 1/ per gallon for a 20 MGY plant and about $.75 1/ for the 100 MGY plant (Table VII-11). Use of government financing would reduce the required subsidy per gallon, but there would be a cost associated with this incentive.

This estimate is based on grain costs of $2.50 per bushel, which is about the historical average of corn prices in 1977 dollars and slightly higher than the grain sorghums. It is also based on a distillers dried grain price of $110 per ton. As discussed in Chapter IX, a large regional gasohol program would be expected to increase grain prices and exert significant downward pressure on distillers dried grain prices. The extent of these charges have not been determined. However, it is concluded that while the above estimates are reasonable for a limited gasohol program, the creation of a large program would likely require increased subsidy per gallon.

1/ Of this amount $.13 and $.09 per gallon for the 20 MGY and 100 MGY plants would be paid as income taxes under the assumption subsidies would be taxable.

Table VII-10. Cost of ethanol as function of construction grants and financing costs in 1977 dollars

Type of financing	Level of grant 1/	20 MGY plant 4/	100 MGY plant 5/
	(pct)	---------($/gal)---------	
Conventional financing 2/	100	1.06	.98
	75	1.11	1.03
	50	1.20	1.07
	25	1.28	1.12
	0	1.35	1.16
Government financing 3/	100	1.04	.96
	75	1.05	.97
	50	1.11	.99
	25	1.13	1.01
	0	1.16	1.03

1/ Assumes working capital equity financed. It was also assumed that the assets funded by grants would not be depreciable for tax purposes.

2/ 10 percent interest, 30 percent leverage and 15 percent cost of equity.

3/ 7 percent interest, 90 percent leverage and 10 percent cost of equity.

4/ Investment base of $31.2 million (1977 dollars).

5/ Investment base of $97.8 million (1977 dollars).

Table VII-11. Estimated direct subsidies 1/ required for ethanol production for gasohol in 1977 dollars

Ethanol selling price	Ethanol cost of production ($/gal) 1.03	1.16	1.35
----------	($/gal)	----------	----------
.39	.64	.77	.96
.40	.63	.76	.95
.41	.62	.75	.94
.42	.61	.74	.93
.43	.60	.73	.92

1/ Payments assumed to be taxable as ordinary income.

Source: DPRA estimate

F. Feasibility of Ethanol Production Under Higher Gasoline Prices

The preceding analysis was based on the assumption that all costs (excepting fixed commitments such as interest and depreciation) inflated proportionately at six percent per annum. One argument that advanced is that if the price of gasoline were to double, ethanol would become viable. This argument implies differential inflation, that is gasoline prices will rise at a faster rate than other goods, or put another way, the real price of gasoline will increase faster than the real price of other goods.

In considering this issue, it should be noted that all energy costs tend to be interrelated and move together (see Table VII-12). Thus any real increase in gasoline prices would be expected to proportionately increase energy costs for the manufacture of ethanol. These costs represent 14 to 16 percent of total costs depending upon plant size. As indicated earlier in this chapter, a 25 percent charge in energy costs would change ethanol production costs by four percent, all other costs remaining constant. This would imply that with a doubling of gasoline prices, the cost of ethanol production would increase by 16 percent.

However, with a real increase in energy costs, non-energy prices would also be expected to increase reflecting their use of energy. For example, one estimate of a doubling of energy prices in 1985 over 1974, with normal export levels, indicated that real corn prices would increase by 14 percent. 1/ This estimate dealt with direct energy use and did not reflect the impact through indirect or invested energy of fertilizers and other farm inputs.

The translation of substantial increases in real energy prices to charges in ethanol costs would be a formidable, if not impossible task, given the rapid changes in the structure of energy during the past five years. While the issue is muddy, it seems unlikely that there would be any sustained long term differential inflation between energy and other goods.

Thus it is the contractor's opinion that price increases in gasoline will not materially alter the conclusion that ethanol production will require substantial subsidies to be competitive.

1/ Dvoskin, Dan and Earl O. Heady. "Commodity Prices and Resource Use Under Various Energy Alternatives in Agriculture," Western Journal of Agricultural Economics, Vol. 2, December 1977.

Table VII-12. Trends in energy prices

Item	Average annual percent change 1958 to 1973	1973 to 1976	1976 to 1977
Wholesale prices 1/			
All energy	.2	14.1	7.9
Petroleum products	-.1	17.3	4.8
Natural gas	1.6	18.6	38.0
Coal	3.4	8.3	.6
Electric power	-.4	6.4	6.9
Consumer prices 2/			
All energy	-.8	6.2	2.9
Fuel oil and coal	.0	12.9	6.1
Gasoline and motor oil	-1.0	5.1	-.8
Natural gas	-.4	7.1	11.6
Electricity	-1.2	3.5	.1

1/ Prices deflated by the wholesale price index for all finished goods.

2/ Prices deflated by the consumer price index for all items.

Source: Council of Economic Advisors. Economic Report of the President, Washington, January 1978.

VIII. ETHANOL: PLANT SIZE, MARKET AND SITE SELECTION FACTORS

Optimum plant size is determined as the least unit cost plant size necessary to minimize an ethanol plant's total per gallon costs for raw material assembly, by-product and ethanol distribution, and plant conversion. Transportation cost estimates for commodity assembly and distribution are based on market parameters including raw material production densities, by-product use densities, market shares, average length of haul, and transportation rates. These depend, in turn, on choice of plant location. Consequently a scenario approach is used whereby transportation cost estimates are determined over a wide range of market parameters reflecting representative values over the seventeen state study area.

Location determines a plant's orientation to input and output markets and, hence to a plant's revenues and costs. In the previous steps of analysis, revenue and cost variations due to locational factors within the seventeen state study area were ignored. Since the proper treatment of all important location dependent variables would involve major study costs which are beyond the scope of this study, the contractor's analysis focused on identifying those areas of concentrated raw material production and high protein feed and ethanol use to point the way for more detailed plant location studies. The data of sections A, B, and C which follow support the conclusion that ethanol plants should be located near sources of raw materials to minimize combined assembly and distribution costs.

Plant size also affects unit ethanol production costs. Because many costs are affected by varying plant sizes, many factors must be assessed to determine optimum plant size. Section A below discusses such factors including market characteristics that affect raw material prices and assembly costs, product and by-product prices, distribution costs, plant conversion costs and capital risk costs.

Section B presents estimates of increasing and decreasing costs as plant size increases under a wide range of possible market parameters. It is shown that for most plausible plant loactions the least unit cost plant size is greater than 40 million gallons annual capacity. Furthermore, reconnaissance grade extrapolations of the cost estimates for 60, 80, 100 and 120 million gallon annual capacity plants show that unit costs continue to decrease but at ever decreasing rates.

Site selection criteria for ethanol plants are briefly outlined in section C below. Generally these relate to guaranteeing an efficient access to process inputs and to the disposition facilities of process outputs. Such criteria indicate that ethanol plants should be raw material oriented. Secondary site location considerations include sites that provide access to by-product user markets, potential gasoline-ethanol blending points, and adequate coal, water, and skilled labor sources. Sites must have primary highway access and rail sidings to accommodate grain, coal, and by-product transportation requirements.

A. Market Parameters

Raw material production and high protein feed use data were used to estimate the average raw material production and high protein feed market densities for selected states and crop reporting districts shown in Table VIII-1. These density statistics for high protein feeds and raw material commodities provide broad geographic coverage and should be supplemented by less aggregated marketing analyses, especially in the case of high protein feeds for which state-based estimates tend to understate local high-use areas. (Note those for the northwest Texas cattle feeding area.) Nevertheless the density estimates in Table VIII-1 provide a gauge for selecting parameter values for subsequent analyses and provide a broad state-based estimate of raw material production and by-product use densities.

1. Raw Material Production Densities

Crop production density estimates shown in Table VIII-1 are based on 1976 production estimates divided by the respective state or crop reporting district total land area.

Crop reporting districts having the maximum production densities among crop reporting districts in the seventeen state area for their respective crops were found to be as follows:

Crop	CRD, State
Corn	Central, Illinois
Grain Sorghum	East, Nebraska
Wheat	Southcentral, Kansas
Sugar beets	Northeast, Colorado
Potatoes	Northeast, North Dakota

Corn densities ranged from zero to over 20,000 cwt per square mile in Central Illinois. Grain sorghum in East Nebraska reached 2,500 cwt per square mile and contributed to a combined corn, grain sorghum, and wheat density of over 12,000 cwt per square mile. Southcentral Kansas lead wheat production density at 4,300 cwt per square mile, Northeast Colorado lead sugar beet production density at 2,800 cwt per square mile, and Northeast North Dakota led in potato production with a density equal to 1,900 cwt per square mile.

Table VIII-1. Average high protein use and crop production densities for selected states and crop reporting districts, 1976

State	Selected CRD's	High protein feeds [1/]	Corn 56#/bu	Grain sorghum 56#/bu	Wheat 60#/bu	Sugar-beets	Potatoes
		-------------	hundredweight per square mile	-------------			
Colorado		57	345.2	39.0	306.2	441.8	107.9
	2 Northeast					2,816.4	
Illinois		323	12,313.4	39.2	767.6	---	9.4
	5 Central		20,262	---	---	---	
Indiana		416	10,693.6	21.7	892.8	---	52.9
Iowa		698	11,678.5	16.8	48.5	---	8.2
Kansas		141	1,169.8	1,156.2	2,472.5	182.1	---
	8 South Central		415.9	751.3	4,300.8		
Michigan		107	1,408.1	---	340.7	529.1	
Minnesota		260	2,200.9	---	931.3	719.9	155.3
Missouri		209	1,397.1	318.2	500.0	---	---
Montana		13	3.1	---	682.2	131.6	12.3
Nebraska		201	3,759.8	868.0	733.4	437.8	21.0
	6 East		9,110.6	2,506.9	989.4		
North Dakota		37	60.5	---	2,443.9	572.3	239.7
	3 Northeast		---	---	---	---	1,863.5
Ohio		250	5,345.2	---	936.5	299.4	80.8
Oklahoma		75	80.6	135.8	1,297.5	---	---
South Dakota		107	270.4	25.4	307.8	---	---
Texas		77	389.6	613.5	232.1	37.6	12.9
Wisconsin		277	1,505.5	---	34.6	---	273.7
Wyoming		9	11.0	---	48.8	238.4	17.4

1/ Equivalent to 400 lbs. of 44% soybean meal consumed per high protein consuming animal unit (milk cow base) for all classes of livestock which includes milk cows, other dairy cattle, cattle on feed, other beef cattle, sheep, hogs, hens and pullets, chickens, broilers, turkeys, horses and mules.

2. Distillers Dried Grain Use Densities

Distillers dried grain is one of several high protein feeds. The high protein feed consumption density reported in Table VIII-1 was computed as each state's equivalent to 400 lbs of 44 percent soybean meal consumed per high protein consuming animal unit (milk cow base) for all classes of livestock divided by that state's total land area. On the basis of total protein content, 1.6 pounds of 28 percent distillers dried grain is equivalent to one pound of 44 percent protein soybean meal; however, since some livestock classes (e.g., swine and poultry) have a lower tolerance for distillers dried grains than for soybean meal, the potential market density for distillers dried grains would be somewhat less than for soybean meal depending on the class of livestock or species mix characteristic of the market area.

The market density statistics presented above are used to develop transportation cost estimates in the next section.

B. Plant Size

As plant size increases over the range of 10 to larger than 100 million gallons annual capacity, net raw material costs are expected to increase as assembly and distribution costs are manifested in direct plant costs or through indirect pricing arrangements for raw materials, by-products, and ethanol. Also as plant size increases, conversion costs are expected to decrease. The estimates of these changing costs and an analysis of the economies of plant size follow.

. Transportation Costs

ransportation costs vary directly with average length of haul. Average length f haul varies directly with plant size but inversely with market density and arket share. Transportation costs include raw material assembly costs and istillers dried grain and ethanol distribution costs. Each has been estiated under a range of market parameters and plant sizes.

ransportation rates (in 1977 dollars) for raw material grain, by-product eeds, and ethanol are shown in Table VIII-2. Published tariffs are not vailable for ethanol, but because of its similar fluid, volatility and ensity characteristics to gasoline, the latter's rates are assumed applible. Rates shown for distances less than 400 miles are based on the Kansas rporation Commission's 1977 Distance Commodity Rates which commonly represent negotiated hauler rates for minimum weights of 45,000 pounds. Similar

Table VIII-2. Representative distance commodity rates (in cents per 100 pounds)

Distance in miles	Grain and seeds	Feed and feed ingredients	Gasoline (and ethanol)
10	.1000	.2514	.1000
50	.1400	.2970	.1400
100	.2375	.3540	.2375
150	.335	.4110	.335
200	.4325	.4680	.4325
250	.5300	.5250	.5300
300	.6384	.6384	.6384
400	.8555	.8555	.8555
450	.7911	.7911	.7911
500	.8222	.8222	.8222
750	.9778	.9778	.9778
1,000	1.1333	1.1333	1.1333

Source: DPRA estimates based on 1977 Distance Commodity Rates, Kansas Corporation Commission and Kansas City Board of Trade Grain Rate Book, March 1977.

rate structures exist throughout all the states in the study area. Rates shown for distances greater than 400 miles reflect grain carload rates by rail into Kansas City based on the Kansas City Board of Trade Grain Rate Book, March 1977. These rates are representative of Midwest carload rates throughout the study area.

a. Grain Assembly Costs

This study estimated a plant's costs for receiving its raw material grains by employing a square grid road system and uniform market density. Grain market densities of 5,000, 10,000 and 20,000 cwt per aquare mile represented the variability of market densities and grain market shares of 1, 5, 15 and 25 pecent were considered at each market density level. Purchase density equal to the product of grain density times market share ranged from 50 to 5,000 cwt per square mile. Purchase densities of 5, 50 and 500 cwt per square mile were selected as low, medium and high values for later analysis. (As Table VIII-1 shows, a grain density of 10,000 cwt per square mile is roughly representative of Nebraska's East Crop Reporting District which had a combined corn, grain sorghum and wheat production density in 1976 equal to 12,607 cwt per square mile.)

Table VIII-3 contains the estimated transportation costs per gallon of ethanol and average length of haul for grain based on alternate plant sizes, market densities and market shares. Plant sizes considered ranged from 10 to 120 million gallons annual capacity.

When a plant's size is 20 million gallons, its grain market density is 10,000 cwt/sq mi, its market share 15 percent, its average length of haul for the grain will be estimated at 25 miles with a transportation cost of $.025 per gallon of ethanol. Under the same market parameters, a 100 million gallon plant will have an average length of haul of 56 miles and a transportation cost of $.034 per gallon of ethanol.

b. By-product Feed Distribution Costs

A square grid road system and a uniform market density were used to approximate average shipping distances and unit distribution costs for distillers by-product feeds. Distillers by-product feed variable densities of 100, 200 and 400 cwt per square mile and market shares at each level of density of 2, 10, 30 and 50 percent were, also, utilized for the analysis. In 1977, distillers dried grains represented approximately 1.8 percent by weight and 1.1 percent by total protein, the quantity of high protein feeds available for feeding. Local markets in an ethanol plant's vicinity would be expected to utilize these feeds above the average rate for recent years. Sales density equal to the product of by-product density times market share, thus, could range from 2 to 200 cwt per square mile. Sales densities of 2, 20 and 200 cwt per square mile were selected as low, medium and high values for later analysis.

Table VIII-3. Transportation costs per gallon of ethanol and average length of haul for grain based on alternative plant sizes, market densities and market shares with a uniform share pattern, 1977 dollars

GRAIN

Grain density (cwt/sq mi)	5,000				10,000				20,000			
Market share (percent)	1	5	15	25	1	5	15	25	1	5	15	25
Purchase density (cwt/sq mi)	50	250	750	1,250	100	500	1,500	2,500	200	1,000	3,000	5,000
Plant size (mil gal)	Grain transportation costs ($/gal of ethanol)											
10	0.051	0.030	0.025	0.024	0.039	0.026	0.023	0.022	0.031	0.024	0.022	0.021
20	0.067	0.036	0.027	0.025	0.051	0.030	0.025	0.024	0.039	0.026	0.023	0.022
40	0.092	0.046	0.032	0.028	0.067	0.036	0.027	0.025	0.051	0.030	0.025	0.024
60	0.111	0.054	0.036	0.031	0.080	0.042	0.030	0.027	0.060	0.033	0.026	0.025
80	0.126	0.061	0.040	0.034	0.092	0.046	0.032	0.028	0.067	0.036	0.027	0.025
100	0.135	0.067	0.043	0.036	0.102	0.051	0.034	0.030	0.074	0.039	0.028	0.026
120	0.142	0.073	0.046	0.038	0.111	0.054	0.036	0.031	0.080	0.042	0.030	0.027
	Average length of haul for grain (miles)											
10	97.8	43.8	25.3	19.6	69.2	30.9	17.9	13.8	48.9	21.9	12.6	9.8
20	138.4	61.9	35.7	27.7	97.8	43.8	25.3	19.6	69.2	30.9	17.9	13.8
40	195.7	87.5	50.5	39.1	138.4	61.9	35.7	27.7	97.8	43.8	25.3	19.6
60	239.7	107.2	61.9	47.9	169.5	75.8	43.8	33.9	119.8	53.6	30.9	24.0
80	276.7	123.8	71.5	55.3	195.7	87.5	50.5	39.1	138.4	61.9	35.7	27.7
100	309.4	138.4	79.9	61.9	218.8	97.8	56.5	43.8	154.7	69.2	39.9	30.9
120	338.9	151.6	87.5	67.8	239.7	107.2	61.9	47.9	169.5	75.8	43.8	33.9

Source: DPRA estimate

As Table VIII-1 shows, the above assumptions of a by-product density of 200 cwt per square mile is comparable to the high protein feed density estimated for Nebraska. It is noted, however, that 200 cwt of 44 percent soybean meal has approximately the same amount of total protein as about 325 cwt of 27 percent protein corn distillers dried grain and that the latter may be limited in use to a greater extent than soybean meal.

Table VIII-4 contains the estimated transportation costs per gallon of ethanol and average length of haul for by-product feeds based on alternate plant sizes, market densities, and market shares. Plant sizes ranged from 10 to 120 million gallons annual capacity.

Average length of haul varies directly with plant size but inversely with market density and market share. Transportation costs vary directly with average length of haul.

When a plant's size is 20 million gallon and its by-product density is 200 cwt per square mile, and market share is 10 percent, the plant's average length of haul for by-product feed will be 129 miles with an average transportation cost equivalent to $.029 per gallon of ethanol. With the same market parameters but increasing plant size to 100 million gallons, the average length of haul increases to 289 miles with an average transportation cost equivalent to $.047 per gallon of ethanol. It is expected that although by-product feeds represent about one-third the mass equivalent of raw material; grain flowing into the plant, the by-product marketing area will be much larger (i.e., 56 mile average haul for corn vs 129 mile average haul for by-product feeds) and may place bounds on plant size and distance between multiple numbers of plants.

c. Ethanol Distribution Costs

To estimate the costs for ethanol distribution, this study's analysis considered the per gallon unit distribution costs, the distances between plant's and their gasohol blending points, and the variations in costs resulting from differing plant sizes. Representative transportation costs per gallon of ethanol over a span of 0-200 highway miles are 0 to $.0281 per gallon as shown below.

Representative ethanol transportation costs vs. length of haul

Miles	$/gal	Miles	$/gal
20	.007	120	.017
40	.008	140	.020
60	.010	160	.022
80	.013	180	.025
100	.014	200	.028

Source: DPRA estimate

Table VIII-4. Transportation costs per gallon of ethanol and average length of haul for distillers by-product based on alternative plant sizes, market densities and market shares with a uniform market share pattern, 1977 dollars

DISTILLERS BY-PRODUCT

By-product density (cwt/sq mi)	100				200				400			
Market share (percent)	2	10	30	50	2	10	30	50	2	10	30	50
Sales density (cwt/sq mi)	2	10	30	50	4	20	60	100	8	40	120	200
Plant size (mil gal)	Distillers by-product transportation costs ($/gal of ethanol)											
10	0.047	0.029	0.024	0.023	0.037	0.026	0.023	0.022	0.030	0.024	0.021	0.021
20	0.055	0.034	0.027	0.025	0.047	0.029	0.024	0.023	0.037	0.026	0.023	0.022
40	0.064	0.044	0.031	0.028	0.055	0.034	0.027	0.025	0.047	0.029	0.024	0.023
60	0.071	0.049	0.034	0.030	0.060	0.039	0.029	0.027	0.052	0.032	0.026	0.024
80	0.076	0.052	0.037	0.032	0.064	0.044	0.031	0.028	0.055	0.034	0.027	0.025
100	0.081	0.055	0.041	0.034	0.068	0.047	0.032	0.029	0.058	0.037	0.028	0.026
120	0.085	0.057	0.044	0.036	0.071	0.049	0.034	0.030	0.060	0.039	0.029	0.027
	Average length of haul for distillers by-product (miles)											
10	289.3	129.4	74.7	57.9	204.5	91.5	52.8	40.9	144.6	64.7	37.3	28.9
20	409.1	182.9	105.6	81.8	289.3	129.4	74.7	57.9	204.5	91.5	52.8	40.9
40	578.5	258.7	149.4	115.7	409.1	182.9	105.6	81.8	289.3	129.4	74.7	57.9
60	708.5	316.9	182.9	141.7	501.0	224.1	129.4	100.2	354.3	158.4	91.5	70.9
80	818.1	365.9	211.2	163.6	578.5	258.7	149.4	115.7	409.1	182.9	105.6	81.8
100	914.7	409.1	236.2	182.9	646.8	289.3	167.0	129.4	457.3	204.5	118.1	91.5
120	1,002.0	448.1	258.7	200.4	708.5	316.9	182.9	141.7	501.0	224.1	129.4	100.2

Source: DPRA estimate

Depending on actual site selection, the distance between a plant site anywhere in the seventeen state study area and an adequate gasohol blending point (refineries, pipeline terminals, jobber bulk stations, retail stations) ranges from 0 to about 150 air miles.

Thus, the maximum average ethanol distribution cost from the ethanol plant to the blending point is about $.03 per gallon.

Since it is likely that ethanol will be transported by truck or rail to a single local blending point in the case of a small 10 million gallon plant or to multiple blending points in the case of larger 40 to 100 million gallon plants, a uniform market pattern is not a plausible assumption for ethanol distribution. More logical is a fixed average point market pattern in which the average length of haul increases as plant size increases and additional blending points are added to the destination points. Unit transportation costs are estimated as though all of the ethanol were hauled the same distance. Average length of haul is assumed to increase as plant size increases. To provide a range of possible values, three cases were assumed as shown in Table VIII-5. Average length of haul assumed for scenario A ranges from 160 to 400 miles; scenario B, 80 to 200 miles; scenario C, 40 to 100 miles. Resulting ethanol transportation costs are: scenario A $.022 to $.056 per gallon; scenario B, $.013 to $.028 per gallon, and scenario C $.008 to $.014 per gallon.

2. Conversion Costs

Chapter VI defined and analyzed conversion costs as direct energy costs, other direct costs, indirect costs and capital recovery. The results of that analysis are repeated in Table VIII-6 for the 10, 20, 40, 60, 80, 100 and 120 million gallon grain ethanol plants. Economies of size, that is, decreasing unit costs as plant size increases, exist for non-energy direct costs, indirect costs, and capital recovery. Total conversion costs decrease from $.901 per gallon for the 10 million gallon plant to $.645 per gallon for the 40 million gallon plant and to $.544 per gallon for the 120 million gallon plant.

3. Economies of Plant Size

To determine the ethanol per gallon costs that stem from variations in production plant sizes, the study compared the diseconomies of increasing plant sizes on raw material and product-by-product transportation costs to the economies that similar plant size increases contributed to product conversion costs. This comparison is discussed below under "a" and "b". A general overview of these total costs is presented in Table VIII-7.

Table VIII-7 presents the conversion costs, ethanol transportation costs, by-product transportation costs, and grain transportation costs for alternative plant sizes (10 to 120 million gallons) and selected raw material and product market densities. Low, medium and high density total transportation costs are defined as the sum of respective low (A), medium (B) and high (C) density ethanol, by-product, and grain transportation costs.

Table VIII-5. Estimated transportation costs per gallon of ethanol and average length of haul for ethanol based on alternative plant sizes and assumed average length of haul scenarios

Plant size	Scenario A	Scenario B	Scenario C
(mil gal)			
	Ethanol transportation costs ($/gal ethanol)		
10	.022	.013	.008
20	.028	.014	.009
40	.034	.017	.010
60	.039	.020	.011
80	.045	.022	.013
100	.051	.025	.013
120	.056	.028	.014
	Assumed average length of haul for ethanol (miles)		
10	160	80	40
20	200	100	50
40	240	120	60
60	280	140	70
80	320	160	80
100	360	180	90
120	400	200	100

Source: DRPA estimate

Table VIII-6. Conversion costs for ethanol production based on alternative sizes of grain ethanol plants.

	Ethanol plant size (million gallon)						
	10	20	40	60	80	100	120
	($/gal)						
Energy	.187	.187	.187	.187	.187	.187	.187
Other direct	.098	.067	.051	.046	.043	.042	.041
Indirect	.155	.108	.084	.077	.073	.070	.069
Capital recovery	.461	.385	.323	.292	.273	.258	.247
Total	.901	.747	.645	.602	.576	.557	.544

Source: Chapter VI.

Table VIII-7. Conversion costs for ethanol production and transportation costs for ethanol, by-product and grain (raw materials) based on alternative sizes of grain ethanol plants and market densities.

	Purchase/sales density (cwt/sq mi)	Ethanol plant size (mil gal/yr) 10	20	40	60	80	100	120
		($/gal)						
Total conversion costs		.901	.747	.645	.602	.576	.557	.544
Transportation Costs:								
Ethanol transportation								
160-400 miles		.022	.028	.034	.039	.045	.051	.056
80-200 miles		.013	.014	.017	.020	.022	.025	.028
40-100 miles		.008	.009	.010	.011	.013	.013	.014
By-product transportation								
Low	2	.047	.055	.064	.071	.076	.081	.085
Medium	20	.026	.029	.034	.039	.044	.047	.049
High	200	.021	.022	.023	.024	.025	.026	.027
Grain transportation								
Low	50	.051	.067	.092	.111	.126	.135	.142
Medium	500	.026	.030	.036	.042	.046	.051	.054
High	5,000	.021	.022	.024	.025	.025	.026	.027
Total Transportation								
Low		.120	.150	.190	.221	.247	.267	.283
Medium		.065	.073	.087	.101	.112	.123	.131
High		.050	.053	.057	.060	.063	.065	.068
Total conversion and transportation								
Low		1.021	.897	.835	.823	.823	.824	.827
Medium		.966	.820	.732	.703	.688	.680	.675
High		.951	.800	.702	.662	.639	.622	.612

Source: DPRA estimate

Total low, medium and high density conversion and transportation costs are defined as the sum of the conversion costs and the respective low, medium and high density transportation costs.

a. Diseconomies of Assembly and Distribution

Total per gallon transportation costs increase as plant size increases when all other parameters are held constant. The rate of transportation cost increase depends on (1) market density and market share in the case of grain and by-product feed or (2) average length of haul in the case of ethanol. The rate of grain and by-product feed transportation costs increase is lowest when their respective market densities are highest.

Under high density market conditions (including ethanol scenario C) total transportation costs for raw material assembly, by-product distribution, and ethanol distribution remain under $.10 per gallon of ethanol. For the 20 million gallon plant, these total transportation costs of $.053 per gallon are composed of (1) ethanol transportation cost of $.009 per gallon; (2) by-product transportation of $.022 per gallon; and (3) grain transportation of $.022 per gallon. For the 100 million gallon plant the total increased transportation costs of $.065 per gallon is a result, respectively, of (1) $.013, (2) $.026 and (3) $.026 per gallon.

Under low density market conditions (including ethanol scenario A) total transportation costs for raw material assembly, by-product distribution and ethanol distribution increase from $.150 per gallon when plant size is 20 million gallons to $.267 when plant size is 100 million gallons. The 20 million gallon plant's total costs subdivide into (1) ethanol transportation costs of $.028, (2) by-product transportation costs of $.055 and (3) grain transportation costs of $.067 per gallon. For the $100 million gallon plant, these costs are, respectively, (1) $.051, (2) $.81, and (3) $.135 per gallon.

Such data clearly indicate the locational advantage of a high density market area in which assembly and distribution activities are conducted over lower average hauling distances and for, consequently, lower unit transportation costs. The data indicate, also, that transportation costs for raw material assembly, by-product distribution, and ethanol distribution for a given location and set of market parameters will increase as plant sizes increase.

b. Economies of Conversion

As the analysis of Chapter VI indicated, total estimated per gallon conversion costs decrease as plant sizes increase. Such a decrease reflected large plant efficiencies per gallon of ethanol in such costs as those for capital recovery and investment, overhead, and labor. Total conversion costs in the range of the 10 to 40 million gallons annual capacity decrease from $.90 to $.64 per gallon. Further conversion cost reductions are estimated to continue but at a decreasing rate as plant size increases above 40 million gallons. It was noted, also that estimates for plant sizes greater than 40 million gallons are extrapolations of cost estimates for the 10, 20 and 40 million gallon plants and that they are, at best, but rough estimates that should be verified by detailed engineering studies. For the 100 million gallon plant, conversion costs were estimated at approximately $.56 per gallon.

c. Least Unit Cost Plant Size

Total conversion and transportation cost estimates for plant sizes ranging from 10 to 120 million gallons annual capacity are shown at the bottom of Table VIII-7. These costs continue to decrease over this range of plant sizes for the high and medium density cases. Such data suggest that the least unit cost plant size is very large, perhaps, greater than a 100 million gallon plant size for most plausible plant locations within the seventeen state study area.

Assuming low density market parameters, total conversion and transportation costs (excluding raw material costs) decrease to $.823 per gallon when plant size is 60 or 80 million gallons and then begin to increase for larger plant sizes.

These results are displayed graphically in Figure VIII-1.

The data and analysis of plant size economies and diseconomies suggest that (and, in part, depending upon market factors) the least cost plant size is large--in excess of 60 million gallons or greater--based on the reconnaissance grade cost estimates used in this study. To determine optimum plant size given the nature of the data and the apparent interrelationships among the cost elements further detailed engineering and economic studies focusing on larger plant sizes and specific locations are needed.

Obviously, the preceding analyses, though based on reasonable data and logical assumptions, cannot be definitive and reflective of real market conditions. Considerations of plant sizes and marketing experiences projected for a hypothetical plant in a yet-to-be developed major ethanol industry would doubtless be modified if such an industry were developed over a wide region of the United States. Too, assumptions concerning site location are here based upon generalized, extrapolated data specific to other sites and different plants. The considerations emerging from such analyses would, if a specific plant's construction were contemplated, have to be supported by an exhaustive, sophisticated analyses of such a plant's projected production, its raw material supply area characteristics, and its potential market area for ethanol and by-product distribution. Doubtless, capital risk considerations attendant upon investment, would require most extensive engineering and economic studies. In general, then, the preceding analyses should be recognized as basically reconnaissance grade estimates. Risk factors to private investors weigh into plant size selection. Some diseconomies such as raw material acquisition costs or DDG selling costs may not have been adequately estimated by the cost estimation procedures used herein.

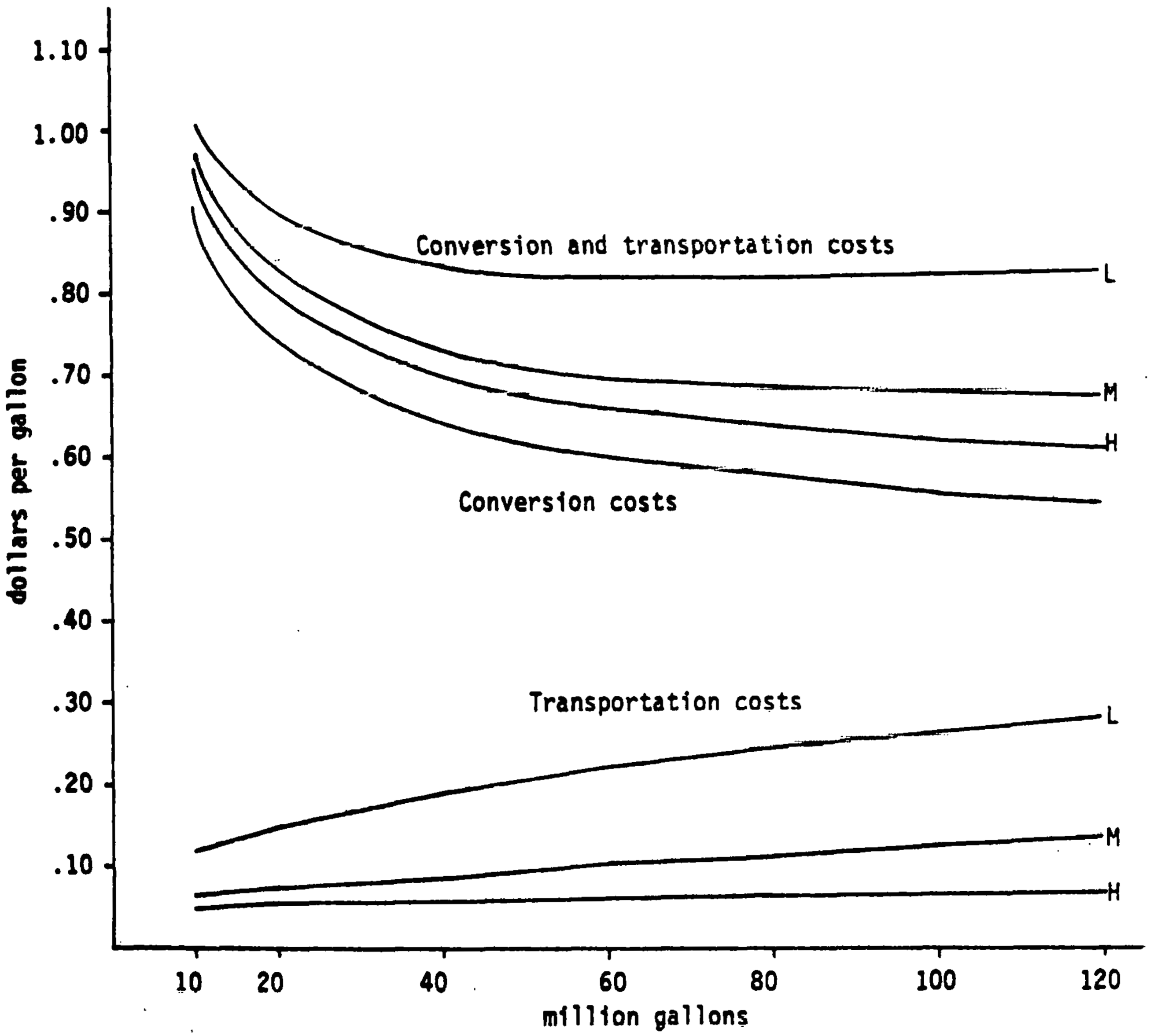

Figure VIII-1. Conversion and transportation costs based on alternative plant sizes and market densities

L = Low market density
M = Medium market density
H = High market density

However, the following observations are offered. Given the underlying ethanol production costs of more than $1.00 per gallon even for the large plant sizes and current ethanol market value of about $.41 per gallon not even the large plants are financially feasible without special incentives. Consequently, plant size decisions will necessarily be made within the context of special incentives if any plant is to be built at all. If public incentives for ethanol production are forthcoming of sufficient magnitude to make ethanol for gasohol production financially feasible for private investors, the plant size question needs to be investigated in light of the specific incentive package available.

Because of the lower unit ethanol production costs for the larger ethanol plants (60 to 120 million gallons annual capacity) larger plant sizes are preferred over the smaller (10-40 million gallon ethanol plants) for purposes of man production of ethanol. For less ambitious goals, the smaller plants appear favored over larger plants. Less total capital and operating costs are required. The smaller plant which should provide ample facilities to provide commercial operating experience and data on ethanol production, marketing and distribution. Private investors backing such semi-commercial-research-demonstration plants are exposed to less absolute risk with smaller plants. To represent small and large plants, the 20 and 100 million gallon plants were selected as representative of small and large plants.

The generalizations of Section C, below, should also be considered in relationship to the above potential determinants apropos of a specific and actual site location decision.

C. Plant Site Selection Criteria

Site requirements for an ethanol for gasohol plant are principally concerned with guaranteeing efficient access to process inputs and the disposition of process outputs.

Annual throughput volume of major process inputs and outputs for a 20 and 100 million gallon grain-ethanol plant are summarized in Table VIII-8. At minimum, site selection criteria would require that these throughput volumes can be managed.

Analysis of transportation costs for ethanol, grain, and distillers by-product in the previous section shows that because of expected different average lengths of haul, the transportation costs for grain, ethanol and distillers by-product are not proportional to their annual throughput volumes. Rather corn and distillers by-product transportation costs are more nearly equal, with the former ranging from $.022 to $.057 per gallon of ethanol and the latter ranging from $.021 to $.049 per gallon of ethanol within the range of parameter values considered.

Table VIII-8. Annual throughput quantity of major process inputs and outputs 20 and 100 million gallon grain-ethanol plants

	Units	Throughput volume Units/year	
Plant size	mil gal	20	100
Major inputs;			
Grain	mil bu	7.69	38.0
Coal	1,000 short tons	124.8	620.0
Boiler and cooling water	mil gallons	356.0 1/	1,780.0
Process water	mil gallons	285.0	1,425.0
Major outputs:			
Ethanol	mil gallons	20.0	100.0
Distilled dried grain	1,000 short tons	65.0	323.0
Waste water	mil gallons	238.0	1,190.0

1/ Excludes recycled water.

Source: Stone and Webster Engineering Corporation, Preliminary Economic Evaluation of Nebraska Grain Alcohol Plant, Agricultural Products Utilization Committee, State of Nebraska, December 1976, and DPRA estimates.

Because raw material assembly costs are expected to be the greatest or, perhaps the second major component of transportation costs (after by-products) and because raw material sources are more geographically concentrated than distillers by-product or ethanol markets, the primary site selection cost criterion should be that for raw material assembly.

Site selection secondary considerations include the efficiency of plant access to potential by-product user markets, potential gasoline-ethanol blending points, and adequate coal, water, and skilled labor resources. Sites must have primary highway access and rail sidings to accommodate grain, coal and by-product transportation requirements.

IX. COMMENTS ON IMPACTS OF REGIONAL GASOHOL PROGRAM

This study of the feasibility of establishing a gasohol program is necessarily a limited one. First, by its Terms of Reference, the study is restricted to the seventeen states comprising the Cornbelt, the Great Plains, and Colorado, Montana, and Wyoming. Secondly, the economic impact of such a program will be affected, in part, by its schedule of development and this, in turn, will be largely dependent upon the implementation of legislation designed to create investment incentives. Thirdly, the Terms of Reference preclude the Contractor's developing the sophisticated, comprehensive economic model that would be necessary to measure definitively the economic interrelationships existing among all aspects of such a program and between these aspects and the program's effect upon area cropland and a region's economy.

Some limited studies of the economic impact of gasohol have been recently completed. Though they do not consider the economic implications for this study's regional area and do not examine all economic sectors, they do offer some general insights into the economic effects of a gasohol program. Where they are pertinent, they will be reported below.

A. Ethanol Requirements

Ethanol production requirements will be a function of regional gasoline use; thus, gasoline consumption provides the basis for deriving potential ethanol use.

1. Historical Gasoline Use

Gasoline consumption in the seventeen state region is currently 39 percent of the total U.S. gasoline consumption (Table IX-1) and was relatively so during the 1974-1976 period. Regional consumption growth has paralleled that of the United States which during the past decade has grown at an average rate of about four percent annually.

From 1967 to 1977, the total domestic consumption of motor gasoline rose from 208.2 million gallons per day to over 300 million gallons per day, with the greatest increases occurring in 1968 and 1972 (Table IX-2). In 1974, the year in which demand was most directly affected by the oil embargo which extended from October 1973 to March 1974, consumption dropped by 2.1 percent. While annual increases have occured since 1974, their rate of increase has been somewhat lower than during the preembargo period.

Table IX-1. Gasoline consumption in the 17 state region and the United States 1974-1976 (on highway, off highway and other uses)

Area	1974	1975	1976
		(mil gal)	
Colorado	1,302	1,359	1,427
Illinois	5,025	5,087	5,342
Indiana	2,739	2,757	2,901
Iowa	1,647	1,657	1,730
Kansas	1,329	1,380	1,499
Michigan	4,565	4,630	4,862
Minnesota	2,034	2,066	2,151
Missouri	2,629	2,669	2,802
Montana	448	455	500
Nebraska	868	881	940
North Dakota	411	434	456
Ohio	5,006	5,095	5,274
Oklahoma	1,675	1,743	1,830
South Dakota	456	500	474
Texas	7,099	7,463	8,008
Wisconsin	2,146	2,197	2,299
Wyoming	299	319	335
Region Total	39,678	40,692	42,780
Total U.S.	101,856	104,267	109,431
Percent of U.S. Total	39.0	39.0	39.1

Source: National Petroleum News Factbook Issue, McGraw-Hill, New York, 1976 and 1977.

Table IX-2. Annual daily gasoline consumption and growth rate, 1967-1977

Year	Consumption	Annual rate of growth
	(mil gal/day)	(pct)
1967	208.2	3.1
1968	221.0	6.1
1969	232.1	5.0
1970	243.0	4.7
1971	252.6	4.0
1972	267.8	6.2
1973	280.3	4.7
1974	274.6	-2.1
1975	280.4	2.1
1976	293.1	4.5
1977	301.5	2.9

Source: Federal Energy Administration, Office of Energy Information and Analysis, Monthly Energy Review, July 1977.

About 97 percent of the motor gasoline consumed in the United States is for private and commercial needs. Ninety-four percent of all consumption was for private and commercial highway use. In 1975, nonhighway private and commercial use accounted for only 2.7 percent of the year's total consumption, with the agricultural sector claiming over half of that. Motor gasoline consumption for public use, highway and nonhighway, accounted for less than 2.3 percent of the 1975 total (Appendix IX-1).

Since passenger vehicles account for over 70 percent of the gasoline consumed in the United States (Appendix IX-2) (corresponding state consumption data are not readily available), passenger car fuel economy is a major factor in considering historical and future gasoline consumption growth. The average miles per gallon attained by all U.S. personal passenger vehicles declined steadily from 13.93 in 1967 to 13.01 in 1973. Since then, fuel economy has increased, but its 1975 rate was still less than that of 1967 (Table IX-3). Fuel economy dropped noticeably in 1973 as pollution control equipment became mandatory on new cars. There was some improvement in 1974 and 1975, but the average vehicle in 1975 still achieved 2.2 percent fewer miles per gallon of fuel than in 1967.

Fuel economy standards for light duty motor vehicles were established by Congress in the Energy Policy and Conservation Act for 1975. 1/ This legislation specified that 1978 model cars must meet a standard of 18 mpg on a production weighted average basis and that the standard must incrementally increase each year to 27.5 mpg by 1985:

Year	Mandated mpg 2/
1979	19.0
1980	20.0
1981	22.0
1982	24.0
1983	26.0
1984	27.0
1985	27.5

As the composition of the passenger car stock changes, this legislation will impact gasoline consumption.

A major change in consumption has resulted from the decrease in the number of cars requiring premium gasoline. In 1970, 32.3 percent of the cars on the road required premium gasoline, and its sales in major cities accounted for 42.6 percent of gasoline sales. By 1977, only 8.9 percent of the cars

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1/ U.S. Department of Commerce, U.S. Industrial Outlook, 1978.

2/ U.S. Department of Transportation, "Technology Sharing", National Transportation Statistics Annual Report, November, 1977.

Table IX-3. Passenger car fuel economy, 1967 to 1977

Year	Average passenger car fuel economy, calendar year basis	New car fuel efficiency, model year basis
	(mpg)	(mpg*)
1967	13.93	NA
1968	13.79	15.4
1969	13.63	15.4
1970	13.57	15.5
1971	13.57	15.1
1972	13.49	15.0
1973	13.10	14.5
1974	13.43	14.4
1975	13.53	15.6
1976	NA	17.7
1977	NA	18.6

* 55 percent city, 45 percent highway miles sales weighted average

Source: U.S. Department of Transportation, "Technology Sharing", National Transportation Statistics Annual Report, November 1977.

required premium, and sales had decreased to 15.5 percent of the total. 1/ Another major change has been the continuing increase in the consumption of the no-lead gasoline required for all cars domestically produced since 1975.

2. Projected Gasoline Consumption

The Department of Energy has recently issued a report to Congress showing demand projections for gasoline (and other energy forms). In projecting the energy demand for the transportation sector, two primary factors were recognized: (1) little substitutability of fuel exists in the short run among types of transportation, and (2) highway vehicle fuel use is large compared to that for other types of transportation. Therefore, the stock of vehicles, their characteristics, and the intensity of their use become significant. These factors embody the effects of trends in income, economic activity, fuel prices, and technology. The average efficiency of the overall stock of vehicles, the more fuel-efficient new cars, the relative number of each, and their intensity of use were incorporated into these projections.

Table IX-4 depicts six different U.S. gasoline consumption scenarios for 1985-1990: five show oil supply and demand situations with a constant dollar price of imported oil and one scenario assumes a high import price of fuel. Using the Projection Series A (high supply, high demand) and E (low supply, low demand) to bracket consumption, the demand for gasoline ranges from 118.3 billion gallons to 126.5 billion gallons in 1985 and from 124.2 to 137.2 billion gallon in 1990. By comparison, the consumption in 1975 was 104.2 billion gallons. The annual rates of growth of 1.0 to 2.0 percent are down from the historical levels of over 4 percent in the 1960's.

As can be seen in the projections, gasoline consumption will not vary widely under the various scenarios. For purposes of determining potential ethanol requirements, Scenario C will be used.

These detailed gasoline consumption projections were not dissaggregated by state or region. As an indication of future gasoline consumption in this study's region, it was assumed that the region's share of the United States total would remain at 39 percent. Applying this assumption to Scenario C, interpolating for interim years, and assuming a 2.0 percent growth for the 1990-2000 period, indicate that the region's gasoline consumption will increase from its 1975 level of 40.6 billion gallons to 53.5 billion gallons in 1990 and to 65.2 billion gallons in 2000 (Table IX-5).

The projections, though but estimates, suggest that regional gasoline consumption will by 2000 increase 60 percent over its 1975 level.

1/ National Petroleum News Factbook Issue, New York: Mc-Graw Hill, May, 1977.

Table IX-4. Projected consumption 1/ and annual rate of growth of gasoline in the United States, 1985 and 1990

Scenario:	A	B	C	D	E	F
Demand:	High	High	Med	Low	Low	High import price
Supply of domestic oil and gas:	High	Low	Med	High	Low	
1985 (mil gals)	126,496	126,344	123,936	118,448	118,256	123,264
Annual rate of growth, 1975-1985 (pct)	1.9	1.9	1.7	1.3	1.3	1.7
1990 (mil gal)	136,400	136,176	137,200	124,528	124,192	135,208
Annual rate of growth, 1985-1990 (pct)	1.5	1.5	2.1	1.0	1.0	1.9

1/ The consumption in 1975 was 104,232 million gallons.

Source: U.S. Department of Energy, Energy Information Administration, "Projections of Energy Supply and Demand and Their Impacts", Annual Report to Congress, Vol. II, 1977.

Table IX-5. Indicative gasoline and ethanol use in the 17 state region, 1980-2000

Year	Gasoline: United States	Gasoline: Region 1/	Ethanol, Percent gasohol use: 25	50	100
	-----(bil gal)---------		----------(bil gal)----------		
1975	104.2 2/	40.6	--	--	--
1980	113.4 3/	44.2	1.1	2.2	4.4
1985	123.9 4/	48.3	1.2	2.4	4.8
1990	137.2 4/	53.5	1.3	2.7	5.4
1995	151.5 5/	59.1	1.5	3.0	5.9
2000	167.2 5/	65.2	1.6	3.3	6.5

1/ Assumes the regions consumption percentage of U.S. total remains at 39 perce

2/ DOE, op. cit.

3/ Estimated at annual 1975-85 medium growth rate (1.7 pct) as reported.

4/ Medium demand and oil price (scenario C) as reported in DOE, op. cit.

5/ Extrapolated from 1990 at a 2.0 percent annual growth rate.

3. Potential Ethanol Requirements

As previously stated, the rate of growth of gasohol use is not known and will depend upon ultimate government policy. However, to provide perspective, the study projected the study region's ethanol requirements by estimating its use under three differing levels of gasohol usage. The first column indicates the percentage of the area's gasoline requirements that gasohol would provide. The second column shows the percentage of gasoline that would be replaced by ethanol at the corresponding levels under a blending ratio of 90:10.

% gasohol	% gasoline replaced by ethanol
25	2.5
50	5.0
100	10.0

The potential ethanol requirements, then, would range from 1.1 billion gallons in 1980 to 1.6 billion gallons in 2000 under the 25 percent replacement scenario (Table IX-5). Under the 100 percent replacement alternative, ethanol requirements would range from 4.4 billion gallons in 1980 to 6.5 billion gallons in 2000 for the region.

The data shown in Table IX-5, are intended to demonstrate the dimensions of various levels of ethanol use in the seventeen state region and to provide insight into the potential impacts of a gasohol program.

B. Agricultural Impacts

The agricultural impacts of a regional gasohol program would include its effects on farm prices and net farm income. A qualitative, definitive estimate of these impacts would require developing an economic model representing the region's and the nation's agriculture and other, affected economic sectors. While similar models exist, no specific analyses of a seventeen state regional program have been done; however, the results of related analyses done under differing assumptions and the results of land resource impact analyses do provide some insights and are included below when applicable.

1. Land Resource Impacts

A gasohol program's impact on land resources would be felt as land was utilized to produce the raw materials for ethanol production. To estimate the impact of the program, then, requires a determination of (1) the area acreage needs for other crop production, (2) the acreage needed for ethanol raw material crop production, and the amount of land available as either new or substitute crop lands. Such estimates, also, must reflect long term cropping requirements.

a. Baseline Acreage Requirements

A baseline condition was determined under two demand alternatives: moderate and high demand. The baseline condition also assumes the following assumptions, generally across both the moderate and high demand scenarios (1) demand functions for farm commodities are perfectly "price inelastic" and (2) supply functions are perfectly "price elastic", characteristics which result in "constant price" projections, consequently certain checks on productive resource availability and productivity are needed.

In addition, both scenarios assume no wars and no major economic disruptions such as another OPEC oil embargo. Both scenarios further assume that current trends in environmental controls, consumers tastes and preferences, and technological change continue during the scenario periods.

Under the moderate scenario, total U.S. population will reach 236 million by 1985. The annual growth rate in total disposable income in 1958 dollars will be 4.1 percent from 1976 to 1980 and 3.8 percent after 1980. Exports of U.S. agricultural commodities will be constrained by the policies of the major prospective importing countries to promote increased self-sufficiency. Concurrently, (1) the world capacity to produce cereal grains will increase faster than consumption, (2) grain reserves will be rebuilt, (3) Europe and the USSR will approach self-sufficiency in cereal grains, (4) the European Community will maintain a high-price policy and thereby encourage the substitution of protein supplements and nongrain feeds for grains, and (5) the People's Republic of China will import wheat and export rice, and (6) Japan will continue to be the largest importer of U.S. wheat and coarse grains.

Under the high demand scenario, the total U.S. population will reach 244 million people by 1985, a result of the continuation of recent birth rates. The annual growth rate in total disposable income in 1958 dollars will be 4.5 percent through 1985. Exports of U.S. agricultural commodities will increase because: (1) the USSR and Eastern Europe will increase trade with the U.S., especially the import of grain to expand livestock production and increase consumption, (2) The People's Republic of China will increase trade by importing U.S. cereal grains to improve diets, (3) the European Community will adopt lower target prices for grains and, thus, lower its production and increase its consumption of grain imports, (4) livestock production will increase in the developing countries, and (5) fishmeal production will stagnate at 1969-71 levels.

These basic assumptions are translated into U.S. production requirements (see Appendix IX-3) which are used to determine regional acreage requirements based on expected regional yields and regional acreage shifts. Based on this approach, the seventeen state region cropland requirements were estimated. Under the moderate demand scenario 229.6 million acres would be required in 1980 and increase to 247.0 million acres in 2000 (Table IX-6). Under the high demand assumption, 259.2 million acres would be used in 1980 and 280.7 million acres in 2000.

Table IX-6. Projected cropland requirements in the 17 state region, for baseline demand, 1980-2010

Demand scenario and crop	1980 2/	1985 1/	1990 2/	1995 2/	2000 2/	2005 2/	2010 1/
	(1,000 acres)						
Moderate demand							
Corn	53,960	53,250	52,500	51,800	51,100	50,400	49,700
Grain sorghum	15,100	15,400	15,700	15,900	16,200	16,500	16,800
Wheat	41,360	40,400	39,400	38,500	37,500	36,600	35,600
Soybeans	41,160	42,000	42,800	43,700	44,500	45,400	46,200
Other crops	78,040	82,950	87,900	92,800	97,700	102,600	107,500
Total	229,620	234,000	238,300	242,700	247,000	251,500	255,800
High demand							
Corn	63,200	62,500	61,800	61,100	60,400	59,700	59,000
Grain sorghum	17,360	17,700	18,000	18,400	18,700	19,100	19,400
Wheat	50,950	49,850	48,700	47,600	46,500	45,400	44,300
Soybeans	41,400	43,400	45,400	47,400	49,400	51,400	53,400
Other crops	86,300	91,150	96,000	100,300	105,700	110,600	115,400
Total	259,210	264,600	269,900	275,300	280,700	286,200	291,500

1/ Development Planning and Research Associates, "Assessment of the Environmental Implications of Regional Crop Production Trends, Interim Workshop Report", EPA, February 1978. This study divided the United States into 5 regions including the Corn Belt, Great Plains and West. The 17 state region of this study includes the Corn Belt, Great Plains plus Colorado, Wyoming and Montana in the West. These states were disaggregated from the West for inclusion in this study.

2/ Interpolated from the 1985 and 2010 projections.

b. Ethanol Acreage Requirements

The indicated ethanol acreage requirements were derived from the ethanol requirements shown in Table IX-5 above and the yield projections (Appendix IX-4) used to develop the baseline acreages shown in Table IX-6 above. The acreage requirements were calculated under four crop situations for each of the gasohol use level scenarios.

As can be seen in Table IX-7, the least amount of acreage (about 17 million acres under 100 percent gasohol use) would be required if only corn were used as an ethanol raw material. An all grain sorghum program would require about 28 to 31 million acres and an all wheat program would require 55 to 60 million acres. If an ethanol industry were developed, all three commodities would probably be used. Assuming the same production ratios 1/ as shown in the baseline, a weighted average acreage requirement of about 25 million acres was calculated.

The analysis, then, indicates that a substantial gasohol program would require significant increases in grain acreage.

c. Available Acreage

The total of both the baseline and ethanol acreage requirements provides one possible perspective of a gasohol's program's acreage impact. As shown in Table IX-8, the total acreage requirement for a 100 percent regional gasohol program under the moderate demand scenario ranges from about 255 million acres in 1980 to 273 million acres in 2000. Under the high demand assumption, the acreage would be increased to 284 to 308 million acres for 1980 and 2000 respectively. A partial gasohol program would reduce the total acreage requirement.

The data of a recent USDA 2/ land use study indicate that the study region has 343.2 million acres of current and potential cropland. This includes 287.2 million acres currently available, 41.8 million acres with high cropping potential, and 14.2 million acres with medium cropping potential. This estimate does not include any allowances for losses due to urbanization, roads, and for other non-cropping uses, and it excludes federally owned lands.

The projected total cropland requirements are within the estimated available cropland. Under the 100 percent gasohol scenario in 2000, 308 million acres would be required and 343 million acres are available.

1/ Wheat production in the baseline is 15 to 17 percent of total production of corn, grain sorghum, and wheat. This percentage is less than the 20 to 25 percent wheat limitation for a grain ethanol plant.

2/ U.S. Department of Agriculture, Soil Conservation Service, "Potential Cropland Study," July 1976.

Table IX-7. Indicative cropland requirements in the 17 state region for ethanol, 1980-2000

Crop	Gasohol use scenario	1980	1985	1990	1995	2000
		(1,000 ac)				
Corn						
	25 percent	4,250	4,179	4,217	4,306	4,384
	50 percent	8,503	8,363	8,438	8,612	8,766
	100 percent	17,008	16,727	16,880	17,224	17,535
Grain sorghum						
	25 percent	6,950	7,023	7,227	7,574	7,841
	50 percent	13,906	14,052	14,459	15,149	15,678
	100 percent	27,811	28,105	28,924	30,297	31,361
Wheat						
	25 percent	13,642	13,727	13,927	14,202	14,963
	50 percent	27,296	27,466	27,865	28,404	29,917
	100 percent	54,593	54,932	55,740	56,808	59,844
Three crop production weighted average						
	25 percent	6,210	6,130	6,190	6,340	6,500
	50 percent	12,420	12,270	12,380	12,680	12,990
	100 percent	24,840	24,540	24,720	25,360	25,990

Source: DPRA estimate

Table IX-8. Total cropland requirements under three ethanol requirement scenarios and assuming no crop substitution for the 17 state region, 1980-2000

	1980	1985	1990	1995	2000
	(mill acres)				
Moderate demand					
25 percent gasohol	235.8	240.1	244.5	249.0	253.5
50 percent gasohol	242.0	246.3	250.7	255.4	260.0
100 percent gasohol	254.5	258.5	263.1	268.1	273.0
High demand					
25 percent gasohol	265.4	270.7	276.1	281.6	287.2
50 percent gasohol	271.6	276.9	282.3	288.0	293.7
100 percent gasohol	284.0	289.1	294.7	300.7	307.7

Source: DPRA estimate

These total cropland estimates are not conclusive, however, further impacts of a regional gasohol program would probably result in a shift in croplands presently used in other crop production, especially for those devoted to soybean production.

d. Impact of Distillers Dried Grains on Other-Crop Acreage

For each gallon of ethanol, about 6.5 pounds (see Chapter IV) of distillers dried grain are produced. As shown in Table IX-9, the quantities of DDG are significant, reaching 21 million tons by 2000 under the 100 percent gasohol assumption. Such a production would affect soybean meal production, for DDG would offer a less espensive substitute product. Current soybean meal consumption of 15 million tons is part of the total high-protein feed use of 36 million tons (Appendix IX-5). The expected impact of the projected quantity of DDG on soybean prices and soybean production is not known, but considering the relative qualities involved, the impact would appear to be significant. Some related studies will provide some insight into this issue.

Wisner and Gidel 1/ have projected the production of distillers dried grains under alternative levels of gasohol usage and the percentage increases in distillers dried grains and total high-protein supplies that would result from the projected production levels. Using the 1973-1974 supplies as a base and a gasohol program for the state of Iowa only, Wisner and Gidel estimated an increase in total U.S. high protein feed supplies of about one percent and an expanded U.S. distillers dried grain production of 119 to 126 percent. If a nation-wide gasohol program were in place by 1980, the percentage increase in high protein feed supply would be 80 to 88 percent and distillers dried grains would increase 60-fold.

The projected relative price impacts of a gasohol program are shown in Table IX-10. These impacts assume high protein feeds, a constant soybean acreage, and all other price influencing variables unchanged. An Iowa gasohol program would be expected to place moderate downward pressure on prices for distillers dried grains and only slight downward pressure on the prices for soybean meal and soybeans. A national gasohol program would sharply depress prices for both distillers dried grains and soybean meal, and lower soybean prices by more than $2.00 per bushel. The projected growth in high-protein feed demand is expected to moderate the situation to some degree.

Projecting the estimates of the Wisner and Gidel study further would show that a five-state program producing 3.9 to 4.3 million tons of DDG would reduce soybean prices by $.60 to $.95 per bushel. A regional program of 15.6 million tons of DDG in 1985 and 21 million tons of DDG in 2000 would reduce soybean prices by $1.00 and $2.00.

1/ Wisner, Robert N., and Jerry O. Gidel. Economic Aspects of Using Grain Alcohol as a Motor Fuel, with Emphasis on By-Product Feed Markets, Iowa State University, June 1977.

Table IX-9. Production of distillers dried grain with corresponding levels of ethanol production, 1980-2000

Year	Percent gasohol use		
	25	50	100
	(1,000 tons)		
1980	3,575	7,150	14,300
1985	3,900	7,800	15,600
1990	4,225	8,775	17,550
1995	4,875	9,750	19,175
2000	5,200	10,725	21,125

Source: DPRA estimate

Table IX-10. Potential Impact of alternative levels of "Gasohol" programs on prices for distillers dried grains, soybean meal and soybeans in 1980, before including growth in demand for high protein feeds.

Level of "Gasohol" program	Potential impact on distillers dried grains	Potential impact on soybean meal prices	Potential impact on soybean prices 1/
Total gasoline usage:			
Iowa	18% to 25% decrease	3% to 4% decrease	7¢ to 10¢/bu decrease
Five-state region	2/	20% to 32% decrease	60¢ to 95¢/bu decrease
United States	2/	2/ over 70% decrease	2/ over $2.00/bu decrease

1/ Based on initial soybean meal price level of $125 per ton and soybean meal yield of 47.6 pounds per bushel. Higher initial soybean meal price levels would lead to greater impacts on soybean prices.

2/ Price decrease would be very large but is impossible to estimate precisely. Past price-quantity relationships suggest prices would become negative with the large supply increases involved, although this seems unlikely.

Source: Wisner, R. N. and J. O. Gidel, *op. cit.*

These results suggest that land would be diverted from soybeans to corn. The USDA concluded that moch of the needed land could be diverted from the production of soybeans because of the competition between distillers dried grain and soybean meal. 1/ Thus, under the considerations of available land or the possible cropping pattern shifts, it is concluded that land, per se, will not be impacted through the increased acreage requirements sufficiently enough for it to be a program constraint.

2. Livestock Production

The impact of a national gasohol program on livestock production was characterized in a recent USDA report as follows: 2/

> Aggregate livestock production would decline from the current base estimates. This occurs because of the shift to distillers grains. The higher fiber content of this feed will require a longer digestion phase. But the much cheaper relative price of this feed should make it sufficiently attractive so as to be substituted for soybean oil meal into hog and poultry rations as well as beef. If livestock producers accept this low cost feed and modify their feeding schedules accordingly, this would slow down the livestock cycle and result in higher total costs to livestock producers.

While the regional program considered in this study would be only about 40 percent of a national program, it would be sufficiently large enough to create an impact on livestock production.

3. Farm Prices

As discussed above, the interrelationship among a large regional or national gasohol program, farm prices, and cropping patterns is difficult to measure. It seems likely that soybean prices would be depressed under a full gasohol program in the seventeen state region. The impact on food and feed grain prices are not as clear, however, since it would depend to some extent on how fast the program developed.

USDA, concluded that the development of a national program by 1982 would increase the price of food and feed grains. 3/ Under a slower rate of development, the impact on grain prices would be moderated for farmers

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1/ U.S. Department of Agriculture, "Gasohol from Grain--The Economic Issues", ESCS Publication No. 11, Jan. 19, 1978.

2/ Ibid.

3/ Ibid.

(who over the long run generally produce near their cost of production) would have time to make production adjustments as price takers. A definitive assessment of ultimate grain prices would require extensive econometric analyses 1/ and specifications regarding the phase-in of the program. Such work is not available and was considered beyond the scope of the present study.

4. Net Farm Income

Estimating the impact of a regional gasohol program on net farm income is subject to the same limitations as on estimating its price impact. The USDA in its recent assessment of gasohol reported the following:

> Crop receipts would be up somewhat, due to increased price of corn and other grain, but this would be partially offset by the higher variable costs of corn relative to soybeans. This would result in a slight net increase in farm income. 2/

Again, to assess the impact on net farm income, a rigorous econometric analyses would be needed.

C. Impact on the Soybean Industry

As suggested in the preceding discussion, one of the major impacts of a large gasohol program is its effect on the soybean industry through the large quantities of distillers dried grain that would be produced (Table IX-9), and the depressing effect of that production on soybean meal prices. The work of Wisner and Gidel would indicate that a national gasohol program with its required ethanol production would virtually eliminate the soybean crushing industry. 3/

The impact of a regional program of the size for the seventeen state region considered in this study might be less severe, but the locating of ethanol plants in locations similar to those for soybean crushers would probably cause soybean plant closures. Definitive estimates of such closures would require additional study, particularly of the extent to which soybean acreage would be reduced.

1/ It should be noted that the impacts would be regional. For example, a reduction of soybeans would require possible new sources of vegetable oil and increased vegetable oil prices might impact cotton production in the Southeast.

2/ USDA, *op. sit.*

3/ USDA reports a similar conclusion in USDA, *op. cit.*

The impact at the local level of substituting corn for soybean acreage may be illustrated by comparing a soybean mill and an ethanol fermentation plant. Soybean crushers are found in the grain producing areas and are concentrated in Iowa, Illinois and Indiana. Ethanol production plants would also be located near grain supplies. The relative impacts in the surrounding area may be deduced by examining the information tabulated below.

Plant	Size	Annual inputs (mil bu)	Employment	Annual output of high protein feeds (1,000 T)
Soybean mill 1/ (218,000 T/yr)	Large	7.3	200	173 (44% protein)
Ethanol	100 mil gal	38.5	340	323 (22-27% protein)

Although the outputs of high protein feeds from the above plants are essentially the same in terms of total protein, the amount of cropland and the number of employees required are greater for the ethanol plant. With current U.S. average yields, 440 thousand acres would be required for corn inputs and 270 thousand acres for the soybeans. The ethanol plant would require 140 more employees.

D. Other Impacts

The impact of ethanol production is not confined to agriculture. The impacts resulting from replacing a portion of the gasoline consumed with ethanol would, for instance, affect other segments of the economy. Too, the ethanol production would affect energy supplies to the extent that they were consumed in ethanol and raw material production.

1. Refinery Operations

With an ultimate decrease by 10 percent in the volume of gasoline refined, impacts on refinery operations would be anticipated. The severity of the impact would depend, in part, on the rapidity of gasohol use phase-in--if relatively slow, then refineries as a whole could adjust their operations with fewer dislocations. Currently, approximately five years lead time, 2/ is required between management approval and refinery start up. In addition,

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1/ Development Planning and Research Associates, Inc. Economic Analysis of Effluent Guidelines--Miscellaneous Foods and Beverages Industry, Vol. I, Edible Oil Industries, EPA, March 1977.

2/ Dixon, J., Bonner & Moore, Private communication, May 15, 1978.

refinery operations would be impacted differently by the decision as to whether to market gasohol of the same octane number as present day unleaded gasoline (which means producing a special base gasoline having a lower octane number) or to market gasohol having an octane number higher than present day unleaded gasoline (which means producing a base gasoline similar to today's unleaded product). The impact would vary by refinery depending on current operations. In addition, it must be remembered that gasoline is but one product of a refinery; thus, a reduction of this magnitude would also impact on all other refined petroleum products, fuels, and petrochemicals.

2. Energy Requirements

Although the primary emphasis in this report has concerned the energy required for the production of ethanol from the raw materials, in an overall assessment of the energy required for the gasohol program, other related energy factors must be considered: for instance, grain and other raw material production energy, transportation energy, and the energy required to produce the fertilizers required by marginal lands.

If, indeed, gasoline prices increased substantially, transportation cost, production costs, fertilizer costs, and in time, grain prices and ethanol costs would also increase.

3. Consumer Prices

Consumer prices would be expected to increase as farm prices increased reflecting higher feed, livestock, and ultimately, meat product prices. It would be necessary to determine farm prices before a definitive answer could be given regarding the magnitude of consumer price increases.

4. Gasohol Program Costs

In Chapter VII, it was concluded that some type of government incentive equivalent to $.75 per gallon of ethanol ($.075 per gallon of gasohol) would be required to attract investment into ethanol production. This estimate is based on a 100 million gallon plant. A 20 million gallon plant would be $.94 per gallon of ethanol ($.094 per gallon of gasohol). Income taxes paid by producers would be $.09 and $.13 per gallon under the assumption which the subsidies were estimated. Thus, in net terms, the subsidies would amount to $.66 and $.81 per gallon for the 20 MGH and 100 MGY plants, respectively. It is also noted that these estimates make no allowances for grain price increases or distillery dried grain price decreases that would be expected with a massive gasohol program.

Extending these by the three scenarios of gasohol use, it can be seen that subsidy payments would be significant (Table IX-11). For example, under a 100 percent regional program based on 100 million gallon plants

Table IX-11. Indicative annual net subsidy 1/ costs under three gasohol programs for the 17 state region

Year	Percent gasohol use: 25 — 20 MGY	25 — 100 MGY	50 — 20 MGY	50 — 100 MGY	100 — 20 MGY	100 — 100 MGY
	($bil)					
1980	.9	.7	1.8	1.4	3.6	2.9
1985	1.0	.8	1.9	1.6	3.9	3.2
1990	1.0	.9	2.2	1.8	4.4	3.6
1995	1.2	1.0	2.4	2.0	4.8	3.9
2000	1.3	1.1	10.9	2.2	5.3	4.3

1/ Income taxes paid by ethanol producers were subtracted from the gross subsidy.

Source: DPRA estimate

would require 1/ an annual net subsidy of $3.2 billion in 1985 and increase to $4.3 billion by 2000. An industry based on smaller units would increase these payments by about 22 percent.

5. Impacts on Plant Engineering, Equipment Manufacturers and Construction Support

In considering these indicated ethanol amounts, the critical importance of the development schedule is demonstrated. For example, a program for 100 percent gasohol in the region would require 48 of the 100-million gallon ethanol plants by 1985 and 65 by 2000 with investments per plant of about $100 million (.97 per gallon of ethanol); thus, to develop an industry of 48 plants by 1985 would require a construction program of $4.4 billion in 1977 dollars. Smaller plants would increase this investment requirement.

This would represent a massive construction effort; indeed, it would be questionable that a 100 percent replacement of gasoline with gasohol would be accomplished by 1985. Even under 50 percent replacement by 1985, a $2.2 billion construction program would be required. Gasohol programs of this magnitude would create a significant strain on engineering, plant equipment, and plant construction capacity. Quantification of this would require careful study of engineering equipment manufacturers and construction firms. Certainly if a significant gasohol program is pursued or contemplated during the next decade, these considerations should receive careful attention.

6. Capital Markets

The investment requirement for a full regional gasohol program for the seventeen state region would be about $4.4 billion, a capital funding that would place pressure on capital markets, the extent of which is not known. Considering the current demands on capital for meeting the various governmental regulatory (pollution, health and safety) and plant modernization requirements, the consequent pressures on the availability of capital and the impact on the capital market of a gasohol program should be considered in detail.

7. Balance of Payments

Ethanol production impacts would not be confined to the domestic situation, but its ramifications would be felt in U.S. foreign trade and in the balance of payments. In particular the imports of crude oil and the exports of food and feed grains would be impacted.

1/ It is noted that the larger plants' financial profiles are based on reconnaissance grade estimates and that more detailed studies could alter these estimates.

The value of the exports of grain, cereal preparation, and soybeans constituted 55.5 percent of total exports in 1977. By contrast, the value of petroleum and related products imported in 1977 was 28.3 percent of the value of total U.S. imports and 1.75 times that of the value of the agricultural exports (Table IX-12).

The possible change in the balance of payments resulting from a large scale gasohol program has been addressed in various studies. 1/ The extent of the reduction in feed grains and soybeans for export is dependent on both the extent of the gasohol program and, thus, the use of these grains in ethanol production and on the increase in acreage or production levels of the grains. Since 6.5 pounds of distillers dried grains are produced for each gallon of ethanol, the impacts on livestock feeds are moderated. But it should be noted that for each bushel of corn fermented, 16.8 pounds of distillers dried grains are produced. These compete more directly with high protein feeds rather than corn. Although the total quantities of potential animal feeds are changed, the quantities are not changed as much as might be anticipated initially. Again, the rapidity of the phase-in of a gasohol program would be important. If it were developed over a period of time, possibly markets for at least a portion of the 20 million tons of distillers dried grains could be developed. If the historical percentage (about 40) 2/ is exported, this quantity of 8 million tons is twice that of the current quantity of soybean meal exported.

The energy situation is complex. For every gallon of gasoline replaced with alcohol, it has been suggested that crude oil use (presumably imports) could be reduced by a factor of 1.6 since not only gasoline but a variety of products are obtained when crude oil is refined. 3/ Thus, for a nationwide gasohol program requiring 10.9 billion gallons of ethanol (260 million barrels), the crude oil use would be reduced by 415 million barrels annually (yields of joint products would be reduced simultaneously). But increased gasohol production requires increased raw material production and this, in turn, requires increased amounts of energy. Again, the effects of one portion of an interrelated system cannot be analyzed in isolation. An elaborate model would need to be developed in order to analyze all the parameters with some degree of precision.

In summary, the economic, environmental and international impacts of a gasohol system depend on the extent of the program and the timing of the phase-in.

1/ Sources include: Smith, Stephen M., M. L. Jackson and L. Johnson, "The Feasibility of Gasohol: An Examination of the Issues", Report No. 202, Agricultural Experiment Station, University of Idaho, April 1978.

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2/ Wisner and Gidel, op. cit.

3/ Putman, W. Farmland Industries, Inc., Private communications, May 12, 1978.

Table IX-12. Foreign trade of the United States.

	Exports		Imports	
	1976	1977	1976	1977
	---------------million dollars---------------			
Grain and cereal preparations	10,910.9	8,754.8	1/	1/
Soybeans	3,315.4	4,393.2	1/	1/
Ag products, total	22,997.6	23,671.0	11,179.3	13,538.3
Petroleum and products	997.6	1,275.6	31,797.9	41,526.1
Total U.S.	113,318.5	117,962.7	120,677.6	146,816.7

1/ Not tabulated separately.

Source: U.S. Department of Commerce, Bureau of Economic Analysis, Survey of Current Business, April 1978.

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APPENDICES

Chemical and physical properties of ethanol

Property	Ethanol
Formula	C_2H_5OH
Molecular weight	46.07
Composition, weight percent	
Carbon	52.2
Hydrogen	13.1
Oxygen	34.7
Specific gravity 60°F/60°F	0.794
Density lb/gal - 60°F	6.6
Boiling temperature, °F	172.0
Flash point °F	55.0
Flammability limits, volume percent	
Lower	4.3
Higher	19.0
Heating value Btu/gal at 68°F (liquid fuel/liquid water)	84,480
Latent heat of vaporization Btu/gal at 68°	2,378.0
Stoichiometric air-fuel ratio (lb air/lb fuel)	9.0
Octane number research	106.0
Octane number motor	89.0

Source: American Petroleum Institute. Alcohols, A Technical Assessment of Their Application as Fuels, Publication No. 4261, July 1976.

Gasoline refinery and distribution system

From the refinery, gasoline goes via one of several possible routes to the retail consumer. The major portion of gasoline flows from the refinery via pipeline to local terminals. From these terminals, the gasoline is loaded onto trucks (or in a few instances rail cars) for transport to the retail outlet,sometimes via a local bulk station. An alternative method of distribution consists of tanker trucks loading "off the rack" at refineries; however, time and safety factors restrict this type of loading to large trucks only. For refineries located on the Great Lakes, petroleum products may be shipped by lake tanker. Refiners on rivers may utilize river barge. The Gulf Coast refineries utilize seacoast tankers to haul some petroleum products to the East Coast. Seacoast tankers also operate along the West Coast. In only a few isolated spots in northern California and Nevada are retailers more than 150 air miles from a pipeline terminal or refinery.

The pipeline system in the U.S. is shown on the accompanying map (Figure A). Large pipelines run from the refineries in the Texas-Louisiana area to the Northeast. Other major routes run from the refineries on the East Coast, the Chicago area and the California Coast.

The pipeline company takes delivery at the refinery, tests for specifications and then at the destination pipeline terminal maintains storage and load-out facilities, with facilities for injecting any required additives as the trucks are being loaded.

Another distribution arrangement utilizes refinery exchanges whereby one supplier buys a base gasoline at a competitor's refinery but its own specific additives are injected during truck loading, much as is done at the pipeline terminal. These exchanges facilitate the distribution of gasoline which meets brand specification, and result in lower overall transportation costs for the consumer. Presumably this same type of arrangement could be made for gaschol distribution.

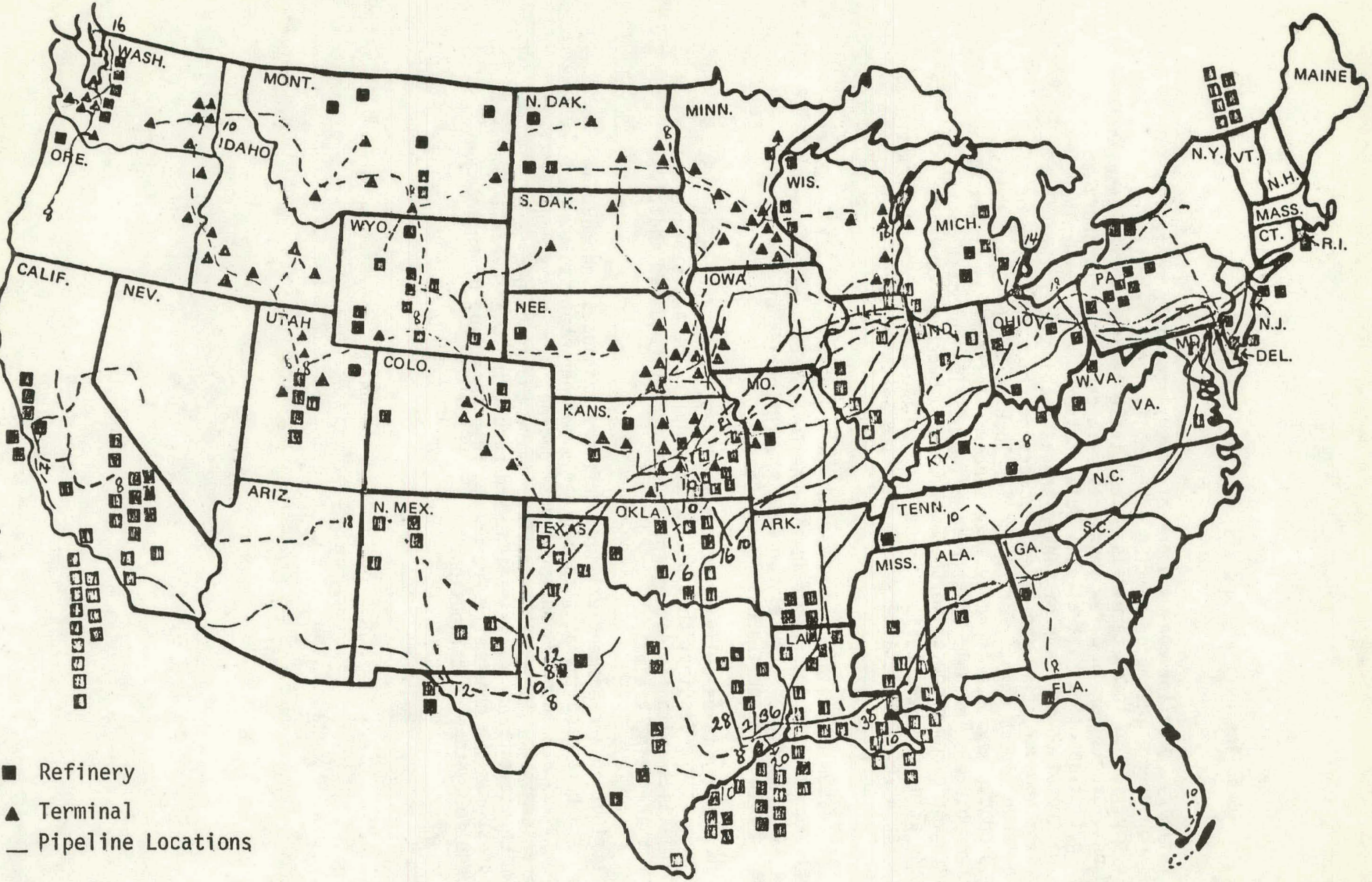

Figure A. U.S. refineries, pipelines and terminals

Source: Compiled from Petroleum Pipelines in the United States and Canada, Petroleum Publishing Co 1976.

Toxicity hazards for ethanol and gasoline

Exposure	Methanol	Ethanol	Gasoline
Acute local			
Irritant	1	1	2
Ingestion	-	-	1
Inhalation	1	-	1
Acute systemic			
Ingestion	3	2	2
Inhalation	2	2	2
Skin absorption	2	1	-
Chronic local			
Irritant	1	1	u
Inhalation	1	-	u
Chronic systemic			
Ingestion	2	1	-
Inhalation	2	1	u
Skin absorption	2	1	u

\- no information given.

0 = no harm or harmful in overwhelming doses.
1 = slight, causes readily reversible changes which disappear after exposure.
2 = moderate, may involve both reversible and irreversible changes, but not severe enough to cause death or permanent injury
3 = high, may cause death or permanent injury after short exposure to small quantities.
u = unknown: no information on humans considered valid by authors

Source: Sax, N. Irving, Dangerous Properties of Industrial Materials 4th edition, 1975.

Crude oil prices

Domestic crude oil prices (average of 8 areas) increased more or less steadily from $2.765 per barrel in 1955 to $3.388 per barrel in 1972. After the oil embargo of 1973-74, the crude prices increased rapidly to $8.130 per barrel in 1976 (Table A).

In accordance with the provisions of the Energy Conservation and Production Act, the ceiling prices of crude oil at the wellhead varies. As of July 1977, there were five crude oil prices: lower tier, upper tier, actual stripper, Alaskan North Slope, and Naval Petroleum Reserves (Table B). The actual domestic average price of crude oil--the average price at which all domestic crude oil is purchased--had increased from an average of $6.87 per barrel in 1974 to $8.72 in November 1977.

The price paid by refiners for domestic crude petroleum includes transportation costs from the wellhead to the refinery. The refiner acquisition cost of imported crude petroleum is the average landed cost of imported crude petroleum to the refiner and represents the amount which may be passed to the consumer. It incorporates transportation costs and fees (including the supplemental import fees) and any other costs incurred in purchasing and shipping crude oil to the U.S. The domestic imported and composite averages are tabulated below.

Year	Domestic	Imported	Composite
		($/bbl)	
1974	7.18	12.52	9.07
1975	8.39	13.93	10.38
1976	8.84	13.48	10.89
1977	9.53	14.52	11.95

All the averages increased during the 1974-77 period. There was, however, a slight drop in imported crude price in the early months of 1976 (Table B).

Table A. Historical crude oil and gasoline prices, 1965-76

Year	Crude oil 8 area average
	($/bbl)
1965	2.864
1966	2.882
1967	2.913
1968	2.941
1969	3.077
1970	3.177
1971	3.385
1972	3.388
1973	3.885
1974	6.739
1975	7.520
1976	8.130

Source: National Petroleum News Factbook Issue, McGraw-Hill, New York, 1977.

Table B. Domestic crude petroleum prices at the wellhead.

Year	Month	Lower tier1/	Upper tier	Actual stripper1/	Alaskan north slope2/	Naval petroleum reserves3/	Actual domestic average4/	Imputed domestic average
		(dollars per barrel)						
1974	Ave.	5.03	10.13				6.87	6.87
1975	January	5.05	11.28					7.61
	February	5.03	11.39					7.47
	March	5.03	11.47					7.57
	April	5.03	11.64					7.55
	May	5.03	11.69					7.52
	June	5.03	11.73					7.49
	July	5.03	12.30					7.75
	August	5.03	12.38					7.73
	September	5.04	12.46					7.75
	October	5.03	12.73					7.83
	November	5.03	12.89					7.80
	December	5.03	12.95					7.93
	Ave.	5.03	12.03				7.67	7.67
1976	January	5.02	12.99				8.63	8.63
	February	5.05	11.47				7.87	7.87
	March	5.07	11.39				7.79	7.79
	April	5.07	11.52				7.86	7.86
	May	5.13	11.55				7.89	7.89
	June	5.15	11.60				7.99	7.99
	July	5.19	11.59				8.04	8.04
	August	5.18	11.62				8.03	8.03
	September	5.17	11.65	13.21			8.39	8.19
	October	5.15	11.62	13.35			8.46	8.23
	November	5.17	11.62	13.31			8.62	8.40
	December	5.17	11.64	13.30			8.62	8.40
1977	January	5.17	11.44	13.27			8.60	8.28
	February	5.18	11.39	13.32			8.57	8.33
	March	5.15	11.03	13.31			8.45	8.19
	April	5.15	10.97	13.28			8.40	8.14
	May	5.18	10.98	13.26			8.49	8.23
	June	5.16	10.92	13.28			8.44	8.17
	July	5.16	11.00	13.31	6.84	12.21	8.48	8.21
	August	5.18	10.93	13.95	6.91	12.29	8.62	8.25
	September	5.20	11.20	14.01	6.98	12.33	8.63	8.26
	October	5.23	11.42	14.01	6.66	12.38	8.72	8.36
	November	5.24	11.63	13.98	5.73	12.40	8.72	8.35
	December5/	5.25	11.76	13.98	5.73	12.36	8.76	8.40

1/ Stripper oil was exempt from price controls beginning September 1, 1976. From February through August 1976 stripper oil was subject to upper tier price ceilings.

2/ Alaskan North Slope (ANS) crude oil prices are treated as Upper Tier for determining the applicable wellhead ceiling prices. ANS is included in both the Actual Domestic Average and the Imputed Domestic Average price determinations

3/ The Naval Petroleum Reserves (NPR) are exempt from pricing regulations but have been reported here as Upper Tier prior to July 1977. NPR is included in the Actual Domestic Average price determination, but not in the Imputed Domestic Average.

4/ The actual domestic average price represents the average price at which all domestic crude oil is purchased. The imputed domestic average price is the average price used to establish ceiling prices for domestic crude oil in accordance with the provisions of the Energy Conservation and Production Act. It is calculated as the weighted average of lower tir, upper tir, and an imputed stripper crude oil price. The imputed stripper crude oil price is equal to $11.63 per barrel plus the difference between the composite price of crude oil in August 1976 (excluding stripper oil) and the composite price of crude oil in the month of measurement (excluding stripper oil).

5/ Preliminary data based on early reports.

Source: U.S. Department of Energy, Energy Information Administration, Monthly Energy Review, July 1977 and March 1978.

Raw material prices, selected markets and grades

Crop year[1]	#2 Yellow Corn Chicago	#2 Yellow Corn Ks City	#2 Yellow Corn Omaha	#3 Yellow Corn Chicago	#3 Yellow Corn Minnea-polis	#2 Yellow Sorghum Ks City	#2 Yellow Sorghum Ft Worth	#2 Winter Wheat HDRW Ks City	#2 Winter Wheat SRW Chicago	#2 Winter Wheat SRW St Louis	Sugarbeets Season average price received by farmers	Potatoes New York	Potatoes Season avg. price received by farmers	Beet Molasses Colorado[2]
	($/bu)					($/cwt)		($/bu)			($/T)	($/cwt)		($/T)
1964	--	1.30	1.26	1.26	1.20	2.08	2.39	1.57	1.46	1.51	11.80	4.91	3.50	32.38
1965	1.32	1.30	1.29	1.27	1.22	1.97	2.27	1.61	1.50	1.64	11.90	3.52	2.53	27.00
1966	1.36	1.36	1.30	1.36	1.29	2.09	2.40	1.85	1.82	1.77	12.80	3.17	2.04	32.66
1967	1.14	1.22	1.14	1.12	1.08	1.99	2.27	1.59	1.47	1.47	13.50	2.63	1.87	36.50
1968	1.22	1.24	1.20	1.17	1.14	2.00	2.31	1.46	1.25	1.32	13.80	3.17	2.23	35.80
1969	1.31	1.33	1.28	1.25	1.16	2.10	2.42	1.45	1.26	1.43	12.70	3.77	2.24	34.90
1970	1.47	1.45	1.44	1.44	1.34	2.42	2.73	1.58	1.60	1.32	14.82	3.58	2.21	36.40
1971	1.23	1.24	1.22	1.18	1.13	2.06	2.51	1.60	1.47	1.51	15.40	3.45	1.90	37.00
1972	1.91	2.06	1.54	1.82	1.86	3.81	3.75	2.26	2.23	2.24	16.00	5.74	3.01	36.55
1973	2.95	2.92	3.22	2.86	2.75	4.95	5.13	4.83	4.54	4.57	29.60	8.54	4.89	50.85
1974	3.12	3.20	3.69	3.23	3.21	5.41	5.61	4.29	4.59	3.91	46.80	4.15	4.01	78.65
1975	2.75	2.78	2.66	2.62	2.62	4.89	5.62	4.08	3.71	3.51	27.60	4.62	4.48	55.80
1976[3]	2.30	2.26	2.15	2.30	2.25	3.49	--	--	2.81	2.77	19.80	--	3.36	66.87
Average (in 1977 dollars)	2.46	2.48	2.45	2.38	2.33	4.11	4.62	3.35	3.08	3.03	25.72	6.22	4.13	61.34

1/ Crop year begins October for corn, sorghum, sugarbeets and potatoes, June for wheat, January for molasses.
2/ Per ton (2,000 lbs) prices are based on 171 U.S. gallons. Prices represent sales f.o.b. terminal to the general feed trade and do not include sales made under various special pricing arrangements. Colorado, Wyoming and Montana prior to 1974. Source: USDA, Sugar and Sweetner Report various issues.
3/ Grain prices from USDA, Grain Market News, July, Nov., 1977.
4/ Average prices in terms of 1977 dollars based on prices shown and GNP implicit price deflator (1977=100).

Source: Agricultural Statistics, USDA, Washington, 1976.

Average price per ton, bulk, in wholesale lots, at leading markets, 1962-76

Year beginning October	Soybean meal 44% protein Decatur	Distillers' dried grains at Cincinnati	Beet pulp (molasses) at Los Angeles
	($/Ton)		
1962	71.30	60.20	N.A.
1963	71.00	57.60	N.A.
1964	70.20	60.20	N.A.
1965	81.50	59.90	52.00
1966	78.80	64.50	53.20
1967	76.90	52.70	46.50
1968	74.10	55.30	45.50
1969	78.40	57.90	50.40
1970	78.60	64.40	54.90
1971	90.20	61.30	N.A.
1972	229.00	102.00	N.A.
1973	146.40	114.30	N.A.
1974	130.90	117.00	106.00
1975	148.00	112.00	107.00
1976	200.00	132.00	106.00
1977			
Average1/ (in 1977 dollars)		109.85	93.17

1/ Adjustment to 1977 dollars based on GNP implicit price deflator (1977=100)

Source: Agricultural Statistics, USDA, Washington, D.C.: U.S. Government Printing Office, 1964 through 1977
Feed Situation, USDA, Economic Research Service, 1964 through 1977.

CORN
INSPECTED RECEIPTS, DESIGNATED STATES,
2 MONTHS FOLLOWING HARVEST, 1976 CROP
ALL INSPECTIONS

STATES	U. S. GRADE							SPECIAL GRADES AND CLASSES			
	NO. 1 NUMBER	NO. 2 NUMBER	NO. 3 NUMBER	NO. 4 NUMBER	NO. 5 NUMBER	SAMPLE GRADE NUMBER	TOTAL NUMBER	WEEV-ILY NUMBER	YELLOW NUMBER	WHITE NUMBER	MIXED NUMBER
ALABAMA	80	1064	1744	3368	1832	416	8536	0	6640	1784	112
ILLINOIS	608	6096	6368	3264	1864	328	18584	8	18584	0	0
INDIANA	544	3960	2560	1328	1368	384	10144	8	10144	0	0
IOWA	3016	14304	9592	7944	2808	616	38424	40	38384	40	0
KANSAS	48	536	320	64	24	24	1016	8	984	24	8
KENTUCKY	440	1840	2024	2384	1912	472	9256	0	9256	0	0
MARYLAND	16	704	720	400	328	312	26584	48	26560	8	16
MINNESOTA	720	5152	2576	864	592	192	10096	16	10096	0	0
MISSOURI	152	1040	560	256	128	32	2192	0	2192	0	0
NEBRASKA	656	3504	2136	664	248	88	7368	0	7368	0	0
OHIO	608	4008	3040	1584	2592	1760	28760	40	28760	0	0
PENNSYLVANIA	192	2648	2072	768	568	112	6368	0	6368	0	0
SOUTH CAROLINA	336	2320	2368	896	384	152	6672	1328	6672	0	0
TENNESSEE	48	1184	256	64	56	0	1616	0	1608	0	8
VIRGINIA	1456	5920	6104	4920	3304	1672	26096	[illegible]	26096	0	0
WISCONSIN	144	1536	864	448	256	136	3384	0	3384	0	0
ALL STATES	9064	55816	43304	29216	18264	6696	205096	1832	203096	1856	144
% 1976 CROP YEAR	5.6	34.4	26.7	18.0	11.2	4.1	100.0	0.9	99.0	0.9	0.1
% 1975 CROP YEAR	5.2	37.9	27.2	16.4	8.9	4.4	100.0	1.4	99.1	0.9	0.0
% 1974 CROP YEAR	3.2	23.0	27.2	21.5	14.0	11.1	100.0	1.6	99.4	0.6	0.0

HARD RED WINTER WHEAT
INSPECTED RECEIPTS, DESIGNATED STATES,
2 MONTHS FOLLOWING HARVEST, 1976 CROP
ALL INSPECTIONS

STATES	U. S. GRADES										SPECIAL GRADES			SUBCLASSES		
	NO. 1 HEAVY	NO. 1	NO. 2 HEAVY	NO. 2	NO. 3 HEAVY	NO. 3	NO. 4	NO. 5	SAMPLE GRADE	TOTAL	TOUGH	WEEV-ILY	GAR-LICKY	DARK HARD WINTER	HARD WINTER	YELLOW HARD WINTER
	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER
CALIFORNIA	8416	384	632	232	152	104	72	32	8	10032	40	0	0	3200	3328	3504
COLORADO	1024	1944	1104	2000	336	728	248	112	272	7816	280	8	8	3024	4320	472
IDAHO	144	32	80	48	24	0	0	0	0	408	0	0	0	160	232	16
ILLINOIS	40	72	0	0	0	0	0	0	8	120	16	0	0	0	0	120
KANSAS	6856	16344	3064	17968	320	4016	976	584	944	51464	11128	144	0	3624	28080	19760
MISSOURI	888	1816	408	1256	24	208	64	32	112	4880	1576	24	0	128	2432	2320
MONTANA	2296	728	96	136	24	48	24	8	16	3888	104	0	0	1360	1992	536
NEBRASKA	1392	2600	1080	4048	104	904	120	48	104	10776	512	40	0	840	8376	1560
OKLAHOMA	5488	9592	1200	5256	200	1480	504	560	352	25048	2944	16	0	640	19072	5336
OREGON	280	40	48	64	0	40	8	0	16	536	0	0	0	200	200	136
TEXAS	4056	2912	728	1768	184	424	176	120	96	10488	568	56	0	3392	6552	544
UTAH	760	1400	320	1344	72	400	240	104	104	4744	112	0	0	2504	2000	240
WASHINGTON	1320	328	40	216	0	32	24	56	128	2544	0	40	0	1088	968	488
ALL STATES	33000	38192	8800	34336	1440	8384	2456	1656	2160	132744	17280	328	8	20160	77552	35032
% 1976 CROP YEAR	25.3	29.3	6.7	26.3	1.1	6.4	1.9	1.3	1.7	100.0	13.0	0.2	0.0	15.2	58.4	26.4
% 1975 CROP YEAR	28.4	39.6	4.7	19.7	0.8	4.0	1.3	0.7	0.8	100.0	11.1	0.1	0.0	18.4	47.0	34.6
% 1974 CROP YEAR	26.3	18.8	12.7	29.7	1.5	7.1	2.0	0.9	1.0	100.0	3.6	0.1	0.0	5.2	93.1	1.7

SORGHUM
INSPECTED RECEIPTS, DESIGNATED STATES,
2 MONTHS FOLLOWING HARVEST, 1976 CROP
ALL INSPECTIONS

STATES	U. S. GRADE						SPECIAL GRADES AND CLASSES			
	NO. 1 NUMBER	NO. 2 NUMBER	NO. 3 NUMBER	NO. 4 NUMBER	SAMPLE GRADE NUMBER	TOTAL NUMBER	WEEVILY NUMBER	YELLOW NUMBER	WHITE NUMBER	OTHER NUMBER
CALIFORNIA	295	650	385	400	280	2015	0	2015	0	0
COLORADO	20	180	50	10	10	270	0	270	0	0
KANSAS	510	4870	2025	930	130	8500	15	8495	0	5
MISSOURI	265	690	390	115	5	1465	0	1460	0	5
NEBRASKA	890	4570	2820	1800	240	10335	10	10255	0	80
OKLAHOMA	95	330	135	30	15	605	0	605	0	0
TEXAS	1745	8360	2985	1470	400	31340	60	31330	0	10
ALL STATES	3820	19650	8790	4755	1080	54530	85	54430	0	100
% 1976 CROP YEAR	10.0	51.6	23.1	12.5	2.8	100.0	0.2	99.8	0.0	0.2
% 1975 CROP YEAR	9.5	55.3	21.7	10.6	2.9	100.0	0.4	99.9	0.0	0.1
% 1974 CROP YEAR	2.6	30.3	26.7	27.0	13.3	100.0	1.4	100.0	0.0	0.0

Source: USDA, Federal Grain Inspection Service, 1976 Crop Quality Report, 1977.

Estimated investment for grain ethanol plants

	Unit	Midwest 1/ Solvent	Stone & 2/ Webster	Scheller 3/	Miller 4/	Indiana 5/
Year Basis	Year	76-77 Ave	1976	1976	1971	1980
Annual Production	mil gal	15	20	20	16.3	20 6/
Land	$1,000	NA	100	NA	NA	252
Plant	$1,000	NA	22,100	NA	NA	32,248
TOTAL	$1,000	30,000	22,200	23,000	14,000	32,500

1/ Cray Jr., Cloud L., Midwest Solvents Corporation, Gasohol Seminar, Rio De Janerio, Brazil, September 1977.
2/ Stone and Webster Engineering Corporation, "Preliminary Economic Evaluation of Nebraska Grain Alcohol Plant," Agricultural Products Industrial Utilization Committee, State of Nebraska, December 1976.
3/ Scheller, William A. and Brian J. Mohr, "Grain Alcohol-Process, Price and Economic Information," Department of Chemical Engineering, University of Nebraska, September 1976.
4/ Miller, Dwight L., "Fuel Alcohol from Wheat," Proceedings of 7th National Conference on Wheat Utilization Research, USDA, ARS, November 1971.
5/ Corcoran, W. P. and A. T. Brackett, Indiana Grain Fermentation Alcohol Plant, Indianapolis Center for Advanced Research, F. Lindrey, 1976.
6/ Based on 190° ethanol. All other estimates based on 200° ethanol.

Ethanol plant employment, direct labor

Item	10 million gallon			20 million gallon			40 million gallon		
	Number employees	Hourly rate	Total	Number employees	Hourly rate	Total	Number employees	Hourly rate	Total
		($)	($000)		($)	($000)		($)	($000)
1st shift	18	7.00	262	21	7.00	306	30	7.00	437
2nd shift	10	7.50	156	13	7.50	203	20	7.50	312
3rd shift	10	7.50	156	13	7.50	203	20	7.50	312
4th shift	10	7.50	156	13	7.50	203	20	7.50	312
Subtotal	48		730	60		915	90		1,373
Fringe benefits (25%)			183			229			343
TOTAL			913			1,144			1,716
Cost per gallon			.091			.057			.043

Source: DPRA estimate

Ethanol plant employment, indirect labor

Item	10 million gallon			20 million gallon			40 million gallon		
	Number employees	Hourly rate	Total	Number employees	Hourly rate	Total	Number employees	Hourly rate	Total
		($)	($000)		($)	($000)		($)	($000)
Guards	4	4.00	32	5	4.00	40	8	4.00	64
Maintenance	7	10.00	140	10	10.00	200	18	10.00	360
Plant manager	1	12.50	25	1	15.00	30	1	20.00	40
Assistant plant manager	0	--	--	1	10.00	20	2	12.50	50
Shift supervisors	4	10.00	80	4	10.00	80	4	10.00	80
Chemists	1	8.00	16	2	8.00	32	3	8.00	48
Technicians	6	8.00	96	10	8.00	160	14	8.00	224
Shipper	1	7.00	15	1	7.00	15	2	7.00	30
Purchasing	1	11.00	22	1	11.00	22	1	12.50	25
Plant engineer	1	11.00	22	1	11.00	22	2	12.50	50
Clerks	2	4.00	16	2	4.00	16	4	4.00	32
Subtotal	28		464	38		637	59		1,003
Fringe benefits (25%)			116			159			251
TOTAL			580			796			1,254
Cost per gallon			.058			.040			.031

Source: DPRA estimate

Ethanol plant employment, administrative personnel

Item	10 million gallon			20 million gallon			40 million gallon		
	Number employees	Hourly rate	Total	Number employees	Hourly rate	Total	Number employees	Hourly rate	Total
		($)	($000)		($)	($000)		($)	($000)
General manager	1	40	40	1	50	50	1	65	65
Comptroller	1	20	20	1	26	26	1	30	30
Secretaries	2	8	16	2	8	16	3	8	24
Clerks	1	8	8	2	8	16	3	8	24
Subtotal	5		84	6		108	8		143
Fringe			21			27			36
Total			105			135			179
Cost per gallon			.011			.007			005

Source: DPRA estimate

Plant employment, marketing personnel

Item	10 million gallon			20 million gallon			40 million gallon		
	Number employees	Hourly rate	Total	Number employees	Hourly rate	Total	Number employees	Hourly rate	Total
		($)	($000)		($)	($000)		($)	($000)
Sales manager	1	25	25	1	30	30	1	40	40
Sales representatives	2	20	40	4	20	80	6	20	120
Secretaries	2	8	16	2	8	16	3	8	24
Clerks	1	8	8	2	8	16	3	8	24
Subtotal	6		89	9		142	13		208
Fringe benefits (25 pct)			22			36			52
Total			111			178			260
Cost per gallon			.011			.009			.006

Source: DPRA estimate

Comparable ethanol direct operating costs as reported

Item	Units	Midwest solvent 1/	Stone & Webster 2/	Scheller 3/	Miller 4/	Indiana 5/
Date		1976-77 average	1976	1977	1971	1976
Annual production	mil gal	15	20	20	16.3	20 6/
Labor	$	.060	.138	NA	.134	.046
Fuel	$	.205	.143	NA	NA	.159
Other direct	$	.050	.008	NA	.022	.057
Total direct	$	.315	.288	.300	.156	.262

1/ Cray, Cloud L. Jr. Midwest Solvents Corporation, Gasohol Seminar, Rio de Janerio, Brazil, September 1977.

2/ Stone and Webster Engineering Corporation. "Preliminary Economic Evaluation of Nebraska Grain Alcohol Plant," Agricultural Products Industrial Utilization Committee, State of Nebraska, December 1976.

3/ Scheller, William A. and Brian J. Mohr. "Grain Alcohol--Process, Price and Economic Information," Department of Chemical Engineering, University of Nebraska, Lincoln, revised September 1976.

4/ Miller, Dwight L. "Fuel Alcohol from Wheat," Proceedings of Seventh National Conference on Wheat Utilization Research, USDA, ARS, 1971.

5/ Corcoran, W. P., A. T. Brackett and F. Lindsey. Indiana Grain Fermentation Alcohol Plant, Indianapolis Center for Advanced Research, 1976.

6/ Reported in 190 proof gallons.

Elements of capital recovery cost

Item	Conventional financing[1/]		Government financing[2/]	
	20 MGY	100 MGY	20 MGY	100 MGY
	($/gal)			
Debt service	.02	.01	.09	.07
Equity return	.23	.16	.07	.04
Income taxes	.13	.09	.03	.02
Total	.38	.26	.19	.13

1/ 10 percent interest, 30 percent leverage and 15 percent cost of equity.

2/ 7 percent interest, 90 percent leverage and 10 percent cost of equity.

Source: DPRA estimate

Estimated cost of Federal incentives used to stimulate energy production, 1918 to date

Energy form	Taxation	Disbursement	Requirements	Traditional services	Nontraditional services	Market activity	Total	Percent
				(Bils 1976$)				
Nuclear		1.2			12.4-14.2	1.7	15.3-17.1	13
Hydroelectric	1.7-0		.03			7.5-17.5	9.23-17.53	10
Coal	3.0		.04	1.8	1.6		6.44	5
Oil	40.5	30.3	.3	4.7	1.0	.2	77.0	60
Gas	11.3	3.5	.2	.1			15.1	12
Total	56.5-54.8	35.0	.57	6.6	15.0-16.8	9.4-19.4	123.07-133.17	100
Percent	44	27	1	5	12	11	100	

Source: Battelle-Pacific Northwest Laboratories, An Analysis of Federal Incentives Used to Stimulate Energy Production, U.S. Deoartment of Energy, March 1978.

Cost of primary oil incentives by type for 1976

Incentive area	Taxation	Disbursement	Requirements	Traditional services	Nontraditional services	Market activity	Total
				(mil. $)			
Research & development					43		43
Subtotal	0	0	0	0	43	0	43
Oil exploration and production							
Geological Survey-data					41		41
Bureau of land management-leasing						38	38
Bureau of mines-data					1		1
Stripper well price incentives		2,890					2,890
Incentives for new oil		6,140					6,140
Federal Energy Administration			130				130
Intagible drilling expensing	842						842
Percentage depletion allowance	533						533
Subtotal	1,375	9,030	130	0	85	38	10,615
Petroleum refining & transportation							
High yield on pipelines		0					0
Maintenance of ports & waterways				255[1/]			255
Subsidies for tankers		176					176
Subtotal	0	176	0	255	0	0	431
Total	1,375	9,206	130	255	95	38	11,089

1/ FY1975

Source: Batelle-Pacific Northwest Laboratories, op. cit.

Cost of primary oil energy incentives by type over time

Incentive area	Taxation	Disbursement	Requirements	Traditional services	Nontraditional services	Market activity	Total	Period
			(mil 1976 $)					
Research & development					771		771	1957-76
Subtotal	0	0	0	0	771	0	771	
Oil exploration & production								
Geological survey-data					260		260	1964-76
Bureau of land management-leasing						217	217	1964-76
Bureau of mines-data					14		14	1964-76
Stripper well price incentives		8,280					2,280	1974-76
Incentives for new oil		16,200					16,200	1974-76
Federal Energy Administration			305				305	1973-76
Intangible drilling expensing	11,152						11,152	1954-76
Percentage depletion allowance	29,306						29,306	1954-76
Subtotal	40,458	24,480	305	0	274	217	65,734	
Petroleum refining & transportation								
High yield on pipelines		4,882					4,882	1921-51
Maintenance of ports and waterways				4,736			4,736	1962-76
Subsidies for tankers		949					949	1970-76
Subtotal	0	5,831	0	4,736	0	0	10,567	
Total	40,458	30,311	305	4,736	1,045	217	77,072	

Source: Battelle-Pacific Northwest Laboratories, *op. cit.*

Area harvested, yield, and production:
corn, wheat, grain sorghum, sugar beets, potatoes; states; 1975-1977

CORN FOR GRAIN

STATE	AREA HARVESTED 1975	AREA HARVESTED 1976	AREA HARVESTED 1977	YIELD 1975	YIELD 1976	YIELD 1977	PRODUCTION 1975	PRODUCTION 1976	PRODUCTION 1977
	1,000 ACRES			BUSHELS			1,000 BUSHELS		
ALA	660	800	375	50.0	60.0	29.0	33,000	48,000	10,875
ARIZ	12	28	50	33.0	60.0	60.0	396	1,680	3,000
ARK	38	45	43	50.0	56.0	53.0	1,900	2,520	2,279
CALIF	254	290	247	109.0	110.0	116.0	27,686	31,900	28,652
COLO	560	630	695	92.0	102.0	116.0	51,520	64,260	80,620
CONN	0	0	0	0.0	0.0	0.0	0	0	0
DEL	170	195	185	92.0	88.0	56.0	15,640	17,160	10,360
FLA	375	480	299	45.0	60.0	35.0	16,875	28,800	10,465
GA	1,880	2,160	1,000	55.0	62.0	24.0	103,400	133,920	24,000
IDAHO	30	35	28	83.0	85.0	86.0	2,490	2,975	2,408
ILL	10,810	11,590	10,980	116.0	107.0	105.0	1,253,960	1,240,130	1,152,900
IND	5,630	6,300	6,210	98.0	110.0	102.0	551,740	693,000	633,420
IOWA	12,420	12,900	12,400	90.0	91.0	88.0	1,117,800	1,173,900	1,091,200
KANS	1,640	1,790	1,680	86.0	96.0	96.0	141,040	171,840	161,280
KY	1,140	1,360	1,410	77.0	102.0	90.0	87,780	138,720	126,900
LA	45	71	65	50.0	66.0	52.0	2,250	4,686	3,380
MAINE	0	0	0	0.0	0.0	0.0	0	0	0
MD	550	630	600	92.0	92.0	72.0	50,600	57,960	43,200
MASS	0	0	0	0.0	0.0	0.0	0	0	0
MICH	2,090	2,230	2,250	80.0	69.0	85.0	167,200	153,870	191,250
MINN	5,820	5,600	6,000	70.0	59.0	100.0	407,400	330,400	600,000
MISS	145	172	160	41.0	47.0	36.0	5,945	8,084	5,760
MO	2,700	2,850	2,700	63.0	61.0	76.0	170,100	173,850	205,200
MONT	10	11	11	73.0	75.0	68.0	730	825	748
NEBR	5,920	6,100	6,350	85.0	85.0	99.0	503,200	518,500	628,650
NEV	0	0	0	0.0	0.0	0.0	0	0	0
N H	0	0	0	0.0	0.0	0.0	0	0	0
N J	83	103	95	81.0	86.0	70.0	6,723	8,858	6,650
N MEX	75	96	114	100.0	105.0	90.0	7,500	10,080	10,260
N Y	545	573	640	83.0	76.0	80.0	45,235	43,548	51,200
N C	1,590	1,880	1,690	67.0	80.0	51.0	106,530	150,400	86,190
N DAK	140	191	237	51.0	40.0	68.0	7,140	7,640	16,116
OHIO	3,340	3,820	3,620	93.0	103.0	105.0	310,620	393,460	380,100
OKLA	91	106	95	80.0	95.0	82.0	7,280	10,070	7,790
OREG	8	10	12	85.0	90.0	95.0	680	900	1,140
PA	1,080	1,150	1,160	82.0	90.0	92.0	88,560	103,500	106,720
R I	0	0	0	0.0	0.0	0.0	0	0	0
S C	550	667	620	68.0	74.0	36.0	37,400	49,358	22,320
S DAK	2,250	1,200	2,150	37.0	31.0	59.0	83,250	37,200	126,850
TENN	615	715	730	60.0	79.0	65.0	36,900	56,485	47,450
TEX	1,150	1,550	1,650	103.0	120.0	90.0	118,450	186,000	148,500
UTAH	15	15	13	86.0	90.0	89.0	1,290	1,350	1,157
VT	0	0	0	0.0	0.0	0.0	0	0	0
VA	565	610	560	88.0	78.0	55.0	49,720	47,580	30,800
WASH	34	44	48	104.0	107.0	106.0	3,536	4,708	5,088
W VA	65	61	54	85.0	88.0	74.0	5,525	5,368	3,996
WIS	2,390	2,220	2,750	83.0	68.0	104.0	198,370	150,960	286,000
WYO	20	22	30	80.0	87.0	85.0	1,600	1,914	2,550
U S	67,505	71,300	70,006	86.3	87.9	90.8	5,828,961	6,266,359	6,357,424

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ALL WHEAT

STATE	AREA HARVESTED			YIELD			PRODUCTION		
	1975	1976	1977	1975	1976	1977	1975	1976	1977
	1,000 ACRES			BUSHELS			1,000 BUSHELS		
ALA	105	85	90	24.0	27.0	28.0	2,520	2,295	2,520
ARIZ	260	431	140	70.0	75.0	72.0	18,200	32,325	10,080
ARK	450	630	660	30.0	39.0	39.0	13,500	24,570	25,740
CALIF	1,001	940	678	61.2	63.5	64.5	61,241	59,720	43,700
COLO	2,495	2,440	2,575	22.6	21.8	22.2	56,263	53,200	57,100
DEL	51	40	34	34.0	35.0	31.0	1,734	1,400	1,054
FLA	13	14	13	25.0	30.0	29.0	325	420	377
GA	135	115	100	27.0	31.0	33.0	3,645	3,565	3,300
IDAHO	1,350	1,430	1,190	44.5	47.8	42.6	60,050	68,320	50,730
ILL	1,730	1,850	1,590	39.0	39.0	43.0	67,470	72,150	68,370
IND	1,400	1,500	1,240	44.0	36.0	45.0	61,600	54,000	55,800
IOWA	100	130	85	34.0	35.0	37.0	3,400	4,550	3,145
KANS	12,100	11,300	12,100	29.0	30.0	28.5	350,900	339,000	344,850
KY	320	330	274	34.0	31.0	37.0	10,880	10,230	10,138
LA	16	23	27	16.0	33.0	34.0	256	759	918
MD	156	138	118	34.0	38.0	37.0	5,304	5,244	4,366
MICH	900	870	825	38.0	38.0	40.0	34,200	33,060	33,000
MINN	2,867	4,056	3,327	30.8	32.2	39.6	88,368	130,482	131,894
MISS	122	120	105	24.0	29.0	34.0	2,928	3,480	3,570
MO	1,470	1,760	1,550	33.0	33.0	39.0	48,510	58,080	60,450
MONT	4,975	5,415	5,060	31.3	30.9	25.9	155,925	167,295	130,920
NEBR	3,070	2,950	2,950	32.0	32.0	35.0	98,240	94,400	103,250
NEV	31	31	28	58.7	54.1	55.7	1,820	1,677	1,560
N J	54	55	42	36.0	42.0	31.0	1,944	2,310	1,302
N MEX	440	262	425	26.0	26.0	21.5	11,440	6,825	9,137
N Y	205	175	175	40.0	38.0	39.0	8,200	6,650	6,825
N C	275	240	200	31.0	29.0	30.0	8,525	6,960	6,000
N DAK	10,213	11,655	9,254	25.9	24.7	24.8	264,392	287,830	229,907
OHIO	1,680	1,600	1,540	42.0	40.0	47.0	70,560	64,000	72,380
OKLA	6,700	6,300	6,500	24.0	24.0	27.0	160,800	151,200	175,500
OREG	1,255	1,333	1,200	46.2	45.2	37.8	58,040	60,301	45,320
PA	317	300	270	32.0	30.0	33.0	10,144	9,000	8,910
S C	130	125	95	27.0	26.0	29.0	3,510	3,250	2,755
S DAK	2,965	2,990	3,016	21.1	13.2	23.9	62,610	39,520	71,964
TENN	270	300	280	31.0	37.0	36.0	8,370	11,100	10,080
TEX	5,700	4,700	4,700	23.0	22.0	25.0	131,100	103,400	117,500
UTAH	282	264	204	25.4	24.7	23.1	7,164	6,519	4,716
VA	292	240	205	31.0	32.0	31.0	9,052	7,680	6,355
WASH	3,060	3,200	2,985	48.3	45.0	33.9	147,880	144,050	101,305
W VA	11	11	10	32.0	32.0	31.0	352	352	310
WIS	93	93	75	30.3	34.8	41.0	2,820	3,238	3,075
WYO	332	330	281	24.9	24.1	20.0	8,277	7,955	5,620
U S	69,391	70,771	66,216	30.6	30.3	30.6	2,122,459	2,142,362	2,025,793

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SORGHUM FOR GRAIN

STATE	AREA HARVESTED 1975	AREA HARVESTED 1976	AREA HARVESTED 1977	YIELD 1975	YIELD 1976	YIELD 1977	PRODUCTION 1975	PRODUCTION 1976	PRODUCTION 1977
	1,000 ACRES			BUSHELS			1,000 BUSHELS		
ALA	33	31	27	37.0	35.0	27.0	1,221	1,085	729
ARIZ	120	91	90	68.0	73.0	80.0	8,160	6,643	7,200
ARK	200	310	252	49.0	50.0	52.0	9,800	15,500	13,104
CALIF	207	210	132	72.0	71.0	73.0	14,904	14,910	9,636
COLO	290	259	273	26.0	28.0	31.0	7,540	7,252	8,463
GA	47	45	24	40.0	43.0	28.0	1,880	1,935	672
ILL	60	67	64	68.0	59.0	64.0	4,080	3,953	4,096
IND	18	21	15	64.0	67.0	78.0	1,152	1,407	1,170
IOWA	26	26	32	62.0	65.0	74.0	1,612	1,690	2,368
KANS	3,430	3,950	4,050	42.0	43.0	60.0	144,060	169,850	243,000
KY	21	29	32	65.0	60.0	57.0	1,365	1,740	1,824
LA	19	28	20	32.0	35.0	33.0	608	980	660
MISS	38	41	24	35.0	37.0	32.0	1,330	1,517	768
MO	530	660	840	53.0	60.0	73.0	28,090	39,600	61,320
NEBR	1,900	2,100	2,130	55.0	57.0	71.0	104,500	119,700	151,230
N MEX	310	199	238	50.0	60.0	48.0	15,500	11,940	11,424
N C	85	90	72	51.0	51.0	37.0	4,335	4,590	2,664
OKLA	520	565	565	38.0	30.0	38.0	19,760	16,950	21,470
S C	17	15	12	35.0	34.0	16.0	595	510	192
S DAK	247	152	343	26.0	23.0	49.0	6,422	3,496	16,807
TENN	26	23	20	48.0	52.0	51.0	1,248	1,196	1,020
TEX	7,200	5,800	4,800	52.0	50.5	48.0	374,400	292,900	230,400
VA	11	11	10	44.0	43.0	43.0	484	473	430
U S	15,355	14,723	14,065	49.0	48.9	56.2	753,046	719,817	790,647

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SUGARBEETS

STATE	AREA HARVESTED			YIELD			PRODUCTION		
	1975	1976	1977	1975	1976	1977	1975	1976	1977
	1,000 ACRES			TONS			1,000 TONS		
ARIZ 1/	17.0	17.0	12.8	21.5	23.0	22.3	366	391	285
CALIF 1/	326.3	312.0	217.0	27.3	28.6	26.0	8,892	8,912	5,642
COLO	154.9	121.0	72.0	17.2	19.0	19.5	2,661	2,303	1,404
IDAHO	158.3	139.4	105.8	18.6	20.7	19.6	2,942	2,879	2,074
KANS	43.0	38.0	24.0	15.5	19.7	16.7	667	749	401
MAINE 2/		5.5	.0		10.2	0.0		56	0
MICH	91.4	91.4	85.5	19.2	16.8	21.0	1,755	1,540	1,796
MINN	196.0	248.0	260.0	14.2	12.2	18.2	2,783	3,026	4,732
MONT	48.5	46.1	45.0	17.1	21.0	19.9	829	968	896
NEBR	96.0	84.5	67.7	18.5	20.0	20.0	1,776	1,690	1,354
N MEX	.9	.9	1.2	16.7	22.2	19.2	15	20	23
N DAK	130.9	149.8	157.0	13.9	13.5	17.8	1,820	2,022	2,795
OHIO	39.2	36.5	22.5	19.8	16.9	20.3	777	617	457
OREG	17.9	14.5	7.8	23.8	25.1	25.4	426	364	198
TEX	33.7	23.3	17.9	13.1	21.6	17.3	440	503	309
UTAH	22.5	18.0	11.1	15.7	17.6	17.8	353	317	196
WASH	82.4	76.5	62.1	26.0	24.4	25.8	2,142	1,862	1,602
WYO	57.7	56.4	48.4	18.4	20.7	19.6	1,060	1,167	949
U S	1,516.6	1,478.8	1,217.8	19.6	19.9	20.6	29,704	29,386	25,115

1/ RELATES TO YEAR OF HARVEST.
2/ ESTIMATES NOT MADE IN ALL YEARS.

POTATOES

STATE	AREA HARVESTED			YIELD			PRODUCTION		
	1975	1976	1977	1975	1976	1977	1975	1976	1977
	1,000 ACRES			CWT			1,000 CWT		
ALA	19.6	19.7	18.0	139	142	112	2,728	2,799	2,010
ARIZ	6.2	6.8	6.5	245	270	270	1,519	1,836	1,755
CALIF	59.9	66.0	60.7	351	364	361	21,015	24,044	21,890
COLO	39.7	43.8	43.4	264	257	260	10,485	11,245	11,284
CONN	2.4	1.9	1.9	230	260	245	552	494	466
DEL	6.0	5.8	5.3	175	200	210	1,050	1,160	1,113
FLA	27.5	31.0	30.1	194	203	206	5,344	6,293	6,207
IDAHO	322.0	363.0	360.0	244	244	245	78,475	88,455	89,200
ILL	2.8	2.8	2.3	190	190	200	532	532	460
IND	7.7	8.1	6.8	227	237	220	1,746	1,919	1,496
IOWA	2.7	2.5	2.1	200	185	225	540	463	473
LA	2.6	2.6	2.3	70	75	75	182	195	173
MAINE	122.0	112.0	118.0	220	245	240	26,840	27,440	28,320
MD	1.8	1.8	1.6	170	170	150	306	306	240
MASS	3.9	3.5	3.7	205	220	240	800	770	888
MICH	36.4	41.6	39.8	222	231	257	8,076	9,622	10,243
MINN	65.1	75.0	79.5	181	174	189	11,796	13,055	15,023
MISS	1.5	1.4	1.3	90	95	90	135	133	117
MONT	7.6	8.4	8.4	230	215	240	1,748	1,806	2,016
NEBR	7.5	7.1	8.1	217	229	209	1,625	1,626	1,695
NEV	12.5	14.0	15.0	330	380	350	4,125	5,320	5,250
N H	.4	.4	.3	230	260	235	92	104	71
N J	7.0	7.6	8.1	195	260	265	1,365	1,976	2,147
N MEX	3.5	3.2	2.9	200	180	190	700	576	551
N Y	47.3	48.8	43.4	257	277	278	12,178	13,510	12,082
N C	16.0	17.0	17.4	149	140	156	2,380	2,385	2,711
N DAK	110.0	121.0	130.0	160	140	160	17,600	16,940	20,800
OHIO	13.5	13.4	13.0	221	249	237	2,985	3,332	3,086
OREG	55.5	65.6	58.4	440	441	441	24,408	28,913	25,774
PA	29.0	28.0	25.5	235	255	250	6,815	7,140	6,375
R I	4.2	4.2	4.1	235	250	230	987	1,050	963
S DAK	5.2	4.4	5.9	115	65	180	598	286	1,062
TENN	5.0	4.7	4.5	85	95	90	425	447	405
TEX	14.1	16.7	15.0	211	207	223	2,975	3,453	3,339
UTAH	5.8	5.2	5.4	260	240	240	1,508	1,248	1,296
VT	1.0	1.1	1.0	235	205	235	235	226	235
VA	25.0	28.5	27.7	96	123	125	2,400	3,506	3,463
WASH	105.0	124.0	107.0	460	450	455	48,300	55,800	48,685
W VA	2.8	2.6	2.4	72	76	64	202	198	154
WIS	49.5	53.0	55.5	300	290	325	14,850	15,370	18,038
WYO	6.8	6.3	6.7	240	270	220	1,632	1,701	1,474
U S	1,264.0	1,374.5	1,349.0	255	260	261	322,254	357,674	352,010

ANNUAL CROP SUMMARY, JANUARY 1978

Appendix VIII-2

Computed high protein grain consuming animal units

-- ALL CLASSES -- COMPUTED HIGH PROTEIN GRAIN CONSUMING ANIMAL UNITS (MILK COW BASE)

STATE	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
	TEN YEAR PERIOD									
MAINE..........:	991.226	998.600	1034.618	993.854	1008.206	1062.905	1114.973	1200.997	1234.379	1244.709
NEW HAMPSHIRE..:	194.786	166.700	142.806	138.627	135.448	136.037	132.864	127.089	120.904	121.910
VERMONT........:	275.714	270.714	246.067	248.657	253.842	259.498	247.009	248.134	252.140	249.134
MASSACHUSETTS..:	341.229	310.602	280.073	267.661	264.087	239.465	235.875	223.132	215.768	214.066
RHODE ISLAND...:	42.518	38.725	33.628	30.032	25.263	24.263	27.859	22.674	21.084	20.084
CONNECTICUT....:	405.550	389.985	380.207	348.796	349.440	348.653	317.991	298.378	332.729	355.004
NEW YORK.......:	2051.001	1996.034	1873.106	1846.634	1821.601	1781.000	1760.842	1734.143	1713.658	1684.638
NEW JERSEY.....:	430.786	382.477	371.735	340.230	301.010	286.938	273.060	246.757	219.686	195.738
PENNSYLVANIA...:	2704.205	2746.240	2661.772	2757.966	2650.181	2617.224	2626.302	2661.116	2756.735	2930.048
DELAWARE.......:	827.697	949.389	963.896	897.641	931.846	993.055	1031.501	965.369	1114.403	1093.710
MARYLAND.......:	1451.698	1555.059	1602.637	1562.930	1539.028	1629.692	1593.216	1538.303	1667.364	1667.672
MICHIGAN.......:	1675.658	1630.375	1616.969	1673.854	1647.193	1617.137	1524.775	1525.472	1557.120	1550.829
WISCONSIN......:	4315.543	4207.355	4022.809	4128.080	4079.161	3997.990	3965.965	3971.048	3930.832	3891.972
MINNESOTA......:	5540.613	5443.699	5415.887	5568.820	5569.340	5557.453	5696.547	5398.828	5405.266	5466.254
OHIO...........:	3122.794	3030.772	3077.845	3125.636	3049.232	2837.586	2722.700	2606.632	2573.749	2572.740
INDIANA........:	4063.097	4037.002	4169.602	4218.340	4199.324	4114.930	3992.543	3642.588	3736.458	3773.980
ILLINOIS.......:	5624.961	5432.105	5291.637	5460.836	5208.672	5159.750	5001.680	4389.805	4440.219	4548.156
IOWA...........:	10695.883	11022.992	10609.453	10865.699	10548.500	10007.098	9462.941	8387.113	8873.937	9823.133
MISSOURI.......:	4063.053	4005.553	3961.227	4199.605	4147.875	3942.523	3802.359	3447.338	3410.710	3640.174
NORTH DAKOTA...:	803.957	755.969	736.718	766.612	767.316	778.561	774.228	744.553	711.614	653.277
SOUTH DAKOTA...:	2519.937	2417.356	2370.365	2475.634	2377.208	2339.303	2402.604	2284.906	2086.213	2067.839
NEBRASKA.......:	3979.982	4012.313	4035.616	4204.359	4152.422	4065.527	4019.287	3478.175	3554.985	3878.406
KANSAS.........:	2430.003	2578.648	2695.471	2897.627	3013.766	3083.708	2922.215	2518.516	2791.986	2894.390
VIRGINIA.......:	1445.564	1449.169	1444.131	1497.196	1510.115	1485.523	1515.415	1500.823	1634.204	1764.899
WEST VIRGINIA..:	405.446	380.372	366.855	376.101	375.031	372.223	389.604	372.842	373.075	389.158
NORTH CAROLINA.:	3727.808	3938.766	4230.262	4281.164	4308.699	4206.742	4296.156	4152.484	4482.469	4671.781
KENTUCKY.......:	1562.272	1526.320	1503.701	1514.627	1415.607	1397.958	1414.919	1374.564	1307.800	1306.156
TENNESSEE......:	1601.712	1602.448	1555.916	1580.079	1533.375	1431.513	1343.968	1247.067	1389.652	1493.723
SOUTH CAROLINA.:	865.141	985.634	1049.996	1038.308	1063.492	1057.588	1039.350	1039.424	1072.102	1029.277
GEORGIA........:	4897.566	5110.746	5340.082	5263.316	5090.461	4970.512	5060.598	4705.402	4865.973	5157.976
FLORIDA........:	1521.756	1665.116	1727.149	1746.178	1775.472	1761.861	1602.600	1850.283	1923.465	1970.698
ALABAMA........:	3670.995	3866.374	3962.409	4028.833	4089.919	4069.388	3961.017	3990.734	4235.141	4194.645
MISSISSIPPI....:	2463.614	2509.728	2638.601	2650.084	2644.338	2488.622	2392.955	2360.079	2405.618	2397.516
ARKANSAS.......:	3923.293	4061.264	4327.062	4500.125	4795.152	4642.824	4555.762	4471.957	4895.781	5165.293
LOUISIANA......:	946.255	957.421	943.805	935.518	956.376	936.969	906.101	873.837	932.150	935.313
OKLAHOMA.......:	1143.094	1197.207	1243.066	1282.713	1317.758	1316.053	1356.524	1289.007	1372.694	1302.965
TEXAS..........:	4345.410	4569.184	5064.445	5222.797	5378.215	5713.285	5701.434	4687.652	5242.047	5136.242
MONTANA........:	563.822	578.827	579.831	606.141	643.068	626.762	600.284	534.171	498.174	486.613
IDAHO..........:	534.495	569.289	540.863	506.074	525.968	468.734	434.509	433.066	421.130	459.403
WYOMING........:	239.300	236.359	233.290	237.525	237.995	229.946	231.859	220.159	208.203	213.364
COLORADO.......:	1181.876	1261.358	1359.084	1480.760	1601.349	1659.329	1557.459	1380.360	1513.715	1474.802
NEW MEXICO.....:	512.077	534.917	543.792	502.038	506.197	555.979	546.436	477.016	542.198	495.138
ARIZONA........:	635.332	682.750	748.560	757.186	758.102	869.608	831.355	573.743	737.771	603.689
UTAH...........:	613.150	608.670	647.717	647.145	631.721	626.229	586.221	577.144	567.777	530.573
NEVADA.........:	134.794	140.859	146.952	146.933	150.994	148.376	149.536	132.416	121.974	112.598
WASHINGTON.....:	830.922	808.212	793.183	767.273	754.811	767.858	751.720	703.958	720.415	736.869
OREGON.........:	609.401	598.410	609.633	615.579	571.159	517.367	524.813	490.960	521.643	541.645
CALIFORNIA.....:	5790.482	5855.871	6001.996	6211.676	6099.555	6049.836	6255.574	5619.461	5948.059	5813.926
---U. S. TOTAL--	102920.562	104073.562	105194.062	107413.500	106776.437	105361.937	103945.125	96719.687	100654.937	102895.750

Gasoline consumption by major end-use category in 1975

	Millions of gallons 1/	Percent of total
Private and commercial use	100,221	96.8
Highway	97,470	94.2
Nonhighway	2,751	2.7
Agricultural use	1,565	1.5
Marine	730	0.7
Industrial and commercial	179	0.2
Other	278	0.3
Public use	2,364	2.3
Federal (highway civilian use only)	195	0.2
State, county, and municipal	2,169	2.1
Losses (evaporation, handling, etc.)	922	0.9
Total Consumption 2/	103,507	100.0

1/ 42 gallons constitute 1 barrel.

2/ Figures may not add exactly due to rounding.

Source: Energy Information Center, Federal Energy Administration *Monthly Energy Review*, July 1977.

Gasoline consumption by type of vehicle in the U.S. in 1975

	Passenger vehicles						
		Buses					
	Cars and motorcycles	Commer-cial	School	All buses	Total passenger	Trucks and combinations	All motor vehicles
Fuel consumed (million gal.)	76,457	553	342	895	77,352	31,632	108,894
Avg. per vehicle (gal.)	685	5,896	929	1,937	690	1,227	790
Avg. miles per gal.	13.74	4.79	7.31	5.75	13.65	8.68	12.20
Vehicles registered (thousands)	111,679	94	368	462	112,141	25,776	137,917
Avg. miles traveled	9,406	28,230	6,778	11,140	9,413	10,648	9,644
Vehicle miles traveled (millions):							
Main rural roads	329,050	928	930	1,858	330,908	134,727	465,635
Local rural roads	118,848	80	1,020	1,100	112,948	22,048	134,996
Urban streets	609,574	1,640	550	2,190	611,764	117,679	729,443
Total travel 1975	1,050,472	2,648	2,500	5,148	1,055,620	274,454	1,330,074
1974	1,013,068	2,610	2,450	5,060	1,018,128	267,519	1,285,647

Source: National Petroleum News FActbook Issue, McGraw-Hill, New York, 1977.

Projections by commodity for selected years 1985 and 2010 under

Commodity	Million Units	72-74	1985 Moderate	1985 High	1985 Percent Change	2010 4/ Moderate	2010 4/ High	2010 4/ Percent Change
Crops								
Wheat	bu.	1,681	1,764	2,206	25	2,109	2,637	25
Rye	bu.	24.9	40	41	3	51.4	52.7	3
Rice	cwt.	88	118	125	6	159	168	6
Corn for grain	bu.	5,290	6,618	7,783	18	9,271	10,903	18
Silage	tons	140 1/	146	153	5	174	182	5
Grain Sorghum	bu.	789	1,132	1,305	15	1,664	1,918	15
Oats	bu.	660	885	937	6	1,106	1,171	6
Barley	bu.	384	550	581	6	699	738	6
Fruits and Nuts	lbs.	48,413 2/	48,795 2/	50,554	4	58,603	60,716	4
Vegetables	cwt.	49,457	56,745	58,924	4	70,416	73,120	4
Hay	tons	130	140	148	6	173	183	6
Soybeans	bu.	1,350	1,835	2,129	16	3,071	3,563	16
Flaxseed	bu.	14.4	28.0	28	0	23.9	23.9	0
Peanuts	lbs.	3,476	4,813	4,996	4	6,998	7,264	4
Cotton	bales	12.7	10.7	10.7	0 4/	10.8	10.8	0
Sugarcane	tons	16.9	19.7	20.1	5 3/	26.5	27.8	5
Sugarbeets	tons	25.1	33.6	35.2	5 3/	43.2	45.3	5
Tobacco	lbs.	1,828	2,140	2,120	-1	2,348	2,326	-1
Irish & Sweet Potatoes	cwt.	324.8	367.9	381	4	446.1	462	4
Dry Beans & Peas	lbs.	2,167	2,234	2,259	1	2,245	2,270	1
Livestock								
Beef and Veal	lbs.	22,669	30,051	32,419	8	39,563	42,680	8
Pork	lbs.	13,304	15,745	16,352	4	19,979	20,749	4
Lamb and Mutton	lbs.	509	195	209	7	202	216	7
Chickens	lbs.	9,028	11,973	12,552	5	16,136	16,916	5
Turkeys	lbs.	2,569	2,639	2,777	5	3,727	3,922	5
Eggs	doz.	5,610	6,353	6,386	1	7,349	7,387	1
Milk	lbs.	1,169	1,211	1,240	2	1,273	1,303	2
Farm Output Index 1967 = 100		110	130	142	9	166	181	9

1/ Production for 1971.

2/ Citrus and non-citrus fruits only.

3/ Preliminary.

4/ Interpolated from 2020.

Source: USDA, "Agriculture the Third Century," ERS, 1976 and OBERS, "1972 OBERS Projections Supplement," U.S. Water Resources Council, 1975.

Projected yields for selected crops in the 17 states, Corn Belt and High Plains

		1980	1985	1990	1995	2000
Crop Yield						
Corn	bu/ac	100	111	122	132	143
Grain sorghum	bu/ac	61	66	71	75	80
Wheat	bu/ac	31	34	37	40	42
Production weighted	bu/ac	68.5	75.7	83.1	89.6	96.5
Ethanol Yield 1/						
Corn	gal/ac	260	289	317	343	372
Grain sorghum	gal/ac	159	172	185	195	208
Wheat	gal/ac	81	88	96	104	109
Production weighted	gal/ac	198	197	216	233	251

1/ Based on 2.6 gals/bu.

Source: DPRA, op. cit.

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