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Grain Ethanol as a Petroleum Substitute: A Perspective

T. G. Alston

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T. G. Alston

Special Projects Group
Energy and Environmental Systems Division

April 1980

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GRAIN ETHANOL AS A PETROLEUM SUBSTITUTE: A PERSPECTIVE

by

T. G. Alston

ABSTRACT

Present tax exemptions for gasohol are more than sufficient to move ethanol into the gasoline market in a number of states. The principal near-term response to this profit opportunity, production of ethanol from feed grains, matches a limited biomass resource to an enormous market. This report estimates upper-bound prices for feed grains resulting from gasohol tax exemptions and concludes that grain price increases could be substantial. As shown elsewhere by Alston and Asbury,[1] industrial uses constitute a more economical market for grain ethanol, one in which the product is now competitive with ethanol derived from petroleum and natural gas liquids. Without tax exemptions for gasohol, grain ethanol would now be displacing petroleum in the industrial market at a net economic gain, rather than in the fuel market at a net economic loss. The present analysis indicates that this industrial market for ethanol could grow significantly, principally by use of grain ethanol as an intermediate in production of chemicals now derived from petroleum and natural gas.

1 INTRODUCTION

The use of grain ethanol in the United States to supplement petroleum supplies is a widely publicized and debated subject.[1] Proponents believe that grain ethanol fuel, currently used principally as a blend of one part anhydrous ethanol (by volume) with nine parts unleaded regular gasoline, can significantly reduce U.S. dependence on OPEC oil. Opponents maintain that grain ethanol consumes more energy than it produces and is a highly uneconomical alternative to petroleum fuels.

The attractions of grain ethanol can be summarized as follows:

- The principal raw material is corn, a product that U.S. farmers produce efficiently, economically, and in abundance.
- There is frequently more grain land available than is needed to produce food and feed for domestic use and export -- land that farmers are paid not to use.
- Commercial technology for converting corn starch to ethanol is readily available. Because plants need not be large, relatively small enterprises can become producers.

- Grain ethanol is a visible response to the growing liquid fuels problem.

This last item, doing something tangible to increase U.S. supplies of liquid fuel, has tended to obscure two important questions:

- What is the role for grain ethanol in a major U.S. biomass liquids program and, in the larger view, in a broad alternate liquids program that includes shale and coal liquids?
- Do current and projected federal and state tax exemptions for alcohol fuels lead to this role, or is there danger of overbuilding a new corn-based industry beyond normal market dictates?

Supporters of crash alcohol fuel programs downplay the possibility of future conflicts between food/feed and energy demands for corn, pointing out that many other raw materials -- corn stover, wheat straw, wood wastes, garbage, etc. -- can be used for alcohol manufacture. This view disregards the fact that technology for converting these alternative raw materials to ethanol will not be commercially available for many years. While technology is available for conversion to methanol, capital costs are higher, and methanol is less easily integrated into a petroleum distribution and end-use system.

Thus, it is probable that the near-term private sector response to the significant, and expanding, federal and state incentives for alcohols from renewable resources will be to produce ethanol from corn or other food/feed grains. An over-response could severely tax the limits of grain supply: to reduce U.S. gasoline consumption by 10% through total conversion to gasohol made with corn ethanol would require two-thirds of the current annual U.S. corn crop and, more significantly, 15% of the prime agricultural land.

This report debates neither the merits of ethanol as a fuel, nor energy balance, which is positive for scarce fuels so long as coal or renewable resources are used as energy sources for producing ethanol from grain. Rather, this analysis addresses:

- The potential effects on grain prices of federal and state incentives for fuel ethanol production, and
- The role for grain ethanol in industrial markets and, in the longer term, as an increasingly important intermediate in chemical manufacture.

2 GRAIN PRODUCTION AND AGRICULTURAL POLICY

Consumption of U.S. food/feed grains has generally fallen short of production capacity. To maintain grain prices, the federal government has encouraged farmers to withhold cropland from production through set-aside and diversion programs. Under set-aside programs, farmers agree to remove land from production, thereby becoming eligible for certain benefits such as nonrecourse loans, deficiency payments, and disaster relief. If the government feels that these measures will not sufficiently reduce production, then direct payments may be made to farmers to divert cropland from production.

From 1961 to 1972, U.S. corn land annually withheld from production under both set-aside and diversion programs averaged 21.7 million acres, varying from a low of 14.1 million acres to a high of 27.2 million acres.[2] During the same period, U.S. land planted to corn averaged 67.1 million acres,[3] indicating that an average of 25% of corn land was withheld annually. Addition of sorghum and barley cropland increases the average amount of feed grain land withheld from production during 1961-72 to 30.3 million acres annually. Based on average corn yields prevailing during those years, this 30.3 million acres could have yielded about 5.7 billion gallons of grain ethanol annually, or 5% of current U.S. gasoline consumption.

These kinds of calculations give strong impetus to a grain ethanol program. In addition, other factors are often cited to lend support:

- There have been significant wheat set-aside and diversion programs, resulting in an average annual withholding of 8.2 million acres during the 1961-72 period. Leaving aside that wheat is higher priced than corn, and that it is a direct food product rather than a feed grain, this withheld acreage could have yielded 0.6 billion gallons of grain ethanol annually.
- During the 1961-72 period, the federal government paid farmers an average of $1.2 billion annually for feed grain land diversion and price deficiencies.[3] Had these payments been applied to corn grown for ethanol on all withheld feed grain land, the ethanol subsidy would have amounted to about $0.20/gal.

Although these calculations appear to support a vigorous grain ethanol program, there are several problems to be considered:

- While domestic demand for corn for feed, food, and seed is relatively stable and fairly predictable, export demand, particularly to the Soviet Unión, is highly variable. A significant grain ethanol program could, at some future time, lead to a choice between corn for export or corn for fuel.
- Corn exports have risen dramatically during the 1970s, accounting for 30% of total demand for U.S. corn in each of the years 1975-78.[3] New trade agreements with China could provide further long-term growth.

- In keeping with increased exports, food/feed grain set-aside and diversion programs have been significantly reduced since 1972. Only 8-9 million acres were withheld from feed grain production in 1973 and in 1978. No acreage was withheld for the period 1974-77. While grain reserves are currently high and cropland withholding could again increase, it is unlikely to again approach the levels of the 1960s.

Although the foregoing considerations indicate that future excess feed grain production capacity will be both variable and diminishing, ways are being explored to make more grain available for ethanol manufacture. Changes in animal feeding practices could substitute forage for corn and distillers dried grains (a by-product from grain ethanol manufacture) for soybean meal. Reduced demand for soybeans could then make more land available for corn plantings. Significant additional feed grain production could also come by converting permanent pasture land into cropland, though only at successively increasing production costs. The problem remains, however, that any energy crop raised on prime agricultural land probably reduces the ultimate potential for food production. World population pressure and changing dietary habits may eventually eliminate the feeding of corn to animals. This does not necessarily mean, however, that the best use for the U.S. corn belt would then be production of corn entirely for conversion to ethanol.

3 ECONOMICS OF GRAIN ETHANOL

3.1 MANUFACTURE

Alternative liquid fuels and chemical feedstocks can be derived from shale, coal, garbage, etc. -- raw materials that generally have only other energy uses as competing markets. Even certain cellulosic biomass raw materials, such as wood, have a waste component for which energy constitutes the principal use. In contrast, feed grains are produced on prime agricultural land and have high-value uses as feed and food. There are no vast quantities of surplus grain waiting as an energy resource, and creation of those quantities on a consistent basis would simply divert agricultural land from food production to energy production. Even coproduction of food and energy crops has limits dictated by erosion control and the crop-carrying capacity of the soil.

Despite these limitations, however, grain ethanol can play a role as a price-support mechanism for grain. The key is to know what levels of grain ethanol production would be beneficial to agriculture and the economy, and to make certain that they are not exceeded because of federal and state incentives. The production of a few more billion gallons per year of grain ethanol must be weighed against the risk of higher food prices, lost grain exports, a disrupted soybean industry, etc., particularly when other alternate liquids are available. Further, the cost of grain ethanol would rise significantly as increased production exerted upward pressure on grain prices. Grain ethanol costs would also rise if the price of distillers dried grain (DDG) were depressed by increased output. However, this latter cause of higher ethanol costs might be partially or completely offset by:

- Converting grain to ethanol by both wet milling (which produces by-product oil and gluten meal) and dry milling (which produces by-product DDG), the mix of processes chosen so as to maximize by-product credits.
- Rising prices of corn, which although secondary to soybean meal in determining prices of high-protein feed, would exert upward pressure on DDG prices.

The economics, then, of grain ethanol manufacture are highly dependent on grain costs and by-product credits. Capital and, to a lesser extent, operating cost estimates vary considerably for a grain ethanol plant. According to one estimate,[4] a 50-million-gal/yr dry milling ethanol plant using the best available technology would require a fixed investment of $58.0 million and working capital of $5.7 million (in 1978 dollars). One bushel of corn yields 2.6 gal of ethanol and 17.7 lb of DDG (or 6.8 lb/gal ethanol). Assuming a price of $115/ton for DDG and a 15% discounted-cash-flow (DCF) rate of return on investment, corn at $2.50/bu would yield ethanol with a plant-gate selling price of $1.12/gal (in 1978 dollars), as shown in Table 1.

Based on current technology, it is difficult to see how grain ethanol could sell for significantly less than $1.12/gal, given a corn price of $2.50/bu. Many other estimates of ethanol selling price are considerably higher. For example, using the above assumptions about DDG market price, DCF rate of return, and corn price, another source[5] calculates a plant-gate selling price for ethanol of $1.70/gal (1979 dollars).

Table 1. Summary of Grain Ethanol Selling Price[4]
(100% company equity -- 20-yr plant life)

Cost Component	1978 $/gal
Corn, at $2.50/bu	0.96
Direct operating costs	0.27
Fixed costs	0.11
Capital recovery, taxes	0.17
	1.51
DDG credit, at $115/ton	(0.39)
Plant-gate selling price	1.12

Whatever the ethanol selling price, it is sensitive to corn price and DDG credit. Each $1/bu rise in corn price increases the ethanol selling price by $0.39/gal. Each $20/ton drop in DDG price increases the ethanol selling price by $0.07/gal (see Table 2).

3.2 MARKET VALUE

The price that an ethanol producer can afford to pay for grain depends on the market value of the product. To determine the value of ethanol fuel it is assumed that the ethanol will be used as gasohol, a blend of 90% unleaded gasoline and 10% ethanol (by volume).

In terms of the amount of gasoline replaced by one gallon of ethanol in end-use application, several opinions have been advanced:

- On the basis of energy content alone, 1 gal of ethanol replaces 0.65 gal of gasoline.
- On the basis of a 2% mileage decrease with gasohol, 1 gal of ethanol replaces 0.8 gal of gasoline.
- On the basis of equivalent mileage with gasohol, 1 gal of ethanol replaces 1 gal of gasoline.
- On the basis of a 2% mileage increase with gasohol, 1 gal of ethanol replaces 1.2 gal of gasoline.

Additional gasoline can be replaced by taking advantage of ethanol's octane boosting properties. At present, ethanol (average research-plus-motor octane of 101-102) is blended with unleaded regular gasoline (average octane of 87-88) to produce gasohol with an average octane of 90-91, about midway between the octane ratings of regular and premium gasolines.[6,7] Refinery savings of gasoline would result if a refinery produced a lower-octane gasoline and blended it with ethanol to produce gasohol (9:1 blend) having an octane rating equal to that of unleaded regular. Although one study[8] estimates these savings to be 0.36 gal of gasoline for each gallon of ethanol used, refinery analysis indicates that the savings could be well below 0.1 gal

Table 2. Variation of Ethanol Selling Price with Corn and DDG Prices

Corn Price ($/bu)	DDG Price ($/ton)	Ethanol Selling Price ($/gal)
Varying corn price		
1.00	115	0.54
2.00	115	0.93
2.50	115	1.12
3.00	115	1.32
4.00	115	1.71
5.00	115	2.10
6.00	115	2.49
Varying DDG price		
2.50	115	1.12
2.50	95	1.19
2.50	75	1.25
2.50	55	1.32
2.50	35	1.39

for each gallon of ethanol used.[9,10] This present study assumes an ethanol refining credit of 0.2 gal of gasoline, a figure that would probably be considered optimistic by most refiners.

Ranges of ethanol values can now be established, based on gasoline prices and ethanol/gasoline replacement ratios in end-use and refining. Table 3 illustrates that refinery-gate prices (Midwest) for unleaded regular gasoline averaged $0.73/gal in November 1979, nearly twice the price in the first quarter of 1978.[11]

Table 4 shows the variation of ethanol value with the acquisition price of crude oil. Based on a March 1980 refinery-gate price for unleaded regular gasoline of $0.85/gal (equivalent to a crude oil acquisition price of $24.50/bbl), ethanol values at the plant gate range from $0.55/gal to $1.19/gal. For gasoline produced from crude at acquisition prices of $35/bbl and $45/bbl (gasoline prices of $1.20/gal and $1.55/gal, respectively, at the refinery gate), ethanol values at the plant gate range from $0.78/gal to $1.68/gal and $1.00/gal to $2.17/gal, respectively.

Although the fuel economy of gasohol as compared to gasoline is still debated, most studies have concluded that gasohol gives lower volumetric economy than gasoline. Based on energy content alone, gasohol would give 3.4% fewer miles per gallon than would gasoline. This decrease is partially offset by a slightly better fuel economy per unit of energy for gasohol, resulting in a net mileage decrease of close to 2% (a gasoline replacement of 0.8 gal per 1 gal of ethanol). Addition of potential refinery savings of 0.2

Table 3. Midwestern Refinery-Gate Prices of Unleaded Regular Gasoline[11]

Period	Average Acquisition Price of Crude Oil $/bbl	Average Acquisition Price of Crude Oil $/gal	Midwestern Refinery-Gate Price of Unleaded Regular ($/gal)
1978			
1st quarter	12.18	0.29	0.39
2nd quarter	12.18	0.29	0.40
3rd quarter	12.18	0.29	0.42
4th quarter	12.60	0.30	0.43
1979			
1st quarter	13.02	0.31	0.46
2nd quarter	15.12	0.36	0.53
3rd quarter	18.48	0.44	0.62
October	21.84	0.52	0.70
November	22.68	0.54	0.73

Table 4. Variation of Ethanol Value with Crude Oil Acquisition Price

Basis	Gallons of Gasoline Replaced per Gallon of Ethanol	Ethanol Value ($/gal) Crude Oil Price of $24.50/bbl	Ethanol Value ($/gal) Crude Oil Price of $35/bbl	Ethanol Value ($/gal) Crude Oil Price of $45/bbl
Btu content	0.65	0.55	0.78	1.00
2% mileage decrease	0.80	0.68	0.96	1.24
Equivalent mileage	1.00	0.85	1.20	1.55
2% mileage increase	1.20	1.02	1.44	1.86
Refinery blending (0.2 gal gasoline replaced), plus:				
2% mileage decrease	1.00	0.85	1.20	1.55
equivalent mileage	1.20	1.02	1.44	1.86
2% mileage increase	1.40	1.19	1.68	2.17

gal of gasoline per 1 gal of ethanol result in an end-use gasoline replacement of one gallon for every gallon of ethanol. Ethanol's value when used in gasohol can thus be summarized as shown in Table 5.

3.3 TAX EXEMPTIONS FOR GASOHOL

Given these market values for ethanol as a fuel, we can now examine the potential effect of federal and state tax exemptions for gasohol on the price

Table 5. Value of Ethanol Used in Gasohol (excluding federal/state tax exemptions)

Crude Oil Acquisition Price ($/bbl)	Refinery Price of Gasoline ($/gal)	Ethanol Value at Plant Gate ($/gal): Replacement of Gasoline in End-Use, 0.8 gal	Ethanol Value at Plant Gate ($/gal): Replacement of Gasoline in End-Use and Refinery, 1.0 gal
20.00	0.69	0.55	0.69
30.00	1.04	0.83	1.04
40.00	1.38	1.10	1.38
50.00	1.73	1.38	1.73

of corn. The government currently exempts the federal exise tax of $0.04/gal on gasohol, equivalent to an ethanol subsidy of $0.40/gal. Recently enacted legislation extends the expiration date of this exemption from 1984 to 1992. This exemption, plus other federal credits amounting to an additional $0.03/gal of ethanol, effectively reduced the January 1980 plant-gate price of grain ethanol from the quoted $1.62/gal to $1.19/gal. Even assuming a gasoline:ethanol replacement ratio of 0.8:1.0, this price still allows ethanol to compete with $45/bbl spot oil.

Gasohol also is exempted from part or all of state motor fuel taxes in 15 states, 9 of which have set no termination date.[12] These exemptions have effectively reduced the price of fuel ethanol well below its market value in several states (see Table 6).

In addition to exempting gasohol from motor fuel taxes, Louisiana and South Dakota also exempt it from the state sales tax -- 3% and 4%, respectively. Indiana exempts the state sales tax (4%), but not the motor fuel tax. Although the states that offer partial or total tax exemption for gasohol represent only 16% of total U.S. gasoline consumption (and 15% of U.S. population), the trend toward state exemptions is clearly increasing. The combination of federal and state exemptions, which in many states exceeds the incentive needed to move gasohol into the market, is allowing grain ethanol producers to push prices far above estimated costs. For example, the January 1980 quoted price of $1.62/gal for grain ethanol had risen to $1.85-2.00 by late March 1980.[12]

3.4 FUTURE CORN PRICES

To assess the extent to which federal/state subsidies and increasing crude oil prices could enable grain ethanol producers to bid up corn prices, the following calculations were made:

- For crude oil acquisition prices ranging from $15/bbl to $60/bbl, the corresponding ethanol values were calculated

Table 6. Federal and State Tax Exemptions for Ethanol Used in Gasohol

Type of Exemption	Tax Exemption ($/gal ethanol)	Effective Ethanol Price[a] ($/gal)	Comments
Federal excise tax	0.40	1.22	
Other federal credits	0.03	1.19	
State motor fuel tax			
Connecticut	0.10	1.09	no expiration date
Maryland	0.10	1.09	"
North Dakota	0.40	0.79	"
South Dakota	0.40	0.79	"
Wyoming	0.40	0.79	"
Nebraska	0.50	0.69	"
Oklahoma	0.65	0.54	"
Louisiana	0.80	0.39	"
Arkansas	0.95	0.24	"
South Carolina[b]	0.40	0.79	expires 7/87
Colorado	0.50	0.69	expires 7/85
Kansas[b]	0.50	0.69	expires 7/85
New Hampshire	0.50	0.69	expires 6/83
Montana	0.70	0.49	expires 3/89
Iowa	1.00	0.19	expires 6/83

[a]Plant-gate price of ethanol = $1.62/gal.

[b]Exemption terminates prior to listed month if motor fuel tax loss exceeds a specified amount.

for three cases: no subsidy, a federal subsidy of $0.40/gal of ethanol, and a federal subsidy of $0.40/gal plus an average state subsidy of $0.40/gal. A single ethanol: gasoline replacement ratio of 1.0 was chosen for these calculations, derived from 1.0 gal of ethanol replacing 0.8 gal of gasoline in use and 0.2 gal of gasoline at the refinery. The refinery price of gasoline was assumed to average 1.45 times the crude oil acquisition cost, as indicated by the 1978 and 1979 data for a typical Midwest refinery.[11]

- For each ethanol value, a calculation was made of the maximum corn input price that would still allow ethanol to be sold at the plant gate at a price equal to that ethanol value. Corn prices were calculated for two conversion cost cases: the "low-cost" case, where $2.50/bu corn produces ethanol selling at the plant gate for $1.20/gal (in 1979 dollars), and the "high-cost" case, where $2.50/bu corn produces ethanol selling at the plant gate for $1.70/gal (in 1979 dollars). In both these cases, the market price of DDG was held at $115/ton.

The results of these calculations are shown in Table 7 and Fig. 1. They illustrate the general conclusion that continuation of federal/state incentives at current levels could, depending on the rate of grain ethanol plant construction, raise grain prices to levels detrimental to food prices and grain exports:

- At a crude oil acquisition price of $30/bbl ($1.04/gal of gasoline at the plant gate, close to current prices), a grain ethanol plant could pay no more than $2.08/bu for corn (low conversion cost) to produce ethanol at unsubsidized market value. This would limit such a plant to distressed grain or low-priced surplus grain. With current tax exemptions for gasohol, the plant could pay $3.12/bu (with the federal exemption) or $4.16/bu (with federal and state exemptions). Thus, under long-term government tax exemptions for gasohol, ethanol plants will not be limited to using distressed grain (supplies of which are generally small and dispersed) and cellulosic waste (conversion of which is not yet commercial). Rather, they will be able to compete for normal quality grains at prices generally above those prevailing in food, feed, and export markets.

- At a crude oil acquisition price of $50/bbl ($1.73/gal of gasoline) -- a situation that may not be too distant -- an ethanol plant could pay up to $3.87/bu for corn (low conversion cost) to produce ethanol at unsubsidized market value. Gasohol tax exemptions push this up to $4.91/bu (federal) and $5.95/bu (federal/state). Thus, federal/state encouragement of massive construction of grain ethanol plants could lead to closer coupling of grain prices with crude oil prices, an undesirable situation so long as crude oil prices are dictated by OPEC.

The foregoing illustrates the potential effect on grain prices of a massive near-term response by ethanol producers to federal and state tax exemptions for gasohol. In contrast, limited use of grain for ethanol production could benefit the agricultural sector, and such production need involve no government incentive if directed toward the higher-value industrial ethanol markets. These markets are described in the following sections of this report.

Table 7. Maximum Corn Input Prices for Production of Ethanol at Market Value[a]

Crude Oil Acquisition Price ($/bbl)	Refinery Price of Gasoline[b] ($/gal)	Ethanol Value ($/gal)			Corn Input Price for Manufacture of Ethanol Having a Plant Gate Selling Price Equal to Ethanol Value ($/bu)					
					Low Manufacturing Cost[c]			High Manufacturing Cost[d]		
		No Subsidy	Federal Subsidy	Fed./State Subsidy	No Subsidy	Federal Subsidy	Fed./State Subsidy	No Subsidy	Federal Subsidy	Fed./State Subsidy
15	0.52	0.52	0.92	1.32	0.73	1.77	2.81	<0	0.47	1.51
20	0.69	0.69	1.09	1.49	1.17	2.21	3.25	<0	0.91	1.95
25	0.86	0.86	1.26	1.66	1.61	2.65	3.69	0.31	1.35	2.39
30	1.04	1.04	1.44	1.84	2.08	3.12	4.16	0.78	1.82	2.86
35	1.21	1.21	1.61	2.01	2.52	3.56	4.60	1.22	2.26	3.30
40	1.38	1.38	1.78	2.18	2.96	4.00	5.04	1.66	2.70	3.74
45	1.55	1.55	1.95	2.35	3.41	4.45	5.49	2.11	3.15	4.19
50	1.73	1.73	2.13	2.53	3.87	4.91	5.95	2.57	3.61	4.65
55	1.90	1.90	2.30	2.70	4.32	5.36	6.40	3.02	4.06	5.10
60	2.07	2.07	2.47	2.87	4.76	5.80	6.84	3.46	4.50	5.54

[a] Gallons of gasoline replaced per gallon of ethanol = 1.0. Distillers dried grain price = $115/ton. Tax exemptions for gasohol = $0.04/gal (federal) and $0.04/gal (state average).

[b] Assumes that the refinery price of gasoline is 1.45 times the crude oil acquisition price.

[c] Plant-gate selling price for ethanol of $1.20/gal ($2.50/bu corn).

[d] Plant-gate selling price for ethanol of $1.70/gal ($2.50/bu corn).

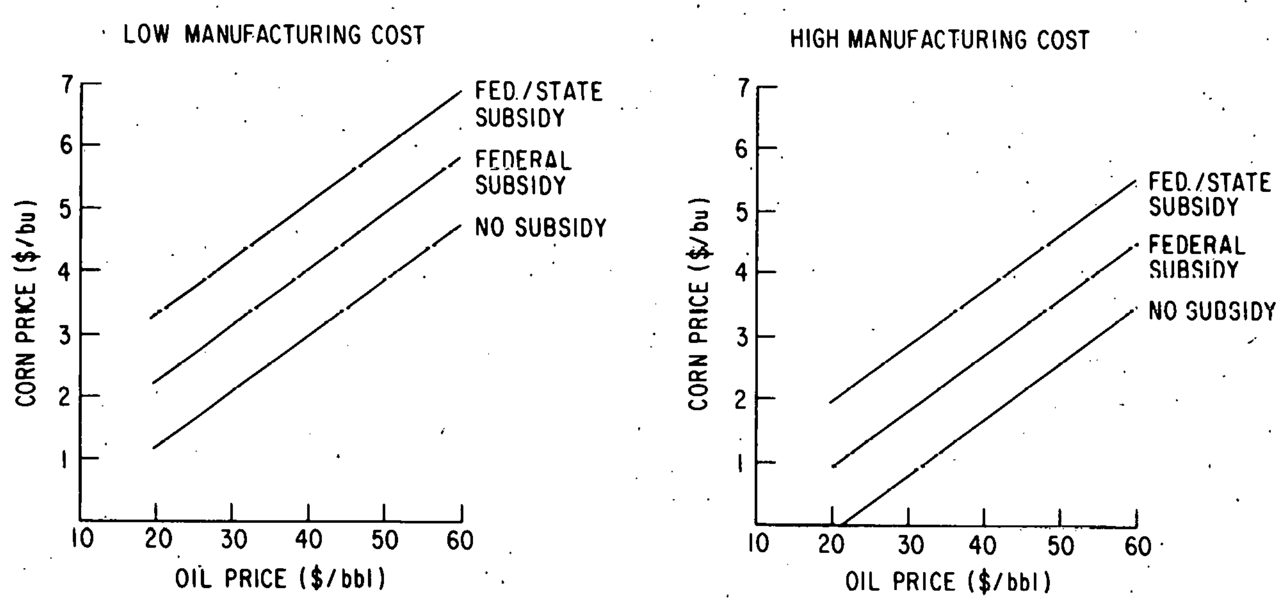


Fig. 1. Maximum Corn Input Prices for Production of Ethanol at Market Value (see Table 7 footnotes for assumptions)

4 INDUSTRIAL ETHANOL MARKETS

4.1 CONSUMPTION

The U.S. market for ethanol can be divided into three segments: industrial, fuel, and beverage. However, beverages do not represent a significant merchant market for ethanol producers. United States consumption of ethanol, exclusive of beverages, totaled about 285 million gallons (100% basis) in 1979, 85% for industrial use and 15% for fuel use (principally in gasohol). Industrial demand consists of two major use segments, chemical manufacture and solvents. Over the past 20 years, increasing use of ethanol as a solvent has not completely offset the decline in use of ethanol as an intermediate in chemical manufacture. As illustrated by Table 8, net industrial ethanol demand increased to about 300 million gal/yr in the late 1960s and by 1979 declined to about 240 million gal/yr. With the federal/state tax exemptions for gasohol, ethanol consumption for fuel, estimated at about 45 million gallons in 1979, could surpass industrial consumption by 1982. Based on an assessment of producer intentions as of January 7, 1980,[12] close to 200 million gal/yr of fuel ethanol capacity could be in place by early 1981. Table 8 also shows that industrial ethanol consumption is projected to total about 250 million gallons in that year.

Solvent applications currently account for close to 60% of industrial ethanol consumption in the United States. The largest solvent use for ethanol is in cosmetics, followed by coatings, cleaning preparations, and pharmaceuticals. Because of the increase in demand for liquid detergents, most of which contain ethanol, cleaning is expected to be the fastest growing industrial ethanol market during the next few years (Table 9).

In contrast to the solvent market, use of ethanol as a raw material for chemical manufacture has been declining. This is principally due to the steep decline in use of ethanol to manufacture acetaldehyde, a product in turn used to produce acetic acid, peracetic acid, pyridine, and other chemicals. Use of ethanol in acetaldehyde manufacture has fallen from more than 50% of total industrial ethanol demand in 1960 to about 7% in 1979. This has happened because ethanol-based acetaldehyde production has been progressively replaced by a process for manufacturing acetaldehyde directly from ethylene, rather

Table 8. U.S. Demand for Ethanol[13-16]
(10^6 gal, 100% basis)

	Industry				
Year	Solvent	Chemical Manufacture	Total	Fuel	Total
1960	65	200	265	0	265
1970	125	155	280	0	280
1979	140	100	240	45	285
1981	145	105	250	200	450

Table 9. Solvent Markets for Ethanol

	% of Total Ethanol Solvent Market			
Year	Cosmetics and Pharmaceuticals	Cleaning	Industrial	Other
1960	21	16	60	3
1970	43	15	40	2
1977	50	23	24	3
1981	50	26	21	3

than via the ethanol intermediate (see Fig. 2). As a result, the amount of ethanol used to manufacture acetaldehyde has dropped from about 150 million gal/yr in the early 1960s to about 17 million gal/yr in 1979.

In addition to this change in technology, acetaldehyde demand has itself slowed, again due to changing technology in the manufacture of several of its chemical derivatives. n-Butanol and 2-ethylhexanol, once major outlets for acetaldehyde, are now produced from propylene. Manufacture of acetic acid, currently accounting for 55% of the acetaldehyde consumption of about 1.1 billion lb/yr, is made principally by three processes, based on three different starting materials: oxidation of acetaldehyde, oxidation of n-butane, and carbonylation of methanol (Fig. 2). The acetaldehyde process has been giving way to the more economical methanol process, with 40-50% of current acetic acid production (about 2.8 billion lb/yr) based on methanol.

Partially offsetting the virtual elimination of ethanol in acetaldehyde production are the increasing use of ethanol-based vinegar (chiefly in the convenience food industry) and a slowly growing miscellaneous category of ethanol-based chemicals that includes ethyl acetate, ethyl acrylate, and glycol ethers (see Table 10). Although the shift from ethanol-based to ethylene-based acetaldehyde is virtually complete, growth in demand for industrial ethanol in the remaining markets is not projected to exceed 3%/yr through the mid 1980s. This would result in a total industrial demand still under 300 million gal/yr in 1985.

4.2 SUPPLY

Ethanol is currently derived from two alternative raw materials: ethylene, which is produced from petroleum and natural gas liquids, and sugar, which is derived from grains and other starch/sugar materials. In the early 1950s, about half the U.S. production of industrial ethanol was by fermentation of sugar and starch materials. The balance was produced predominantly by absorption of ethylene in sulfuric acid to form ethyl sulfates, followed by hydrolysis to ethanol. Fermentation rapidly gave way to both the ethyl sulfate process and a newer process based on direct catalytic hydration of ethylene. Production by the ethyl sulfate process peaked in the mid 1960s and, in turn, gave way over the next ten years to the catalytic process. By 1975, no ethanol was manufactured via ethyl sulfate, although 7% of industrial output was still derived by fermentation, as shown in Table 11.

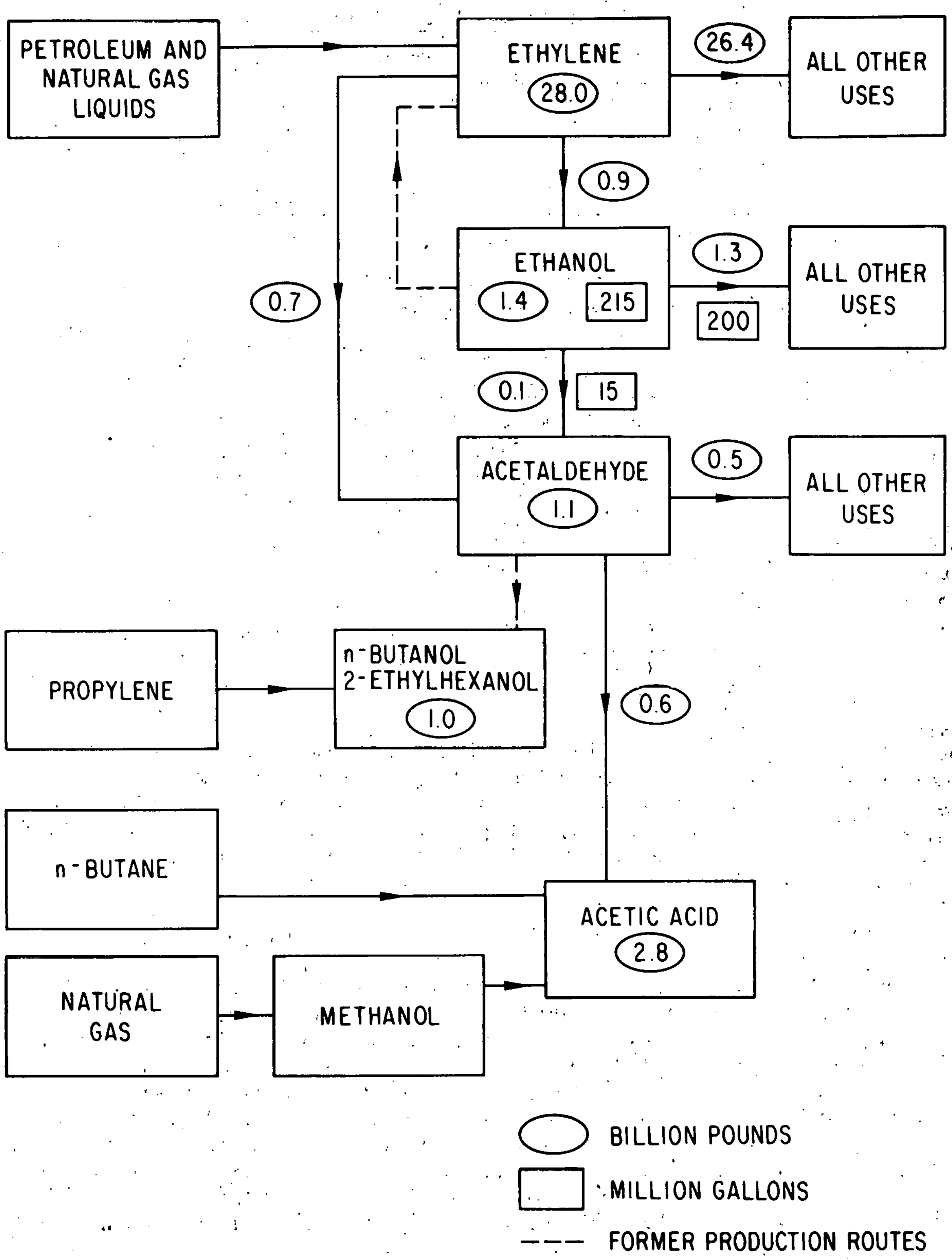


Fig. 2. Production and Use of Industrial Ethanol, Based on 1979 Quantities

Table 10. Chemical Markets for Ethanol

	% of Total Chemical Market		
Year	Acetaldehyde	Vinegar	Other
1960	73	5	22
1970	50	11	39
1977	17	21	62
1981	15	23	62

Table 11. Industrial Ethanol Production[13]
(percent by process)

	Ethylene-Based			
Year	Catalytic Hydration	Ethyl Sulfate	Total	Fermentation
1951	7	41	48	52
1954	14	63	77	23
1960	16	75	91	9
1965	19	73	92	8
1970	44	48	92	8
1975	93	0	93	7

Four companies, listed in Table 12, now operate ethylene-based ethanol plants, with a combined production capacity of 271 million gal/yr (95% basis). An additional 40-million-gal/yr unit at Deer Park, Texas, was mothballed by Shell Chemical early in 1979. The company continues to sell ethanol obtained from Union Carbide under a long-term tolling agreement, indicating that Shell intends to restart the plant if demand warrants.

Fermentation-based industrial ethanol production, probably amounting to no more than 20 million gal/yr in the mid 1970s, has been considerably augmented by gasohol production. As of January 1, 1980, there were eight producers of fermentation ethanol with a combined capacity of about 90 million gal/yr.[12] The raw material for 80% of this capacity is corn, the balance of the capacity being fed with sugar, wood pulping liquors, cheese whey, and grain sorghum. The largest fermentation ethanol plant is Archer-Daniels-Midland's corn wet milling facility at Decatur, Illinois, with an ethanol capacity of 50 million gal/yr. This will be expanded to 100 million gal/yr by early 1981, and several other potential producers are planning corn-based facilities. A survey conducted in early January 1980 indicates a fermentation capacity of 160-200 million gal/yr by mid 1981, of which over 85% will be corn-based.[12]

Table 12. U.S. Production Capacity for Ethylene-Based Ethanol[16]

Producer	Plant Location	Capacity[a] (10^6 gal/yr)
Union Carbide	Texas City, Texas	120
USI Chemicals	Tuscola, Ill.	66
Publicker Industries	Philadelphia, Pa.	60
Eastman Chemical	Longview, Texas	25
Total		271

[a]95% basis.

4.3 PRICE

Throughout the 1960s, the price of industrial ethanol remained at \$0.52/gal (95% basis, delivered East in tanks); the price of absolute ethanol was \$0.07/gal higher. The price moved to \$0.54/gal in 1970, but did not begin to increase significantly until 1974. Prices have recently moved rapidly from \$1.25/gal in mid 1979 to \$1.57/gal in March 1980 (\$1.68 on a 100% basis). During the same period, ethylene prices have moved from \$0.14/lb (contract delivered) to \$0.20/lb (see Table 13).

Fuel ethanol, which is eligible for tax exemptions only if produced from renewable resources, was priced above industrial ethanol in mid 1979. As of January 1980, Archer-Daniels-Midland had priced fuel ethanol (100% basis) at \$1.62/gal at the plant gate, about \$0.06/gal below the price of ethylene-based ethanol (100% basis). Fermentation ethanol could, therefore, begin to displace the ethylene-based product, assuming that fermentation producers are prepared to set up the marketing and technical service capabilities needed to serve the industrial market. Instead, federal/state tax exemptions have allowed fermentation producers to realize higher prices in the lower-value fuel market. As of March 1980, the price for grain ethanol had risen to \$1.85-2.00/gal,[12] higher than the \$1.78/gal price for ethylene-based ethanol.

Table 13. Prices of Industrial Ethanol and Ethylene[13,17]

Date	Industrial Ethanol[a] ($/gal) 95% by Volume	Industrial Ethanol[a] ($/gal) 100% by Volume	Ethylene[b] ($/lb)
July 1955	0.40	0.45	0.047
July 1959	0.52	0.59	0.050
July 1969	0.52	0.59	0.033
July 1970	0.54	0.61	0.031
July 1973	0.54	0.61	0.033
July 1974	0.65	0.70	0.065
July 1975	1.00	1.07	0.10
July 1977	1.22	1.30	0.12
July 1979	1.25	1.35	0.14
Oct. 1979	1.41	1.51	0.155
Dec. 1979	1.41	1.51	0.18
Jan. 1980	1.57	1.68	0.20
Mar. 1980	1.67	1.78	0.20

[a]Delivered in tanks to the East.

[b]Contract delivered.

5 ROLE FOR GRAIN ETHANOL

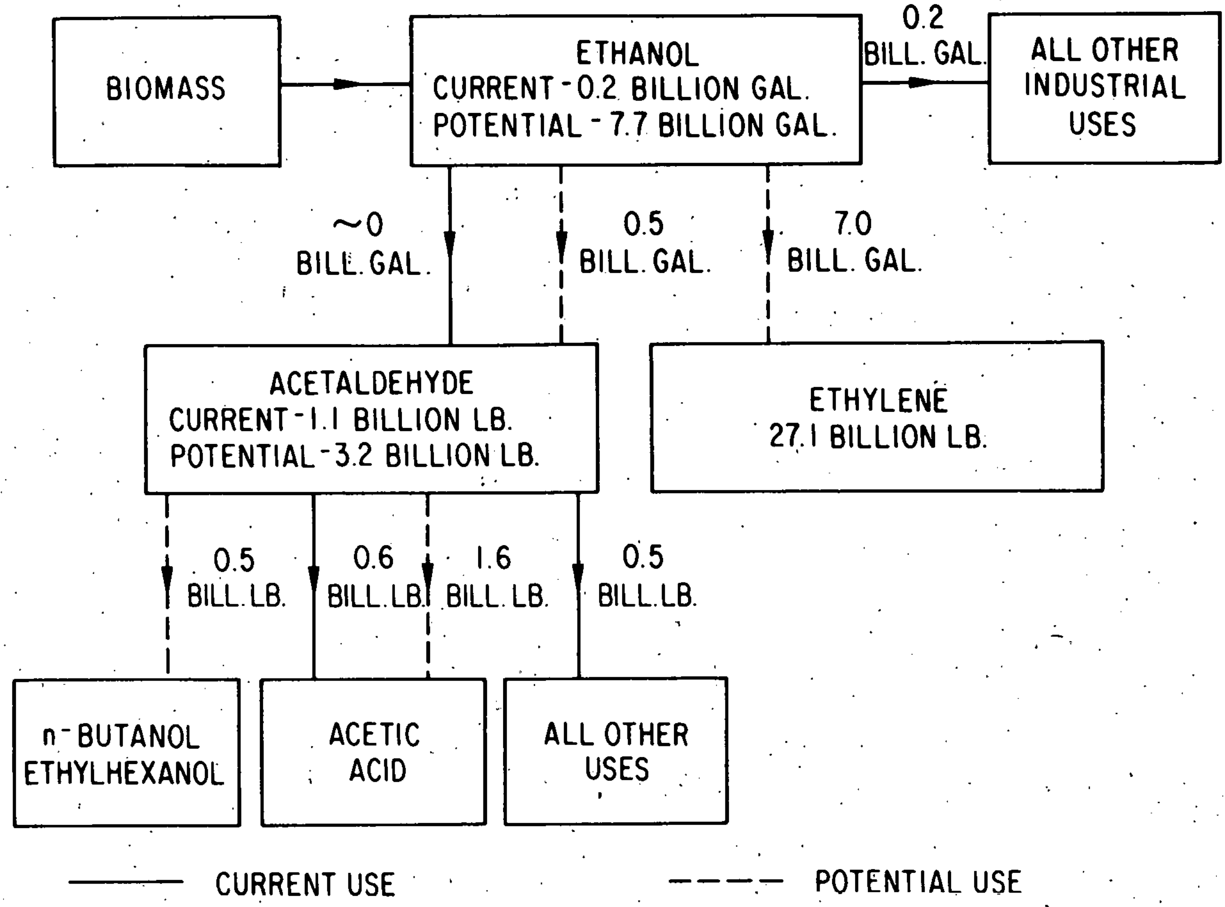
In a free market situation, grain ethanol would now be moving into chemical markets rather than into fuel markets.[1] As the price of petroleum-derived ethylene increased, grain ethanol might recapture lost ethylene-based ethanol markets and, complemented by cellulose-derived ethanol, even break into large chemical feedstock markets through its conversion into ethylene. Ethanol produced from cellulose could also move into the much larger, but lower-value, fuel market. Because of such characteristics as octane enhancement and higher combustion efficiency, ethanol might play a significant role in the fuel market as a liquid fuel extender or, in higher-compression engines, as a straight fuel.

Irrespective of long-term projections, it seems clear that the near-term economic role for grain ethanol is to replace ethylene-based ethanol as prices of petroleum and natural gas liquids continue to rise. The industrial market for ethanol (currently 215 million gal/yr) could expand significantly if future prices for petroleum and natural gas feedstocks rise much more rapidly than the cost of producing ethanol from grains or other biomass resources. In this situation, the point could be reached where acetaldehyde, derived from biomass ethanol, would again constitute an economical route to acetic acid and other derivatives, thereby displacing natural gas and petroleum-derived starting materials (see Fig. 2). Based on 1979 production levels, the potential for biomass ethanol in such an expanded use for acetaldehyde would be about 0.5 billion gal/yr (see Figs. 2 and 3).

While expanded use of acetaldehyde as a chemical intermediate could triple the industrial ethanol market, the most significant chemical potential for biomass ethanol lies in its dehydration to ethylene. This process for ethylene production was common in the United States until the early 1950s, when large-volume hydrocarbon cracking became more economical. Dehydration facilities are still operated in India, where ethylene demand is low and hydrocarbon feedstocks are expensive.[18] Furthermore, the economics of dehydration now appear favorable in countries such as Brazil, where ethanol prices are controlled and the price of ethylene is relatively high.[19]

Chemical feedstocks now account for about 8% of U.S. petroleum consumption. Ethylene, by far the largest-volume primary organic derived from these feedstocks, is produced principally by cracking of natural gas liquids and petroleum liquids, with minor amounts derived from refinery gases. U.S. ethylene consumption has risen from 5 billion lb/yr in 1960 to 28 billion lb/yr in 1979. Consumption has increased 8% annually since 1975 and is forecast to continue to increase at a rate only slightly lower through 1985.[20] Most of this growth comes from the ethylene-based major plastics -- low- and high-density polyethylene, polyvinyl chloride, and styrenics -- which together account for over 65% of total ethylene demand.[20]

Production from ethanol of all ethylene consumed in the United States in 1979 would require nearly 8 billion gallons of biomass ethanol (Fig. 3). This is more than 10 times the potential in existing industrial ethanol markets, even with the expansion into acetaldehyde manufacture. Based on projections for ethylene consumption,[20] this 8 billion gal/yr potential increases to 12 billion gal/yr in 1985 and about 15 billion gal/yr in 1990.



CHEMICAL MARKETS FOR BIOMASS ETHANOL
(USING DATA FOR 1979):

		BILLION GALLONS
CURRENT	-- SOLVENT AND CHEMICAL MANUFACTURE	0.2
POTENTIAL	-- IN ACETALDEHYDE PRODUCTION	0.5
	-- IN ETHYLENE PRODUCTION	7.0
TOTAL - CURRENT AND POTENTIAL		7.7

Fig. 3. Some Potential Chemical Markets for Biomass Ethanol Based on Approximate 1979 Quantities

Use of biomass ethanol as a feedstock for ethylene production depends on future price increases of petroleum feedstocks relative to biomass. The economics of ethanol dehydration to ethylene are dominated by feedstock (ethanol) cost, which in turn is dominated by biomass cost. For a 132-million-lb/yr ethylene plant based on fluidized-bed catalytic dehydration, full conversion costs (including return on investment, but excluding feedstock cost) would amount to about \$0.05/lb of ethylene in 1979 dollars.[21] Each pound of ethylene produced would require 1.66 lb of ethanol[21] which, using the low cost estimate of \$1.20/gal for corn-based product, results in an ethanol cost of \$0.30/lb of ethylene. Thus, the plant-gate selling price of ethylene would be \$0.35/lb, of which 85% is ethanol cost (of which, in turn, at least 50% consists of net corn cost, depending on by-product DDG credits).

This price of \$0.35/lb for ethylene is 75% higher than the current \$0.20/lb (March 1980). An integrated biomass ethanol/ethylene plant could transfer ethanol at cost (about \$0.95/gal), bringing the plant-gate price of ethylene down to \$0.29/lb. While this is still 45% above the current price, quoted ethylene prices have risen 40% in just the past year.

Table 14 summarizes ethanol-based ethylene prices at various ethanol costs. An ethanol cost of \$0.60/gal is required to produce ethylene selling at \$0.20/lb. Each \$0.20/gal rise in ethanol cost increases the ethylene selling price by \$0.05/lb. Based on the 1977 ethylene price of \$0.12/lb, ethylene derived from grain ethanol would be competitive by 2000 if corn cost increased 5%/yr and petroleum costs increased 10%/yr.[21] With ethylene selling for \$0.20/lb in 1980, ethanol-based ethylene could become competitive by 1990, depending on commercialization of low-cost ethanol from cellulose.

Whatever the future for biomass ethanol, it seems clear that, from an economic standpoint, grain ethanol should be moving not into fuel use, but into higher-value chemical and solvent uses. These uses offer a market in which grain ethanol is now competitive, without tax exemptions, with petroleum-based ethanol. Furthermore, grain ethanol saves more scarce fuels when used as a replacement for ethylene-based ethanol than when used as a replacement for gasoline. The limited size of chemical markets, particularly in the near-term future, would restrain grain ethanol production within normal limits of economic grain supply. Expansion of ethanol into the much larger fuel markets could then be dictated by future availability of low-cost ethanol from cellulosic residues and wastes.

Table 14. Ethylene from Ethanol: Plant-Gate Selling Prices[21]

Ethanol Cost		\$/lb of Ethylene		
\$/gal	\$/lb	Ethanol Cost	Operating Cost Plus Return on Investment	Selling Price
0.60	0.09	0.15	0.05	0.20
0.80	0.12	0.20	0.05	0.25
1.00	0.15	0.25	0.05	0.30
1.20	0.18	0.30	0.05	0.35
1.40	0.21	0.35	0.05	0.40
1.60	0.24	0.40	0.05	0.45
1.80	0.27	0.45	0.05	0.50
2.00	0.30	0.50	0.05	0.55

REFERENCES

1. Alston, T.G., and J.G. Asbury, *Grain Alcohol: The Right Product in the Wrong Market*, Argonne National Laboratory Report ANL/EES-TM-79 (March 1980).

2. Dovring, F., *Cropland Reserve for Fuel Production*, prepared for the Alcohol Fuels Policy Review, U.S. Department of Energy (Nov. 1978).

3. *Agricultural Statistics*, U.S. Department of Agriculture (1960-78).

4. *Grain Motor Fuel Alcohol - Technical and Economic Assessment Study*, prepared by Raphael Katzen Associates, U.S. Department of Energy Report HCP/J6639-01 (Dec. 1978).

5. Mittelhauser Corp., Downers Grove, Ill., unpublished information (1979).

6. Wagner, T.O., et al., *Practicality of Alcohols as Motor Fuel*, SAE Paper 790429 (Feb. 1979).

7. Keller, J.L., *Methanol and Ethanol Fuels for Modern Cars*, prepared for 7th General Assembly of World Federation of Engineering Organizations, Jakarta, Indonesia (Nov. 1979).

8. *Gasohol*, prepared by Office of Technology Assessment for the U.S. Congress, U.S. GPO Stock No. 052-003-00706-1 (Sept. 1979).

9. Kozinski, A.A., Amoco Oil Co., Naperville, Ill., private communication (April 1980).

10. Lawrence, D.K., et al., *Automotive Fuels - Refinery Energy and Economics*, SAE Paper 800225 (Feb. 1980).

11. McHenry, K.W., Jr., Vice President - R&D, Amoco Oil Co., Naperville, Ill., private communications (Dec. 1979, March 1980).

12. National Alcohol Fuels Commission, Washington, D.C.

13. *Chemical Economics Handbook - Industrial Ethyl Alcohol*, Stanford Research Institute (Aug. 1976).

14. *Ethanol: It's a Slow, Uphill Climb*, Chemical Week (Jan. 12, 1977).

15. *Ethanol Market Rebounds After Bad Year*, Chemical & Engineering News (Dec. 18, 1978).

16. *Chemical Profile - Ethanol*, Chemical & Engineering News (July 1979).

17. Chemical Marketing Reporter (selected issues, 1975-1980).

18. Winter, O., et al., *Make Ethylene from Ethanol*, Hydrocarbon Processing (Nov. 1976).

19. *Lummus Develops New Fluidized-Bed Route to Ethylene from Ethanol*, Chemical Week (Nov. 23, 1977).

20. Hamilton, C.W., *Building Blocks and Erector Sets: The Olefins Game*, in Review and Forecast, Chemical Marketing Research Assn. (May 1979).

21. Brandt, D.E., *Long-Term Changes Are Possible in Ethylene Feedstocks*, The Oil and Gas Journal (Feb. 5, 1979).

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