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PRODUCTION COSTS AND TECHNOLOGICAL CHANGE: A CASE STUDY

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ABSTRACT

This paper presents and analyzes new data on ethanol production costs. Future industry expansion and the economic potential of technology advances are evaluated. For ethanol to compete in the 1990's without the Federal subsidy, crude oil prices would have to rise to $40 per barrel.

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Introduction

Increased domestic U.S. ethanol production and use potentially enhances energy security, contributes to reductions in carbon monoxide emissions, and uses surplus grains and agricultural production capacity. The past few years have seen a renewed debate concerning the merits of using public programs that subsidize ethanol production to meet these goals. The public debate has suffered from lack of a clear picture of industry production costs. Previous studies have used estimates of production costs that were made in the early 1980's before significant fuel-ethanol production experience existed (Gavett, U.S. Congress). These data have been challenged by claims of steadily improving cost performance in the industry since its inception in 1979. Other studies base cost estimates on generic engineering designs (Congressional Research Service, National Advisory Panel). While invaluable, costs based on engineering designs fail to represent the range of operating cost levels experienced in the industry, do not address the possibility of adapting existing industrial capacity, and are projected rather than based on actual operating experience. The future competitiveness of ethanol and expansion of the industry depend, in large part, on production costs.

As part of our investigation of the economic and policy tradeoffs associated with ethanol production (LeBlanc, *et al.*), comprehensive data on industry operating costs in 1987 were obtained. This paper reports these data and assesses the economics of fuel ethanol production in the 1990's. Expected biotechnological advances in ethanol production over the next 3-5 years are examined along with those that may be commercially successful in 10-15 years. Lastly, ethanol's cost competitiveness with petroleum and other energy technologies is explored.

ETHANOL INDUSTRY OVERVIEW

The U.S. ethanol industry is composed of a diverse group of companies and production facilities. Plants in the industry vary by size, type of technology, financing, traditional grain processing experience, and diversification. A few large ethanol plants account for the bulk of ethanol production. According to Information Resources Incorporated, nearly 75 percent of operating capacity in 1986 was accounted for by the eight largest plants, owned by the five largest companies. While over 150 fuel ethanol plants have been constructed in the United States since 1979, only 17 plants have a capacity of at least 10 million gallons per year (mgy). Most commercial plants are at least 1.0 mgy although a few on-farm plants of .05 to .5 mgy exist. We consider plants of less than 10 mgy as small plants, plants in the 10-39 mgy range as medium plants, and large plants as those above 40 mgy.

The Federal government has had substantial involvement in the industry. The largest financial incentive has been the exemption of ethanol/gasoline blends from at least part of the excise tax on fuel. The excise tax level and the exemption have both risen over time. Under current law, 10-percent ethanol blend fuels are exempt from 6 of the 9-cent tax through September of 1993. At the 10 percent blending rate allowed under fuel standards, the exemption is effectively a 60-cent per gallon subsidy. Many states provide similar exemptions on State gasoline taxes or provide direct producer subsidies which average 20 to 30 cents per gallon.

The tax code as it affects investment and depreciation write-offs can also be seen as a subsidy. In addition to the Accelerated Cost Recovery System (ACRS) of depreciation and the general investment tax credit (ITC) of 10 percent, an additional energy investment tax credit (EITC) of 10 percent was available from alternative energy property such as, in many cases, ethanol plants.1/ Together, the value of these incentives to the ethanol industry approached

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1/ Plants using gas or oil as an energy source or constructed as an addition to an existing corn wet-mill were generally ruled ineligible to receive the credit.

$1 billion in 1986. The Tax Reform Act of 1986 eliminated the ITC and the ACRS and phased the EITC out over 1 or 2 years depending on the specific energy property.

In addition to the direct production incentives, the Federal government also has loan guarantee programs to assist with plant construction. The United State Departments of Agriculture (USDA) and Energy (DOE) were given responsibility for these programs. Compared to the USDA assisted ethanol facilities, DOE has assisted much larger facilities. Only two of the USDA assisted plants have annual capacities greater than 10 million gallons. All the DOE assisted plants have annual capacities greater than 20 million gallons. Even though USDA has guaranteed a greater number of loans, the value of DOE loan guarantees is twice that of USDA. Overall, federally financed plants constitute approximately 25 percent of industry capacity. Federal involvement has been greatest in plants with capacities of 10-39 million gallons; in this range, over 60 percent of capacity in the industry was Federally guaranteed.

The incentive value, if any, of loan guarantees and similar financial assistance is difficult to assess. Many of the Federally financed plants have declared bankruptcy and have been sold or dismantled. Out of the 13 plants built with loans guaranteed by USDA's Farmers Home Administration (FmHA), only one has fully paid off its loan and four are operating and making loan repayments. Of the three facilities constructed with DOE loan guarantees, only one is operating and making payments on schedule.

A variety of factors have been cited for the high failure rate among Federally guaranteed plants. Both small Federally guaranteed and privately financed plants were put under pressure by the decline in oil prices. Other factors such a financial resources, experience, and quality of technical and engineering staffs have influenced over-all operating performance.

The implications of the high failure rate among Federal financed plants are unclear. The Federal loan programs have several goals beyond keeping fuel-ethanol production enterprises profitable. The programs emphasized dry mill technology, regional equity, and small-scale production. The benefits of the Federal loan guarantee did not sufficiently outweigh the constraints of complying with the requirements to induce those producers who eventually proved most successful to take advantage of the program. Any loan guarantee program is likely to offer the largest advantage to small, new enterprises that have unproven records and therefore are unable to obtain private financing at competitive rates.

Production Costs

The cost of ethanol production varies considerably among existing plants.2/ The net cost of corn for ethanol production is the most important cost factor and has been even more variable than the cost of corn itself. The net cost of corn has ranged from nearly 79 cents per gallon of ethanol produced to less than 10 cents for a short period during early 1987 (Table 1). Over the past 7 years, corn prices have varied from $1.41 to $3.16 per bushel. For the most part, corn prices fell consistently over those 7 years. Byproduct values also varied but not nearly as much as corn prices. In recent years, byproduct prices have risen and corn prices declined.

The component costs of production are less variable than the net cost of corn and are substantially lower than when the industry began. Technological improvements have generally been evolutionary rather than revolutionary and often involve plant-specific improvements in operations with minor changes in the physical plant or other material inputs (e.g., Gadomski).

Cash operating costs vary considerably by plant size. Large plants spend between 40-59 cents per gallon of ethanol produced. Costs for small and midsized plants vary more markedly, 32-65 cents per gallon. The greatest outlay is for energy, averaging 36 percent of total cash operating costs. Both energy and labor costs tend to be higher for midsized plants compared to large plants.

Estimated construction cost for a new dry mill with an annual capacity of 40 million

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2/ Cost estimates were collected by W. Robert Schwandt from ethanol producers.

gallons or a wet mill with an annual capacity of 100 million gallons is \$2-\$2.50 per annual gallon. Fermenter/distiller additions to existing sites cost about \$1-\$1.50 per annual gallon. For an operating wet mill with seasonal excess corn grind capacity, the \$1-\$1.50 represents the full additional capital cost of ethanol production. Given capital costs per annual gallon of capacity range from \$1 to \$2.50, the capital charge per gallon of ethanol produced can be placed at 19 cents to 48 cents.

Table 1 -- Net corn costs of wet and dry milling

		Wet milling 1/			Dry milling 2/		
Period	Corn cost	Byproduct value as share of corn cost	Net corn cost		Byproduct value as share of corn cost	Net corn cost	
	Dollars/ bushel	Percent	Dollars/ bushel	Dollars/ gallon	Percent	Dollars/ bushel	Dollars/ gallon
1981	3.16	44.9	1.74	0.70	41.0	1.86	71.5
1982	2.48	55.8	1.10	.44	51.5	1.20	46.2
1983	3.12	48.2	1.62	.65	44.6	1.73	66.5
1984	3.11	44.0	1.74	.70	34.0	2.05	78.8
1985	2.52	45.4	1.37	.55	33.8	1.67	64.2
1986	1.95	59.3	.79	.32	54.7	.88	33.8
1987	1.41 3/	89.1	.15	.06	78.6	.30	11.5

1/ CO_2 recovery not included; ethanol yield is 2.5 gallons/bushel.
2/ Dry-mill by-products are evaluated at 125 percent of value of corn gluten feed, and yield is assumed to be 18 pounds/bushel; ethanol yield is 2.6 gallons/bushel.
3/ First quarter.

The Process Technology

The two main process configurations used for ethanol production are dry and wet-mills. The two processes are similar (e.g., Keim, 1983 and 1980). Both require that the corn be ground. In the dry-mill process, the corn is then slurried with water and cooked. At this stage, enzymes that convert starch to sugar are added. The next stage is the fermentation of sugars using yeast to produce beer. The dissolved solids are then separated out from the beer, which contains alcohol and water in addition to the dissolved solids. The alcohol/water mixture is then distilled and dehydrated to create anhydrous ethanol. Distillation reduces the water content to approximately 5%. Dehydration removes the remaining water.

In contrast to the dry-mill process, the wet-mill process removes solids prior to the conversion of starches to sugar and produces more co-products, a few of which have high market values. Early removal of solids results in a clarified substrate, yielding a more pure sugar and water mixture for fermentation.

The ethanol wet-mill plant is identical to a fructose plant up through the starch production phase. Combining ethanol and fructose production in a wet-mill plant has proven to be financially advantageous because it provides utilization of expensive processing equipment during times when demand is low for the main product, high-fructose corn syrup.

State-of-the-Art Technology

In general, a state-of-the-art plant would feature a number of design changes that are a continuation of previous improvements. Continuous processing, from the cooking stage through to distillation, would be implemented. Yeast would be recycled. Process control would be fully computerized. The plant would likely combine starch conversion and fermentation to gain higher yields. Large plants may choose on-site production of enzymes. Wet-mills would separate fine fibers from the gluten meal and feed. Two alternatives to dehydration could be utilized, neither of which uses benzene: corn grits (Ladisch) or the molecular sieve technology.

Further up-grading of by-products, e.g. human grade by-products, to obtain higher market value may be a component of the new plants. The barrier to new or higher value by-products is the development of markets for the products (e.g., Gaines and Karpuk). In addition, it is possible to upgrade the fusel stream to separate small amounts of other alcohols produced during fermentation; the other alcohols, for which markets already exist, can generate high-valued products, e.g. chemicals used in perfumes.

Perhaps the most significant design feature of a state-of-the-art plant involves the full integration of the power plant and waste energy utilization. The most efficient plant currently operating bypasses cogeneration and uses direct steam drive to replace large electric motors.

Experience from existing plants will help to minimize the extent of over-building and upgrading of new plants. Annual capital charges in the state-of-the-art plant are estimated at $.40 per gallon assuming some site-related costs could be saved through use of an existing industrial site. A completely new facility requiring complete site development including such items as railroad sidings, electrical transmission, and sewer and waste treatment incurs capital charges of $.47.

A direct comparison can be made between the average operating costs experienced by existing plants and engineering design costs for a planned plant incorporating state-of-the-art technology; these costs do not include the cost of corn. The state-of-the-art plant could achieve an estimated 17 percent reduction in operating costs, unevenly distributed among three cost categories; that is operating costs of $.47/gallon of ethanol for average existing technology could be reduced to $.38/gallon using state-of-the-art technology. The greatest absolute savings result from reduction in energy costs, i.e. $.06/gallon. Of the remaining categories, costs of management, administration, insurance, and taxes could be reduced easier than ingredients, personnel, and maintenance.

Reduction in net corn costs resulting from state-of-the-art technology would be extremely sensitive to corn and by-product prices. For example, a four percent improvement in yield for wet-mills using technologies that are able to separate all the starch from the fiber (i.e., moving from yield of 2.5 to 2.6 gallons per bushel) would reduce net corn costs by less than one-half cent, when corn prices are low and when by-product prices are high as was the case in the spring of 1987. With corn prices of $2.50 per bushel and by product recovery of only 40 percent of the corn cost, the savings per gallon for the same yield increase would be over one and a half cents or more than 3 times larger.

Potential Improvements in the Near Term

There are three new technologies whose potential has been demonstrated at less than the commercial level and involve risk in production at full-scale. These new technologies are the replacement of yeast with the *Zymomonous mobilis* bacteria, membrane separation of solubles, and the immobilization of enzymes and yeasts (or the *Z. mobilis* bacteria) in the wet-mill process.

Z. mobilis offers considerable promise (Buchnolz, Dooley, and Everleigh; Doelle and Greenfield). Its desirable features are greater temperature tolerance and higher yields due to its higher selectivity for producing ethanol. Membrane separation of solubles might allow 40 percent of the water to be separated out prior to the boiling process, greatly reducing the energy needed (Wu and Sexson). The remaining obstacle is reducing the tendency for the membrane to become clogged with the solubles. Immobilization of yeasts and enzymes involves passing the starch or sugar solution, the clarified substrate, through a medium containing the enzyme, yeast, or bacteria. This would allow improved control of the process and maximize the use of the yeast or bacteria and enzymes. Immobilization replaces recycling by holding the yeast in place. As a result, it will likely reduce concerns of contamination associated with yeast recycling which requires removal of the yeast from the beer and return to the fermenter. Because the process requires a clarified substrate it is only applicable to wet-milling.

Beyond the specific technologies discussed above continued small gains can be expected through improvements in process control and waste heat utilization. Without predicting the specific source of cost savings, it is likely that the state-of-the-art plant of 3 to 5 years in the future may obtain an additional 5 cent savings in operating costs per gallon over the state-of-the-art plant of today without substantial changes in capital costs.

Longer Term Considerations

The focuses of near- and long-term ethanol research and development differ by degree. Long-term pay-offs can not be examined in the narrow context of the ethanol production facility itself. An analysis of whether the industry is to grow beyond a role as a user of surplus corn and grain production must consider the following trends: the production cost of using other grains, sugar, and potato crops; biological conversion technologies capable of using a broader set of feedstocks; and the development of and markets for by-products from both the new and existing technologies (e.g., Hudson).

Technologies that may provide pay-offs in the longer term include alternative crops such as potatoes, sweet potatoes, Jerusalem artichokes, sugar beets, fodder beets, sweet sorghum, and grains other than corn not used currently (e.g., Barrier, Cabler, and Broder). Use of these crops for ethanol do not present particular technological hurdles. Should corn prices rise, these alternative feedstocks may prove to be cheaper because they can be grown on marginal lands and climates not suitable for corn production. Bioengineering and traditional plant breeding technologies that increase per acre yields or increase starch and sugar contents of corn and other crops also offer the potential for lower cost ethanol through reduction in feedstock costs.

Processes used to break down various types of cellulosic biomass materials into sugars that can then be fermented is an active research area (e.g., Coombs and Parisi; Ladisch and Tsao; Lin *et al.*). Ultimately, ethanol could be produced from woody plants and a broader spectrum of organic waste. Examples of cellulosic feedstocks include alfalfa, corn stover, and bagasse. Direct cost competitiveness of these technologies will be difficult to achieve if grain prices remain low. However, the by-products derived from these technologies will be considerably different than existing ethanol by-products and hence, may find other market niches which are just as attractive as those for corn. With some of the proposed technologies, ethanol could become a complimentary output, with demand for relatively high valued chemicals derived from the process driving the production process (e.g., Sproull, Bienkowski, and Tsao).

The best current cost estimates for producing alcohol and co-products from cellulose range between 1.00 to 1.20/gal (Wright). This estimate includes CO_2 and the energy value of unconverted cellulose as by-product credits. It is difficult to make a direct comparison to a corn processing plant. Processing costs for a grain plant at current corn prices can be placed between 60 to 90 cents/gallon. Despite this apparently large difference, improvements in experimental cellulose conversion technologies combined with petroleum price increases could make cellulose conversion more economically attractive in the future.

Industry Expansion

Current industry plans are for modest capacity expansion at existing sites despite a relatively high return to ethanol production as of the first half of 1987. Subdued interest in capacity expansion has been attributed to the expiration of the motor fuel excise tax exemption in 1993 combined with the projection of only modest increases in world petroleum prices.

Many abandoned facilities are adaptable to producing ethanol. Many abandoned corn wet mills, built in the 1970's, are near the Northeast gasoline market. Over 20 oil refineries in the Midwest, with a distillation capacity 17 times the current ethanol industry capacity, have been abandoned since the early 1980's. Lastly, unused fertilizer plants, chemical plants, and breweries can be adapted for ethanol production.

Figure 1 displays potential longrun supply expansion for the industry. An additional 1 billion gallons of ethanol capacity may be available by adding to existing wet mills that do not have ethanol production capacity and by adding incrementally to existing ethanol production facilities. With corn at $1.50 per bushel, the full cost of ethanol production before subsidies would be roughly $1.00 per gallon (50% by-product cost recovery). With corn at $2.50 per bushel, ethanol costs would be $1.30 per gallon. Adapting the best of abandoned industrial sites could easily add another 1-2 billion gallons of capacity or more at ethanol production costs of $1.15-$1.40, depending on corn prices. Fully new ethanol plant construction, limited to geographic areas of strategic marketing interests, can be added with costs ranging from $1.20-$1.45, depending on corn prices.

Cost Competitiveness with Petroleum

Ethanol competes with gasoline and gasoline blending agents. The prices of gasoline and gasoline blending agents are closely tied the uncertain price of crude oil. The competitiveness of ethanol, as influenced by the variability in the prices of corn and crude oil and the additional uncertainty of the future status of the Federal subsidy for ethanol, is displayed in Figure 2. We assume that a new state-of-the-art plant is used to produce ethanol with byproduct recovery of 50 percent of the cost of corn. Ethanol is assumed to compete on a direct cost per gallon basis with gasoline, reflecting a middle position between decreasing the value of ethanol on the basis of its lower Btu level and increasing its value on the basis of its higher octane value.

With $2.00 per bushel corn and the existing Federal subsidy, ethanol is competitive with crude oil prices at a level of $20 per barrel (break-even curve 2). Without the subsidy, crude oil prices would have to rise to at least $40 per barrel (break-even curve 4). Without the subsidy, there is no corn price that would make ethanol competitive with crude oil prices below $25 per barrel as long as the byproduct credit does not exceed the cost of the corn.

The state-of-the-art plant represents an improvement over the average existing technology and has, therefore, enhanced the competitiveness of ethanol. With $2 per bushel corn and the existing Federal subsidy, ethanol produced using average existing technology is competitive with crude oil at $22-$24 per barrel (break-even curve 3), compared with $20 per barrel with state-of-the-art technology. Further improvements in the next 3-5 years could make ethanol competitive at $18 per barrel crude oil (break-even curve 1).

Figure 1

Ethanol costs and industry capacity expansion

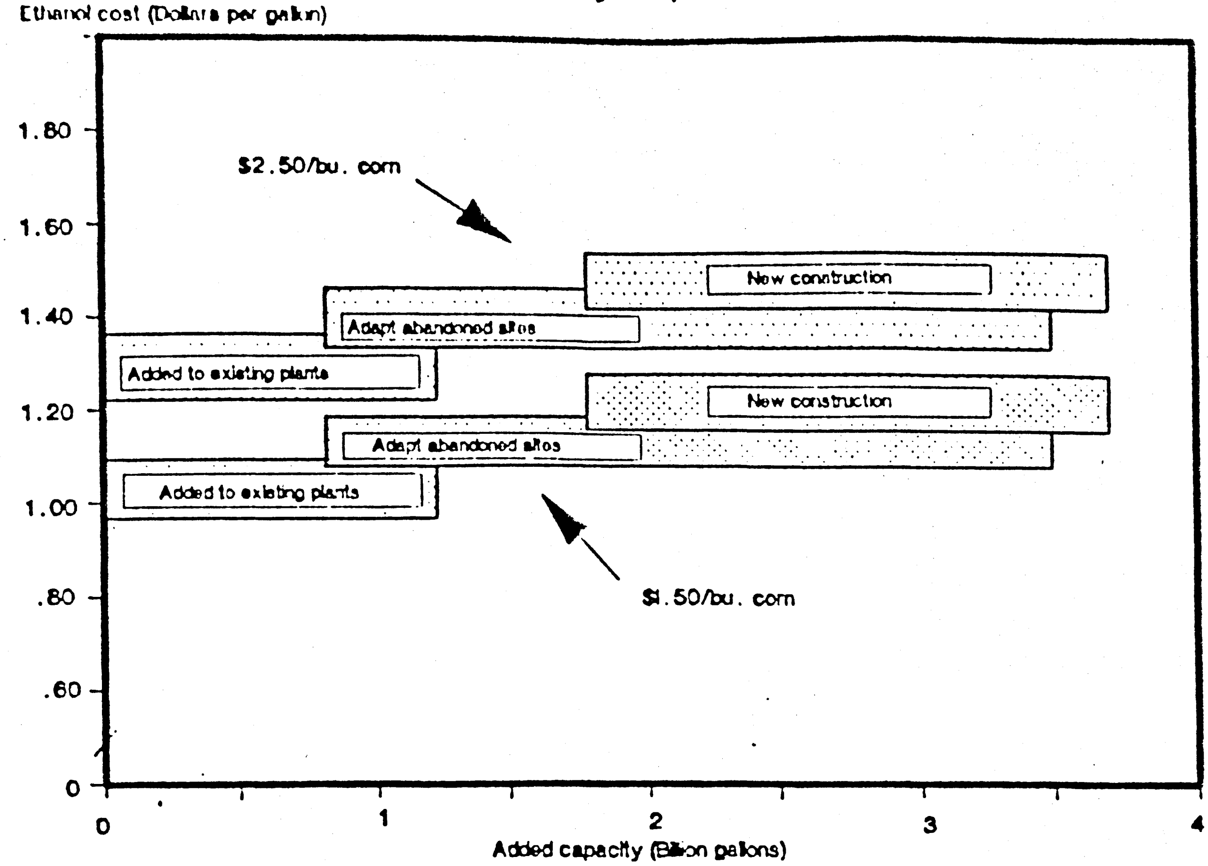
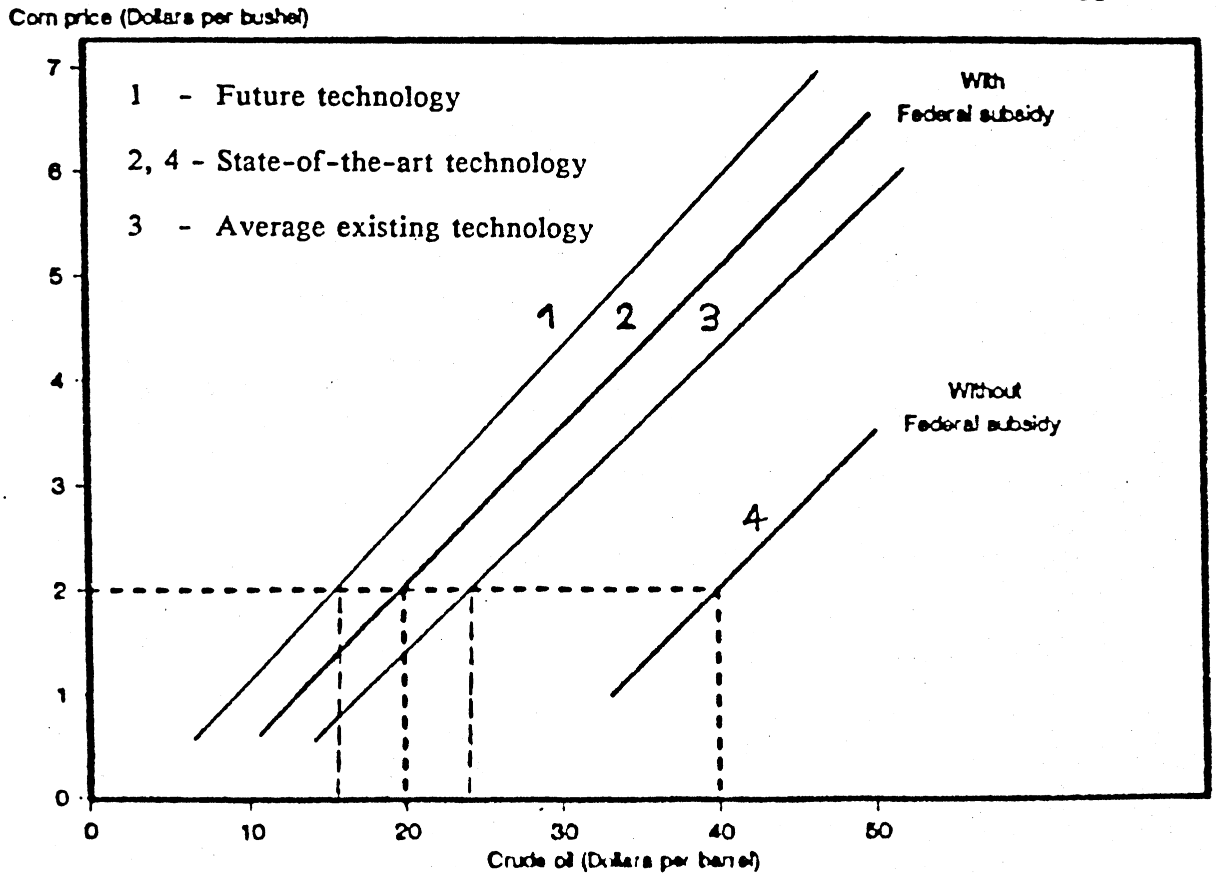


Figure 2

Ethanol breakeven curve: Effect of subsidy and New technology



Other Energy Technologies

The long-run future of ethanol depends on availability and costs associated with other energy sources. Biomass fuels generally do not compare well with the future cost and quantity estimates for many other energy technologies (Figure 3). Liquid fuels from coal and shale oil appear to be less expensive and are available in unconstrained quantities for the next 100 years or more. Tar sands and further efforts at enhanced oil recovery while somewhat limited in terms of quantity, can provide a significant contribution to conventional oil production.

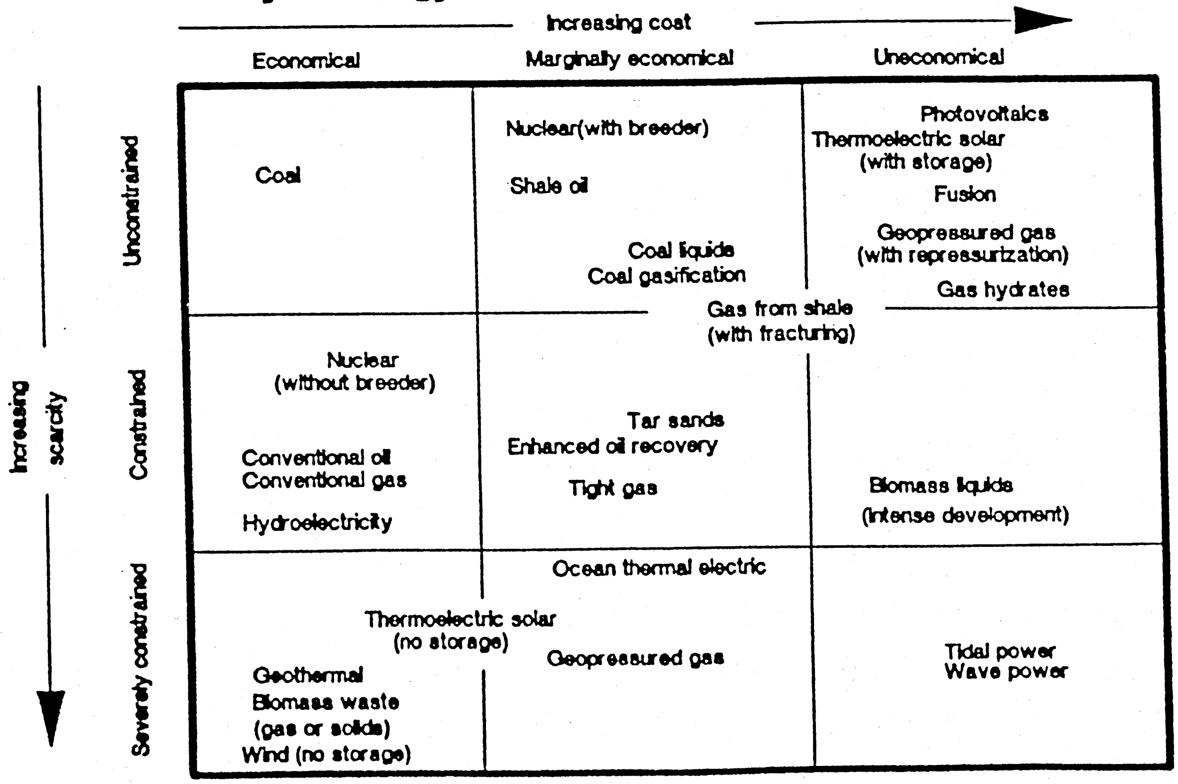
Ethanol production could result in future upward pressure on cost of ethanol feedstocks. The development of crops or silviculture that produce high levels of dry matter per acre combined with further breakthroughs in cellulosic conversion processes could lower feedstock costs if grain prices rise. The cost of large-scale biomass use would, however, remain high in terms of traditional inputs and in terms of disruptions of the environment through increases in land under cultivation. The more successful ethanol is in contributing to long-term energy supplies, the more it will drive up feedstock prices and its own cost of production. Thus, ethanol production tends to limit itself to the role of a small fuel contributor using temporary agricultural surpluses and organic waste.

Conclusions

The ethanol industry has grown quickly, from 20 million gallons produced in 1979 to 800 million gallons produced in 1987. Many small plants including those receiving Federal loan guarantees have closed, reorganized under bankruptcy proceedings, or defaulted, particularly in 1986 when oil prices collapsed. Federal subsidies to the industry approached $1 billion in 1986. Ethanol production costs have averaged $1.40 to $1.50 per gallon since 1980 but there has been considerable variability among firms and over time as corn prices have changed. Conditions existing in 1987 were relatively favorable for the industry despite low crude oil

Figure 3

Cost and scarcity of energy resources



Source: Edmonds and Reilly, 1985.

prices due to low corn and byproduct prices; in 1987 ethanol production costs ranged from about 85 cents to $1.20 among large producers.

Incremental reductions in ethanol production due to improved technology will occur but reductions that would offset the loss of the Federal tax exemption are unlikely. A state-of-the-art plant built today can achieve a 9-cent per gallon over the average industry costs; some firms approach state-of-the-art cost levels today. It is likely that the state-of-the-art plant of 3 to 5 years in the future can achieve an additional 5 cent savings in operating costs per gallon over the state-of-the-art plant.

Looking ahead 5-10 years, converting cellulose and processing other renewable resources into oxygenated fuels and chemicals will remain a major challenge to agricultural product utilization research. The time-frame depends on research and development in the cultivation, processing, and fermentation of cellulosic materials in addition to the emphasis on fundamental research in transformation of the resources into value-added products.

Under favorable conditions for expansion, as much as 1 billion gallons of capacity could be added for about half the cost of a new plant through incremental additions at existing ethanol facilities and at operating wet mills. Another 1-2 billion gallons could be added to the industry by adapting abandoned industrial oil refineries and wet mills at 10-25 percent less than the cost of a new plant.

For the industry to expand significantly, there would have to be a reasonable likelihood that favorable conditions existing in 1987 would continue to exist through the 1990's. Prospects of only modest increases in the price of crude oil well into the 1990's means that industry expansion hinges largely on extension of the Federal excise tax. For ethanol to be competitive in the 1990's without the Federal subsidy, crude oil prices would have to rise to nearly $40 per barrel or more.

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