REPORT OF THE

ENERGY RESEARCH ADVISORY BOARD

ON

GASOHOL

PREPARED BY THE

GASOHOL STUDY GROUP

APRIL 29, 1980

Department of Energy
Washington, D.C. 20585

May 2, 1980

The Honorable Charles W. Duncan, Jr.
Secretary of Energy
Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Dear Mr. Secretary:

I am pleased to transmit the report developed by the Energy Research Advisory Board's Gasohol Study Group. The members of the Study Group were selected for their technical expertise, prominence and integrity. The report has the endorsement of the Energy Research Advisory Board.

The principal conclusions of the Study Group are as follows:

1) Ethanol production as a near-term (mid-1980's) partial solution to the liquid fuels problem (based on current incentives) will probably reach 200-300 million gallons per year by 1985. Thereafter, about 800 million gallons of ethanol could be produced per year. This level of ethanol production would displace an equivalent of 26,000 barrels of oil per day or less than one percent of U.S. gasoline consumption; and

2) utilizing the best available technology before 1985 the net energy balance is about zero for ethanol produced from corn and other crops in fermentation/distillation plants. If the fermentation/distillation plants are fueled by coal or wood, each gallon of ethanol produced could save roughly 0.5 gallons of oil.

These and other conclusions and recommendations in the report are based on the best data available to the Study Group at the time it conducted the study (December 1979). The study itself was undertaken on a quick turn-around basis to address some specific issues then of interest to the Department. The draft report of the Study Group was discussed at the February meeting of the Board. As a result of that discussion the draft was modified to clarify some of the points made in the original draft.

The Board also received comments from members of the public at the February and May meetings of the Board. Most of these comments addressed the benefits of small-scale operations and the long-range prospects for gasohol. The benefits of small-scale operations are recognized in the report but perhaps are not highlighted to the extent some would desire. Both matters deserve further research.

I realize that the gasohol issue is in a continuous state of flux. The Board is prepared to render additional assistance should you require it. In any case, as new data becomes available the Board's Biomass Panel will study the matter as part of its overall charge.

Sincerely,

Solomon J. Buchsbaum

Solomon J. Buchsbaum, Chairman
Energy Research Advisory Board

Attachment:
As Above

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29 April 1980

Dr. S.J. Buchsbaum
Executive Vice President,
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Holmdel, N.J. 07733

Dear Dr. Buchsbaum:

I am pleased to submit the Gasohol Report prepared for the Energy Research Advisory Board by the Gasohol Study Group. In our search for alternative sources of liquid fuels for the future, the potential of gasohol should be carefully evaluated. The use of food grains for alcohol production raises several important issues. In its deliberations the study group considered these issues from a broad perspective including the energetics, economics, social, agricultural, and environmental aspects.

Clearly there are benefits as well as risks in the production and use of alcohol for gasohol. We must emphasize that a major effort to convert food grains into alcohol using no-oil/gas-fired distilleries will supply the nation with about 800 million gallons after 1985. This amount of alcohol used as gasohol would replace the equivalent of 26,000 bbls of oil per day or less than 1% of current gasoline consumption.

We hope that this report will be of value to the Energy Research Advisory Board.

Sincerely yours,

David Pimentel
Chairman, Gasohol
Study Group

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OF THE
ENERGY RESEARCH ADVISORY BOARD

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Introduction

The United States must find alternative sources of liquid fuels for the future. One alternative that has received a great deal of attention is gasohol (a 10% ethanol and 90% gasoline mixture). The Gasohol Study Group was asked to investigate the following questions:

(1) What are the potential benefits of gasohol from both an energetic and economic perspective?

(2) What is the potential impact of gasohol production on agriculture, land use, and the environment?

(3) In addition to grain and other starches and sugars, are there other biomass sources available for gasohol production?

(4) What are the comparative benefits of ethanol production from grain and methanol production from coal?

(5) Are additional tax incentives needed for gasohol production?

Findings

Gasohol Energetics and Economics

(1) Using either existing technology or the best available technology before 1985 with existing oil- or gas-fueled fermentation/distillation plants, the net energy return for ethanol production from corn and other crops is about zero. If fermentation/distillery plants were fueled by coal, then each gallon of ethanol produced could save roughly 0.5 gallon of oil.

(2) In the 1985 time period, total ethanol production using grains and non-oil/gas-fired distilleries could have significant effects in certain regions, but a limited impact on total U.S. oil consumption. Production of ethanol could reach 800 million gal/yr. If utilized in producing gasohol, 20% of the current national unleaded gasoline requirement could be blended to gasohol. This would displace an equivalent of 26,000 bbls of oil per day or less than 1% of U.S. gasoline consumption.

(3) Most U.S. fermentation/distillery plants producing ethanol are fueled by oil and gas and, therefore, are not providing the nation with any new net high-grade fuel.

(4) Additional gasohol benefits in the petroleum refinery operation and for the mileage performance of gasohol are currently subjects of controversy. Adequate testing is needed, with further assessments of gasohol taking into account the state of future technology both in automotive engines as well as petroleum refining.

(5) The cost of corn constitutes about 73% of the manufacturing cost of ethanol; hence, process research directed to other areas of cost reduction will have little impact.

(6) The value of the by-product cattle feed (distillers' dark grains) could reduce the impact of the high material (corn) cost by as much as one half.

(7) Current tax incentives for ethanol production, especially state tax rebates, appear to be more than adequate to encourage investment today with existing technology.

(8) Current federal and state tax incentives for ethanol production appear to have encouraged some ethanol from petroleum ethylene to be sold in the market place. The production of ethanol from ethylene that was produced from oil does not contribute to the nation's energy needs.

(9) The cost of high-grade fuel produced as grain ethanol with current best available technology should be greater than methanol produced from natural gas or coal with best available technology. Research on methanol production from coal is needed to fully investigate this potential.

(10) Research is needed on various agricultural systems that would allow for the production of food and some ethanol while protecting land productivity and environmental quality.

(11) Cellulosic biomass is more abundant and available than grain and other agricultural crops and could be a cheaper substrate for ethanol production; unfortunately because of research and development needs, ethanol from cellulose fermentation is not likely to be commercialized until after 1985.

Gasohol Impact on Food and the Environment

(1) The advantage of ethanol production from cereal grains and other food crops is that it can provide a quick supply of liquid fuel during the 1980s. A small surplus of grain exists today for ethanol production (in part because of the Russian grain embargo) but there

are uncertainties about future demands, especially in light of the world food problem.

(2) Gasohol production, stimulated by high subsidies, will reduce the amount of grain available for meat, milk, and egg production.

(3) Gasohol production will intensify environmental degradation with standard crop culture technology because of greater pressure for the use of land for agricultural production.

(4) Ethanol can be produced on individual farms in small-scale operations and the wet stillage fed to livestock. Assuming that woody residues were available on the farm as a distillation fuel, then there would be net energy benefit for these small operations. Although the total energy contribution will probably be small, these small-scale units would offer a degree of family self-sufficiency.

(5) The supply of grain available for gasohol and livestock production will continue to vary from year to year due to climatic variability and world food demand. This variability in grain supply will have an important impact on gasohol production.

(6) The pool of grain[1/] available for gasohol and livestock production is projected to decline in the future because of the rapidly growing world population and demand of this grain for food. Even without gasohol production, projections are that both demand and prices for grain on the world market will increase.

Forestry and Agricultural Residues for Gasohol Production

(1) Forestry residues and waste products are a major resource with potential to produce about 27 billion gallons per year of ethanol with production beginning in 1985-1990 by fermentation routes (this technology, however, requires additional research). Utilization

1/This takes into account the distillers' grains available for livestock.

of these materials should not compete with other commercial forest-based industries.

(2) Technology for energetically and economically efficient use of cellulosic biomass to produce ethanol by fermentation is being developed and could be available in the late 1980s for commercialization.

(3) The cost of ethanol from cellulosic biomass is expected to be lower than from grain and sugar crops.

(4) There is inadequate quantitative information on the amounts of energy, especially oil and gas inputs, needed to maintain a sustained yield of agricultural and forestry biomass for energy production. An investigation is needed of the total inputs including: site preparation, fertilizers, pesticides, machinery, fuel, and any other inputs for sustained agricultural and forestry biomass production systems.

Methanol Production from Coal

(1) The capital cost for one 500 million gallon/year methanol production plant is approximately the same as for twelve 50 million gallon/year ethanol fermentation plants.

(2) Methanol as well as ethanol contribute some problems in automobile engine operation with methanol causing more problems.

(3) The conversion of coal directly to methanol is projected to cost about one-half to one-third that of ethanol production from grain.

(4) Methanol production technology[1/] from coal or natural gas is commercially available now and is capable of producing methanol on a large scale. Future cost reductions may be achievable first by initiation of commercial coal-processing plants to allow

[1/] Natural gas conversion technology is available in the United States whereas coal conversion technology is available outside the United States.

"learning curve" improvements, and then by research and development in the coal gasification step, which carries the major burden of the capital investment.

(5) Given adequate guarantees for product revenue, commercial production of methanol from coal is achievable by the late 1980s.

(6) Production of methanol from coal carries with it potential environmental problems of major concern: land damage, air and water pollution, and increased production of carbon dioxide.

Recommendations

(1) Current incentives for investment in ethanol production for gasohol are adequate and should not be increased. For facilities where there are significant oil savings from the production of ethanol, assurances should be required that they will not be fueled by oil or gas. Tax incentives should be tied to this condition.

(2) Ethanol production as a near term, mid-1980s limited contribution to the liquid fuels problem should be allowed to find its own level based on current incentives, with a high probability of reaching 200-300 million gallons per year by 1985 (assuming no oil and gas is used in distillery). Production of 800 million gallons of ethanol per year, if obtainable thereafter, could provide sufficient ethanol to blend about 20% of current U.S. unleaded gasoline as gasohol. This gross ethanol production would displace an equivalent of 26,000 bbls of oil per day or less than 1% of U.S. gasoline consumption.

(3) Tax incentives should be monitored carefully to insure that alcohol production from grains and other food supplies does not reduce the availability of feed supplies for meat, milk, and egg production and lead to further inflation in foods. In fact, current subsidies may already be excessive for modern low-cost ethanol plants.

(4) An additional incentive in the form of protection of investment (whether equity or loan-financed) over the investment lifetime would insure capital investment in new alcohol plants.

(5) Additional financial initiatives to promote more dramatic increases in ethanol production above those mentioned should not be implemented, because of the likely advent of lower cost alternative liquid fuels, such as methanol from coal and ethanol from cellulose in the 1990s.

(6) National land use policies are needed to prevent environmental

degradation associated with an expanded effort to produce grains and other crops for gasohol production.

(7) Assessments of fuel replacement equivalents of ethanol compared with gasoline beyond their BTU equivalents are currently inconclusive and await completion of sound automotive fleet tests.

(8) Progress toward implementation of other lower cost technologies (methanol from coal, other synfuels, etc.) must be monitored carefully with the expectation that their relative merits and timetables will be more clearly discernable by the mid-1980s. If practical lower cost alternatives to ethanol are not emerging, a more massive ethanol effort may be called for, using cellulosic biomass as a substrate.

(9) Markets should be monitored to insure that ethanol from ethylene from petroleum is not used to replace fermentation ethanol used for gasohol. Producing ethanol from ethylene derived from oil does not contribute to the nation's energy needs.

(10) Significantly increased support for research and development of cellulosic biomass production and processing technology is needed should an extensive production effort be called for in the future. Research is especially needed on problems of land and water resources and oil and gas inputs that are required to support sustainable agricultural and forestry biomass production systems.

(11) Alcohol production from coal should be encouraged because this technology has the future potential for lower costs than alcohol production from grain; has vastly greater liquid fuel availability for the nation; and would have less impact on food production and prices than the alcohol/grain technology. (The panel considered only transportation and did not give consideration to all other potential uses).

(12) The alternative of direct production of alcohol from coal should be encouraged by some government assistance.

(13) Any U.S. program for gasohol production should take into consideration the world food problem and the future demand by developing nations for grains and other foods.

(14) The environmental issues arising from methanol production from coal should be examined in more depth, and the benefit of the lower cost of methanol should be balanced against the perceived risks. This balance should be weighed in turn against the same analysis for a comparable level of ethanol production to help determine priorities for the two principal alcohol technologies.

An Assessment of Gasohol Potential

Energy Balance

The energy balance for existing fermentation ethanol technology with existing petroleum or gas-fueled plants is about zero; i.e., there is no net consumption or gain in energy (Table 1). Most U.S. fermentation/ distillation facilities today are in fact oil or gas-fueled. Savings calculated from decreased energy for gasoline production at the refinery slightly increase the net savings. Energy efficiency in the fermentation/ distillation plants can be improved through advanced technology, but the impact on net energy will be small (Table 1). The largest effect will be obtained from fermentation/distillation plants that derive their energy from sources other than oil or gas, primarly coal. (The use of crop residues will be limited [see pages 19 and 20]). Effectively, then, with oil-and gas-derived energy consumption in fermentation/distillation plants reduced to zero, the net savings is about 53,000 BTU (LHV) per gal of ethanol; this is the equivalent of about 0.5 gallon of gasoline (@ 115,000 BTU [LHV] per gal) (Table 1).

Using no high fuel (oil and gas) in the fermentation/distillation plants and assuming that about 9 million tons of grains were available, production of ethanol could reach 800 million gallon/yr. If blended with gasoline, 20% of the current national unleaded gasoline requirement could be available as gasohol. This would displace an equivalent of 26,000 bbl oil per day or less than 1% of U.S. gasoline consumption.

Cost of Gross Alcohol Fuel Produced at the Distillery

The corn raw material dominates the production costs (73% of the overall cost) in a 50 million gallon/year fermentation plant (Figure 1). Only about 15% of manufacturing costs are susceptible to process improvements such as continuous fermentation and membrane separation techniques (Hartline, 1979).

In contrast to manufacturing costs, a specific projection of selling price is not presented because selling price is subject to considerable variation depending on the extent of debt financing and the assumptions in the DCF[1/] calculations (e.g. 15% vs. 20%). Projections of profitable ethanol selling prices from new plants range as low as $1.20 per gallon at the plant gate (OTA, 1979). These figures are more sensitive to financial consideration than to likely technological advances. Definitive price projections must be determined on a case-by-case basis.

Process costs are also sensitive to plant size. At a plant with a 10 million gallon/year capacity, ethanol production costs would be increased by about one-third (DOE, 1979a; Honohan, E.J., 1979, Personal communication, Pfizer Inc.). Small plants may be profitable in selected situations with favorable raw material supplies (e.g., food processing wastes) that help offset increased operating costs. Farm distilleries also may be helpful in alleviating local effluent waste problems. Such farm operations are not likely to have a significant impact on gasoline supply, but may provide some benefits to a few people who desire a sense of self-sufficiency in their operations.

Cost of Net Fuel Produced

If no high grade fuel energy (oil or gas) is used in the distillery[2/], 1 BTU of fuel energy produces about 2 BTUs of alcohol fuel energy; the agricultural process consumes the 1 BTU of energy. Although the equivalent yield of 2 gallons for 1 is positive, the process of producing the net ethanol fuel energy is expensive.

First, the 2 gallons are produced at a price of $1.20 per gallon or a total of $2.40. If the $0.26 [3/] cost for fuel input is

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1/ Discounted Cash Flow.

2/ Coal fired fermentation/distillation plants.

3/ Gasoline costs $0.48 and natural gas $0.30 per 115,000 BTU--the 76,000 BTUs of high grade fuel is assumed to be half gasoline and half gas (Anonymous, 1977a; AGA, 1979).

subtracted from $2.40, then the real cost to produce 1 net gallon of new fuel energy as alcohol is $2.14. If future automotive fleet tests demonstrate that the gasohol blend is mechanically equal to gasoline, then the real cost will be slightly less than $2.14.

Current federal and state tax incentives run as high as a $1.13 per gallon (DOE, 1979b). These tax incentives make alcohol competitive with gasoline, but it must be recognized that consumers pay the total bill per gallon of alcohol produced and used.

The cost of producing methanol directly from coal in terms of gasoline replaced (see pages 22 and 23) has been estimated[1/] to be between $0.40 and $1.00/gal. If "octane number" credits were applied as they are sometimes proposed for grain ethanol, they would have also to be applied to synthetic methanol and reduce their effective costs.

Ethanol from Ethylene

There is some evidence that ethanol from ethylene is being used to replace fermentation ethanol (CMR, 1979). It is undesirable when ethanol from oil-derived ethylene is used in gasohol because oil is being converted into another form of liquid fuel and, therefore, is not providing a net gain in liquid fuels for the nation. Thus, markets should be monitored to insure that ethanol produced from ethylene is not being used to replace fermentation ethanol used for gasohol production.

1/ Based on methanol costs of $0.20 to $0.50 per methanol gallon, multiplied by 2 to obtain BTU equivalence.

Impact of Gasohol Production on Food and the Environment

Competition for the Grain Resource

The use of grain to produce gasohol will influence the quantities of grains that are available for use in U.S. livestock production as well as the amount available for export (Pimentel et al., 1980a). The effect can be illustrated by reexamining the situation that occurred in 1973-74 when world demand for grains increased and U.S. exports of grain increased--prices of U.S. grains more than doubled (corn rose from $1.15 to $3.05/bu [USDA, 1975-76]). Because it was unprofitable to raise livestock with high-priced grain, farmers sent large numbers of animals to market and the amount of grain fed livestock declined by nearly 30% (Figure 2). As a result consumers paid high prices for meat, milk, and eggs (USDA, 1972-77).

Basically because livestock and gasohol production use the same resource, they will compete for surplus grain. Therefore, incentives to encourage gasohol production must be set and carefully monitored so that the availability of grain for livestock production is not seriously reduced; otherwise animal protein prices will rise and result in added inflation.

Furthermore, even with the current incentives to encourage the use of grain for gasohol, its production is as sensitive to grain price changes as is livestock production (Pimentel et al., 1980a). If, for example, grain prices were to rise three-fold or more a bushel, as occurred recently, gasohol as well as livestock systems would be affected.

The projected trends for the world grain market are increasing grain demands (NAS, 1977). The prime reasons for this are: (1) a rapidly growing world population--at least a 70% increase in the next 25 years--will require more food (NAS, 1977); (2) most cropland in the world is already in production (NAS, 1977); and (3) grain yields per acre in the world are declining due to land degradation and other factors (Brown, 1979). Therefore, assuming increased world demand for grain, U.S. grain prices will increase. This, in turn, will reduce the amount of surplus grain that is available for livestock and gasohol production. Whether the grain is utilized in the world community depends upon numerous factors including: (1) seriousness of famines; (2) grain prices; (3) ability to pay or economics; (4) balance of payment problems; and (5) politics.

Land Use and Degradation

Land available for grain production in the United States is limited[1/]. The total set aside land acreage in 1972 was about 60 million acres. Because of the high grain prices for export in 1974, this acreage abruptly dropped to zero. Although the set aside land is now 15 million acres, it can be expected to decrease as the demand for grain on the world market and grain prices rise. In addition, it should be pointed out that about 2.5 million acres of cropland is lost annually to highways and urbanization (USDA, 1971). Although the rate of loss may decline with reduced automobile use, the U.S. population growth, projected to increase 24% during the next 25 years, will probably keep the loss at high levels (USBC, 1976).

Some cropland, about 40 million acres, that is currently in pastures could be converted into grain production (USDA, 1979). However, this is marginal cropland and therefore for the same agricultural energy input, the yields would be less than average. In addition, the forage that is being produced on the land would no longer be available to livestock and other suitable feed would have to be found.

1/ Various agricultural systems have been proposed that include interplanting and integrating multiple crop systems with livestock production systems suggesting that crop and livestock technology could be improved (Pimentel et al., 1973; Pimentel and Pimentel, 1980; Carlson et al., 1979a; 1979b; Commoner, 1979). Whether these proposed systems will function effectively and economically remains to be tested.

Raising grain and sugar crops with current agricultural technology degrades the soil[1/]. Over a 25-year period, with corn production, for example, it is estimated that an additional 12 gal of fuel equivalents per acre per year would be needed in the form of fertilizers and other fossil energy inputs to offset this degradation (Pimentel et al., 1980b). Therefore, land degradation must be included in any energy input/output analysis for gasohol production.

Variable Grain Supplies

A major dilemma in the long term in using grain as a resource for ethanol production is how much surplus grain will be available in the future (Pimentel et al., 1980a). This depends on climatic trends and world food production (USDA, 1967-79). Climate has become more variable and this has influenced the annual grain yields in all regions of the world (including the United States) and in turn has significantly influenced world grain demand and prices (Brown, 1979; Pimentel, 1979). Poor climatic conditions in the future could have dramatic effects on the world food problem (Schneider 1978).

Cellulosic Biomass as a Source for Ethanol Production

The single most important cost in the economic analysis of ethanol production is the carbon source. Cellulosic biomass is expected to cost less than starch and sugar materials and as a result could have major impact as a raw material for production of alcohol (DOE, 1979b). Cellulosic biomass contains approximately equal parts of cellulose, hemicellulose, and lignin (cellulose and hemicellulose are used to produce ethanol). It is expected that the initial impact of cellulosic biomass on ethanol production will begin in the mid 1980s and could be substantial by 1990.

1/ Numerous agricultural technologies exist for controlling soil erosion and degradation and these technologies have been available for more than 40 ye (Bennett, 1939). Although the technology has been available for several decades and over $15 billion spent since 1935, soil erosion has not decli and remains a serious problem today (GAO, 1977; SCS, 1977).

Agricultural residues, particularly from corn and small grains, offer a supply of cellulosic biomass that could be collected and utilized. Currently, this valuable residue is returned to the soil. Crop residues play a vital role in agriculture by controlling soil erosion, preventing rapid water runoff, maintaining soil organic matter and soil structure, providing soil nutrients (N, P, K, etc.) and protecting other environmental qualities (Larson et al., 1978; Pimentel et al., 1980b). For these reasons, agronomists and other agriculturalists recommend that corn residues, for example, be harvested only on land with a 0-2% slope (Gupta et al., 1979). Furthermore, for each acre, at least 1500 lb of the 5000 lb of corn residues should be left on the land and conservation tillage employed (Larson et al., 1978; Gupta et al., 1979).

It is estimated that about 3500 lb of corn residue per acre could be removed from about 20% of the land currently used for corn: i.e., land with a slope of 0-2% (Gupta et al., 1979). In addition, 1200 lb of small grains residue per acre could be removed from 25% of the land used for small grains, primarily wheat (Pimentel et al., 1980b), these estimates assume that good conservation practices would be employed and nutrients removed would be added back as commercial fertilizer. If a cover crop were planted on corn fields at the end of the season, then all of the corn residue (about 5000 lb) could be removed from about 30 percent of the land (e.g. land with 0-5% slope) currently used for corn production (Pimentel et al., 1980b). The estimated potential alcohol production from crop residues is about 1.9 billion gal per year (Table 2).

The cost and energy input for collecting and transporting crop residues are significant. For example, in Illinois the price per delivered dry ton of crop residue is $36 to $53 within a 15 mile range (USC, 1978). This is from $2.40 to $3.50 per million BTUs and thus is more expensive than coal.

The energy input for collection and transport of corn residue is estimated at 200,000 BTU per acre (Pimentel et al., 1980b). In addition, the fertilizer value of this corn residue is calculated at about 1.6 million BTU. Thus, the total cost in energy for removing the corn residue is about 16 gal fuel equivalents per acre. This cost must be assessed against the potential energy benefits (140 gals of alcohol per acre) of utilizing corn residues.

Forest residues and products provide a major biomass resource (Pimentel et al., 1978). The anticipated availability of noncommercial and therefore noncompetitive wood from forest biomass, and its potential annual yield of pure ethanol is about 20.5 billion gallons per year (Table 2). The extent to which forest biomass can be utilized depends strongly on research and development of hydrolysis and conversion technology into commercially viable production routes.

The technology available today for production of ethanol from cellulosic biomass utilizes acid hydrolysis to produce sugars that are fermented to ethanol (DOE, 1979b). This technology is practiced by only one commercial firm as a pilot plant operation (DOE, 1979b).

Processes for improved use of cellulosic biomass are being investigated. They include: improved methods for acid hydrolysis, the use of enzymatic hydrolysis of cellulose, pretreatment of biomass to enhance hydrolysis and direct fermentation of cellulosic biomass to ethanol (SERI, 1979). In these processes, the cellulose and hemicellulose are converted to liquid fuels and the combustion of the remaining lignin will provide the process energy. Thus, the utilization of cellulosic biomass probably would not require the input of nonrenewable fuels.

With presently emerging technology, we can expect to see implementation of cellulose plants for ethanol production in the mid 1980s. With improved technology there is the potential for significant production of ethanol by

1990. In addition, technology is under development to gasify cellulosic biomass (SERI, 1979). Because of the large size requirement for scale economy of gasification plants, it is likely to be difficult to supply sufficient biomass without major shipping penalties and mixed feeds of coal and biomass may be used to produce synthetic gas for methanol production.

Because of the relatively low cost and widespread availability of cellulosic materials, they are, in the long run, with successful technical development, expected to be the most important biomass material for fuel alcohol production. In contrast to the use of grain and sugar crops, the conversion of cellulosic biomass to alcohol should offer no competition with respect to grains and other foods. Furthermore, there should be no significant impact on the sustained favorable trade balance deriving from grain exports (USDA, 1979).

The use of conservative agronomic practices for use of crop residues should be obligatory to avoid soil degradation (Larson et al., 1978; Gupta et al., 1979; Pimentel et al., 1976; Pimentel et al., 1980b). In any case, there should be close monitoring of soils used in this fashion to assure that degradation is not occurring because the nation already has a serious soil erosion problem (GAO, 1977; SCS, 1977). In the case of forest biomass destined for conversion to alcohol, its harvest will have less environmental impact from soil erosion and water runoff compared with crop residues, as long as conservation practices in culturing and harvesting are used. The environmental problem with forests, however, has not been investigated well and requires a great deal of research before any major program is considered in using forest residues and products for ethanol production (Pimentel et al., 1979; Pimentel et al., 1980b).

Production of alcohol from biomass must be considered on a regional basis. Generally, those regions with the most favorable growing conditions should have the greatest quantities of residue available. Crop residues, for example, for use in alcohol production are available in the major grain-growing areas. Likewise, regions well endowed with forests should be identified with wood conversion facilities.

. Cellulosic biomass, especially forest products, has a lower potential loss from pests and spoilage than grain and sugar crops and is capable of longer storage under less rigorous conditions than crop products.

Methanol Production from Coal

Methanol production from coal can be practiced on a large commercial scale using known technologies of coal gasification and methanol[1/] synthesis (Morel and Yim, 1977; DOE, 1978; Schreiner, 1978; Bailey, 1979; Kasem, 1979). Such processes could be in production as early as 1985 with suitable incentives.

Several variants have been evaluated by DOE (DOE, 1978: Schreiner, 1978). One example would be conversion of lignite, using the Koppers-Totzek gasification system coupled with the ICI[2/] methanol production process (Anonymous, 1977b). Process efficiency is considered to be about 50%.

For a typical case, the proposed plant has a capacity of 6,600 tons-per day methanol or about 48,000 bbls/day (SRI, 1978). Coal consumption is 19,000 tons per day of which 4,700 are consumed for plant use and 14,300 are processed to methanol. Sited near a coal mine, total capital investment would be about $1 billion with 100% equity financing. With coal costing $8.40 per ton, the selling price of methanol would be $0.67 per gallon for 15% DCF (Table 3).

1/ Methanol can be converted directly to gasoline employing the MTG process (Meisel et al., 1976; Lee et al., 1980).

2/ Imperial Chemical Industries.

A second example presented in Table 3 is the use of Illinois #6 coal to produce 7,300 tons of methanol per day or about 55,000 bbls, by a Texaco partial oxidation gasification system coupled to a Chem System methanol conversion synthesis process (SRI, 1978). With coal costing $29.40 per ton, the cost of methanol is $0.53 per gallon at 100% equity.

Other more detailed estimates for manufacturing costs of methanol have been made by contractors of DOE (SRI, 1979). The methanol costs are estimated to lie in the range of about $0.20/gal for an optimistic case (involving majority debt financing) to $0.50/gal for a more realistic case (involving 100% equity financing). This range corresponds to $0.40 to $1.00 per gasoline equivalent gallon.

The use of methanol and ethanol as blends with gasoline causes problems in automotive engine operation (DOE, 1979a); methanol results in more engine problems than ethanol.

Potential environmental problems associated with coal conversion to methanol are a major concern (NAS, 1979). These environmental impacts include: agricultural and forest land damage; air and water pollution; water use in water-short regions; and degradation in natural biota. The trade-offs between lower methanol production costs from coal and the potential environmental impacts must be carefully weighed.

Table 1. Energy Balance for Ethanol Production from Corn.[a]

	Thousand BTU/gallon[b]			
Consumed	Best Available Technology High Quality Plant Fuel		Future Coal-Fueled Plant	
Fermentation/ distillation[c]	69		0[d]	
Farming[e]	45		45	
Total	-114		-45	
Produced				
Ethanol	76(130)[f]		76 (130)[f]	
By-product Animal Feed[g]	11		11	
N value of crop residue [h]	3		3	
	+90	(+144)[f]	+90	(+144)[f]
Net	-24	(+30)[f]	+45	(+99)[f]
Refinery Credit	+8		+8	
	-16	(+30)[f]	+53	(+99)[f]

a/ Corn is the grain crop used for this example because it is the most common food crop used to produce ethanol. Other grain and sugar crops could be utilized for ethanol production but, like corn, all require a significant energy input for culture (Pimentel, 1980) and similar energy inputs in the fermentation/distillation process (E.J. Honohan, 1979, personal communication, Pfizer Inc.).

b/ For consistency, all heating values are expressed as LHV (low heating values)

c/ Energy inputs for fermentation/distillation vary depending on size of plant and technology employed and these range from 40,000 to 148,000 BTU (Scheller and Mohr, 1976; Reilly, 1978; Katzen, 1978; David et al., 1978; ACR, 1978; DOE, 1979b; Hertzmark, 1979; Weisz and Marshall, 1979; Chambers et al., 1979). For a modern 50 million gallon per year ethanol plant about a 69,000 BTU input is calculated per gallon of ethanol produced using vapor recompression evaporators (about 100 BTU/lb of water evaporated)(E.J. Honoha 1979, Personal communication, Pfizer Inc.).

Table 1, footnotes, continued.

d/ Assumed to be zero because coal is substituted for oil and gas.

e/ Energy inputs for raising corn vary depending on the technology employed, soil quality, rainfall, pest attack, and other factors. Reported energy inputs for corn production prorated per gallon of ethanol range from 35,000 to 74,000 BTU (Scheller and Mohr, 1976; ACR, 1978; Reilly, 1978; DOE, 1979b; Hertzmark, 1979; Weisz and Marshall, 1979; Chambers et al., 1979). An average energy input for corn used to produce a gallon of ethanol is at least 45,000 BTU (Pimentel and Pimentel, 1979).

f/ The value in brackets assumes a mechanical equivalency, i.e., that a gallon of gasohol will move an automobile as far as a gallon of gasoline. A gallon of gasoline has an equivalent of 115,000 BTUs or as an equivalent of crude oil is 130,000 BTUs. A serious question exists concerning the assumption that a mechanical equivalency of gasohol as gasoline exists.

g/ Energy credit is taken for distillers' grains, which are produced as a by-product and used for animal feed. Reports of credits range from 1,000 to 52,000 BTU per gallon produced (Scheller and Mohr, 1976; DOE, 1979b; Hertzmark, 1979; Weisz and Marshall, 1979; Chambers et al., 1979). For a 50 million gallon per year ethanol plant with a well-designed drying facility, a credit of about 11,000 BTU was calculated

h/ Crop residue contains about 1% nitrogen, 0.1% phosphorus, 0.9% potassium, 0.6% calcium (NAS, 1978). Energy value as fertilizer was calculated to be 3,000 BTU.

Table 2. Estimated Available Cellulosic Biomass and its Potential for Ethanol Production for after 1985.

Crop Residue	Amount Available (million dry ton)	Ethanol Production[a/] (billion gal alcohol)
Corn[b/]	15	1.2
Wheat[c/]	9	0.7
Forest Biomass		
Wood as Residues[d/]	120	9.3
Fuel wood production[e/]	120	9.3

a/ The yields in alcohol listed below are estimated yields by Charles Cooney and Jack Spurlock. The energy costs for collection, transportation, and fertilizer replacement of the nutrients removed with the biomass are not included in the ethanol production.

b/ Corn residue values were taken from Table 3A of "The Report of the Alcohol Fuels Policy Review: Raw Materials Availability Report" DOE/ET-0114/1, Sept. 1979. It was assumed that 70% of the residue could be removed from 20% of the land currently used for corn.

c/ Wheat residue, the largest of small grains residue, values were taken from the same Table as in b/. It was assumed that 43% of the residue could be removed from 25% of the land used for wheat.

d/ Franklin, 1973; J. Zerbe, 1978, USDA-Forest Service.

e/ It is assumed that the 60 million acres of forest land could be converted into fuel wood farms without seriously affecting forestry production (Pimentel et al., 1978). The yield was assumed to be 2 tons per acre per year.

Table 3. Conversion of Coal to Methanol (SRI, 1978).

Lignite Conversion to Methanol at $8.40/ton

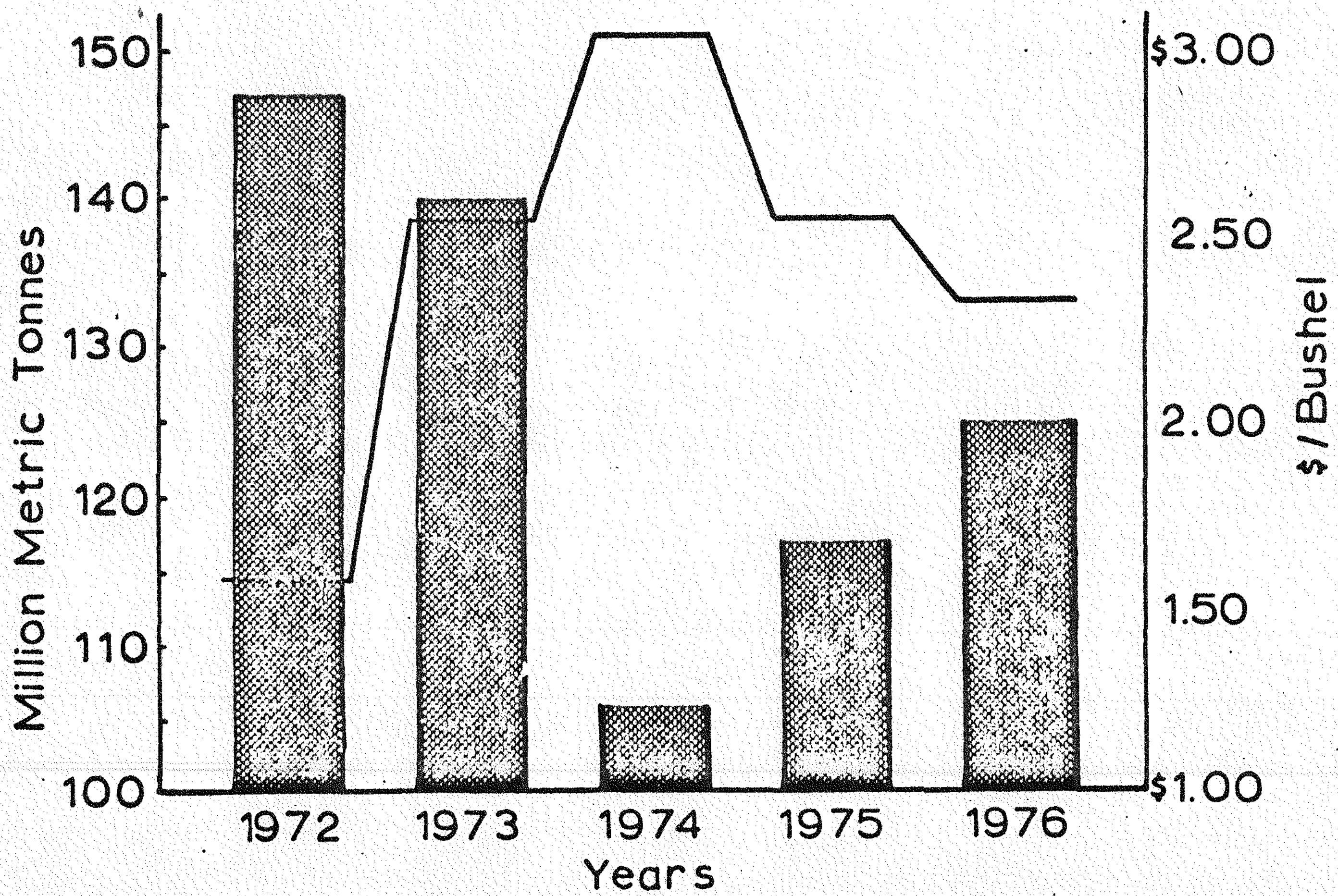
	$/gallon 1980	
Materials	0.09	
Labor	0.06	
Utilities	0.01	
Other Operating Costs	0.14	
	0.30	
Return on Investment at 15% (DCF*)	0.67	= $10.40/million BTU

Bituminous to Methanol at $29.40/ton

	$/gallon 1980	
Materials	0.14	
Labor	0.04	
Utilities	0.01	
Other Operating Costs	0.09	
	0.28	
Return on Investment at 15% (DCF*)	0.53	= $8.27/million BTU

*Discounted Cash Flow

Figure 2. Amounts of cereal grains fed livestock from 1972 to 1976 (USDA, 1977). Average price of corn as an index of grain price changes (——).



References Cited

ACR. 1978. Energy balance. Part of a preliminary plot project application to the USDA (Food and Agriculture Act of 1977, Public Law 95-113, Sect. 1420, and subsequent notice soliciting pilot project applications, Fed. Reg. 20, Oct. 77). ACR Process Corporation. (A copy can be obtained from Chambers et al.).

AGA. 1979. American Gas Association. Monthly Title. Forecast of the economic demand for gas energy in the U.S. through 1990. 61(3):14.

Anonymous. 1977a. The Oil and Gas Journal. Feb. 5. Page 97.

Anonymous. 1977b. Proceedings International Symposium on Alcohol Fuel Technologies. November. NTIS Cen/771175.

Bailey, E.E. 1979. Methanol from coal: an adaptation from the past. Energy 4(4):19-20.

Bennett, H.H. 1939. Soil Conservation. McGraw-Hill, New York. 993 pp.

Brown, L.R. 1979. Resource trends and population policy: a time for reassessment. Worldwatch Paper 29, Worldwatch Institute, Washington, D.C.

Carlson, R., B. Commoner, D. Freedman and R. Scott. 1979a. Studies on the economic potential of on-farm energy production systems. Interim Report. Center for the Biology of Natural Systems, Washington University, St. Louis, Mo. 49 pp.

Carlson, R., B. Commoner, and D. Freedman. 1979b. A critique of the Report of the Alcohol Fuels Policy Review. Center for the Biology of Natural Systems, Washington University, St. Louis, Mo. 49 pp.

Chambers, R.S., R.A. Herendeen, J.J. Joyce and P.S. Penner. 1979. Gasohol: does it or doesn't it produce positive net energy? Science 206:789-795.

CMR. 1979. Chemical Marketing Reporter. December 10. p. 1492.

Commoner, B. 1979. Testimony before United States Senate Committee on Agriculture, Nutrition and Forestry, Subcommittee on Agricultural Research and General Legislation on "The Potential for Energy Production by U.S. Agriculture". Center for the Biology of Natural Systems, Washington University, St. Louis, Missouri.

David, M.L., G.S. Hammaker, R.S. Buzenberg and J.P. Wagner. 1978. Gasohol economic feasibility study. Devel. Planning & Research Assoc., Inc., Manhattan, Kansas. July.

DOE. 1978. Badger Energy, Inc., DOE Report. FE 2416-24.

DOE. 1979a. Grain Motor Fuel Alcohol, Technical and Economic Assessment Study, Prepared by: R. Katzen Associates, Cincinnati, Ohio for U.S. Department of Energy.

DOE. 1979b. The Report of the Alcohol Fuels Policy Review. U.S. Department of Energy, Washington, D.C. 119 pp.

Franklin, W.E. 1973. Paper Recycling: the Art of the Possible, 1970-1985. Rept. Midwest Research Inst. for Solid Waste Council. 181 pp.

GAO. 1977. To protect tomorrow's food supply; soil conservation needs priority attention. Report to the Congress No. CED-77-30. General Accounting Office, Washington, D.C. 59 pp.

Gupta, S.C., C.A. Onstad and W.E. Larson. 1979. Predicting the effects of tillage and crop residue management on soil erosion. J. Soil Water Conserv. 34:77-79.

Hartline, F.F. 1979. Lowering the cost of alcohol. Science 206:41-42.

Hertzmark, D.I. 1979. A preliminary report on the agricultural sector impacts of obtaining ethanol from grain. Solar Energy Research Institute, SERI/RR-51-292, July.

Kasem, A. 1979. Three Clean Fuels from Coal: Technology and Economics. Synthetic natural gas, methanol, medium BTU gas. Marcel Dekker, New York.

Larson, W.E., R.F. Holt, and C.W. Carlson. 1978. Residues for soil conservation. pp. 1-15 in Crop Residue Management Systems. W.R. Oschwald, ed. Am. Soc. Agron. Spec. Publ. No. 31. Madison, Wisconsin. 248 pp.

Lee, W., J. Mazieuk, V. Weekman and S. Wurchak. 1980. Mobil methanol-to-gasoline process. p. 171 in Large Chemical Plants. Elsevier, Amsterdam. In press.

Meisel, S.L., J.P. McCullough, C.H. Lechthaler and P.B. Weisz. 1976. Chem. Tech. 6:86.

Morel, W.C. and Y.J. Yim. 1977. Economics of producing methanol from coal by entrained and fluidized-bed gasofiers. Natl. Mtg. ACS, Chicago, IL, Div. Fuel Chem. 22(7):95-99.

NAS. 1977. World Food and Nutrition Study. National Academy of Sciences, Washington, D.C.

NAS. 1978. Nutrient Requirements of Domestic Animals. Nutrient requirements of dairy cattle. Number 3, Fifth revised ed. National Academy of Sciences, Washington, D.C.

NAS. 1979. Energy in Transition 1985-2010. Final Report of the Committee on Nuclear and Alternative Energy Systems, National Academy of Sciences, Washington, D.C. 783 pp.

OTA. 1979. Gasohol. A technical memorandum. September. Office of Technology Assessment. U.S. Govt. Print. Off., Washington, D.C. 71 pp.

Pimentel, D. 1979. Increased CO_2 effects on the environment and in turn on agriculture and forestry. AAAS-DOE Workshop on Environmental and Societal Consequences of Possible CO_2-Induced Climate Change, Annapolis, Md.

Pimentel, D. (ed.) 1980. Energy Utilization in Agriculture. CRC Press, Boca Raton, Florida. In press.

Pimentel, D. and M. Pimentel. 1979. Food, Energy and Society. Edward

Arnold (Ltd.), London. 165 pp.

Pimentel, D. and M. Pimentel. 1980. Food, energy and the environment: alternatives for new lifestyles. UNEP, ECE Regional Seminar on Alternative Patterns of Development and Lifestyles. Dec. 3-8, Ljubljana, Yugoslavia.

Pimentel, D., L.E. Hurd, A.C. Bellotti, M.J. Forster, I.N. Oka, O.D. Sholes and R.J. Whitman. 1973. Food production and the energy crisis. Science 182:443-449.

Pimentel, D., E.C. Terhune, R. Dyson-Hudson, S. Rochereau, R. Samis, E. Smith, D. Denman, D. Reifschneider and M. Shepard. 1976. Land degradation: effects on food and energy resources. Science 194:149-155.

Pimentel, D., D. Nafus, W. Vergara, D. Papaj, L. Jaconetta, M. Wulfe, L. Olsvig, K. Frech, M. Loye and E. Mendoza. 1978. Biological solar energy conversion and U.S. energy policy. BioScience 28:376-382.

Pimentel, D., S. Chick and W. Vergara. 1979. Energy from forests: environmental and wildlife implications. pp. 66-79 _in_ Trans. 44th N. Am. Wildl. Nat. Res. Conf., Washington, D.C.

Pimentel, D.,P.A. Oltenacu, M.C. Nesheim, J. Krummel, M.S. Allen, and S. Chick. 1980a. Grass-fed livestock potential: energy and land constraints. Science 207:843-848.

Pimentel, D., M.A. Moran, S. Fast, C. Cleveland, P. Boveng, S. Hindman, L. Balliet, and M. Young. 1980b. Environmental consequences of utilizing crop and forestry residues for biomass energy conversion. Manuscript.

Reilly, P. 1978. Economics and energy requirements for ethanol production. Dept. Chem. and Nucl. Eng., Iowa State Univ., Ames. Manuscript.

SCS. 1977. Cropland erosion. Soil Conservation Service, USDA, Washington, D.C. 50 pp.

Scheller, W. and B. Mohr. 1976. 171st Natl. ACS Mtg., New York, April 7.

Schneider, S.H. 1978. Climatic Limits to Growth: How Soon? pp. 219-226 in Carbon Dioxide, Climate and Society. J. Williams, ed. Pergamon Press, New York. 332 pp.

Schreiner, M. 1978. DOE/Lurgi/Mobil Report FE 2447-13.

SERI. 1979. The Third Annual Biomass Energy Systems Conference. Solar Energy Research Institute. Rept. SERI/PP-33-285.

SRI. 1978. Alcohol Fuels Production Technologies and Economics. SRI International.

SRI. 1979. Mission Analysis for Federal Fuels from Biomass Program. Vol. 4. March. SRI International.

USBC. 1976. Statistical Abstract of the United States 1976. 97th ed. U.S. Bureau of the Census, U.S. Govt. Print. Off., Washington, D.C.

USC. 1978. Bioconversion. U.S. Congress. Hearings before the Subcommittee on Advanced Energy Technologies and Energy Conservation, Research, Development and Demonstration of the Committee on Science and Technology, U.S. House of Representatives, 95th Congress, Second Session, July 15, August 5. U.S. Govt. Print. Off., Washington, D.C.

USDA. 1971. Agriculture and the environment. U.S. Dept. Agr., Econ. Res. Serv. #481, July.

USDA. 1979. Agricultural Statistics. U.S. Department of Agriculture, U.S. Govt. Print. Off., Washington, D.C.

USDA. 1967-79, 1975-76, 1972-77. Agricultural Statistics. U.S. Department of Agriculture, U.S. Govt. Print. Off., Washington, D.C.

Weisz, P.B. and J.F. Marshall. 1979. High-grade fuels from biomass farming: potentials and constraints. Science 206:24-29.