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FARM AND FOREST PRODUCED ALCOHOL: THE KEY TO LIQUID FUEL INDEPENDENCE

A COMPENDIUM OF PAPERS

SUBMITTED TO THE

SUBCOMMITTEE ON ENERGY

OF THE

JOINT ECONOMIC COMMITTEE

CONGRESS OF THE UNITED STATES

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LETTER OF TRANSMITTAL

AUGUST 18, 1980.

HON. EDWARD M. KENNEDY,
Chairman, Subcommittee on Energy, Joint Economic Committee, Congress of the United States, Washington, D.C.

DEAR MR. CHAIRMAN: I am pleased to submit a compendium of papers entitled "Farm and Forest Produced Alcohol: A Key to Liquid Fuel Independence."

The compendium is intended to show that the Nation has the capacity to totally displace all petroleum-based transportation fuels it consumes with alcohol produced from renewable farm and forest feedstocks without jeopardizing adequate supplies of food and fiber.

The papers were presented during a series of Subcommittee on Energy hearings which I chaired in the spring and summer of 1980 to examine alcohol fuel policy. They were furnished by Dr. Barry Commoner of the Center for the Biology of Natural Systems, Washington University, St. Louis, Mo.; Alfred Campbell, president of MAR-CAM Industries, Glennside, Pa.; and Donald Patterson, Virginia State Director of the American Agriculture Movement and a member of the Department of Energy's Biomass Panel advisory group.

In my view these papers collectively constitute a new and vitally important set of findings and recommendations on alcohol fuel development and utilization. They show the Congress and the Nation that we have it within our grasp to achieve liquid fuel independence through the use of renewable resources alone.

It should be understood that the views contained in the papers are those of the authors and not necessarily those of the Joint Economic Committee or individual members.

Sincerely,

GEORGE MCGOVERN,
Member, Subcommittee on Energy.

CONTENTS

FARM AND FOREST PRODUCED ALCOHOL: THE KEY TO LIQUID FUEL INDEPENDENCE

INTRODUCTORY STATEMENT BY SENATOR GEORGE McGOVERN

The alternative energy policies which have thus far been proposed by the Administration and approved by Congress in response to the rising cost and reduced supply of foreign oil are alarmingly unbalanced. There is convincing evidence within this compendium that the nation can displace all of the gasoline it now consumes with alcohol fuel produced from renewable farm and wood feedstocks. Despite this potential, of the $20 billion authorized under the Energy Security Act of 1979, only $2 billion is earmarked for biomass energy.

SHORT-CHANGING FARMERS

These numbers indicate that the capacity of agriculture to quickly produce a huge volume of low cost farm-based alcohol fuel continues to remain largely unrecognized. This myopia remains even though farm-based alcohol is the only alternative liquid fuel currently available to the Nation and will remain so for some years to come. Moreover, alcohol fuel produced from farm feedstocks can and should remain a significant source of alternative liquid fuel even after complete development of the alcohol fuel production potential of wood and coal. Present inadequate program initiatives rob agriculture of the opportunity to fully participate in the overall effort to develop alternative energy resources. Hundreds of millions of dollars have been available for the better part of a year in Department of Energy and Department of Agriculture loan guarantees, direct loans and grants to support the production of on-farm and rural community alcohol fuel. But both departments have failed to deliver anything more than token financial resources and technical assistance to farmers and entrepreneurs who are capable of quickly reaching the production level of several billion gallons of alcohol fuel a year which would bring the agriculture industry of the country close to liquid fuel self-sufficiency.

Whether by design or by accident, the American farmer is being short-changed for the benefit of multinational oil conglomerates which hold large reserves of coal, tar sands, and shale deposits. Under the present program framework the extraction of fuel from these sources will require enormous public and private investments over an extended period of time and entail serious and as yet unsolved water, air and other environmental problems. It is questionable whether the complexities of our present synfuels policy will allow the nation to approach liquid fuel independence, absent a major role for biomass.

REAL POTENTIAL OF BIOMASS ALCOHOL

This compendium of papers is presented to indicate to Congress and the public the full potential of the farm and forestry sectors to produce alcohol fuels from renewable resources (Figure 1). As such it constitutes an effort to achieve a better balance in the activities of the Federal Government to support the development of practical and economically sound alternative fuels.

The papers were produced by the Center for the Biology of Natural Systems, Washington University, St. Louis, Missouri; John D. Ferchak and E. Kendall Pye of the Department of Biochemistry and Biophysics, University of Pennsylvania School of Medicine, Philadelphia; and Donald Patterson, Virginia State Director of the American Agricultural Movement, and a member of the DOE Biomass Panel policy advisory group. Some of the findings and recommendations of the papers were focal points of discussion during the Subcommittee on Energy hearing on alcohol fuels policy which I chaired on June 25, 1980. The papers are presented here in their entirety.

Data presented in the studies leads to the following summary:

(1) Forty-five percent of all the crude oil used in the United States in 1979, 100 billion gallons, was imported. In that year the nation consumed a total of 146 billion gallons of gasoline, diesel, jet and residual fuel oil for transportation purposes.

(2) Within the next two decades we could achieve domestic production of 150 billion gallons a year or more of alcohol for use as a pure fuel in gasoline, diesel and other types of engines.

(3) We can produce this volume of alcohol fuel from renewable farm and wood feedstocks alone.

(4) This production level can be reached without jeopardizing food supplies required for human consumption and livestock production in both domestic and export sectors. To the contrary, production of alcohol fuel from renewable farm and wood feedstocks will actually increase food supplies.

(5) Achievement of the total biomass alcohol fuel potential and the need to expand economic opportunities for the American family farm require that full reliance be placed on small as well as large scale production.

We have the capacity, the knowledge of required engine design changes and tillage practices, and will shortly have all the distillation technology to ultimately displace all of the domestic and imported crude oil now utilized to produce transportation fuel (Figure 2).

With a reduction of our overall transportation fuel needs, the nation can more than achieve petroleum energy independence through our own inexhaustible farm and forest resources.

As it is, we presently have all of the on-shelf technology, tillage and alternative crop know-how to produce 50 billion gallons a year of alcohol fuel from farm feedstocks. The only missing link in the technology chain applies to production of alcohol fuel from wood through fermentation. Current research efforts are expected to solve this problem in the very near future.

The technology for the production of modified automobile and truck engines capable of utilizing alcohol fuel alone has been available for some 40 years. A number of car manufacturers are now producing vehicles with such engines for sale in Brazil which is firmly committed to the production and utilization of alcohol fuel. Furthermore, the technology for the low cost conversion of existing gasoline and diesel engines to alcohol has been developed and only the lack of available and dependable supplies of alcohol fuel prevent its widespread dissemination and use.

DOE's Policy Development Conflict of Interest

Despite the impressive near-term potential, DOE has been told by the Gasohol Study Group of its Energy Research Advisory Board that the production of farm-based alcohol must be limited to a very low level of 800 million to 900 million gallons a year, less than one percent of our total gasoline consumption. In submitting its report on April 30, 1980, the Study Group said it based its estimate on data available at the time and acknowledged that new information could change its assessment. Most of the facts, projections and conclusions drawn in the study by the Center for Biology of Natural Systems was available to the Study Group long before it handed in its report to the Energy Research Advisory Group which rubber stamped it the next day and forwarded it to the Secretary of Energy as a set of policy findings and recommendations on alcohol fuel.

In the face of loud protests, from Members of Congress and a large number of private sector groups and individuals and even certain officials within DOE itself, Secretary Duncan indicated he would file the Study Group report and hold to his present course to promote the development and utilization of alcohol fuel. At his direction, DOE's Office of Alcohol Fuels evaluated the Study Group report, found it contained serious errors of both fact and judgment, and estimated that the potential for farm feedstock production of alcohol fuel was in excess of 10 billion gallons a year without adversely affecting food supplies. This response on the part of Secretary Duncan and the Office of Alcohol Fuels is encouraging, but nevertheless unsatisfactory, given the fact that DOE has yet to develop and articulate a comprehensive alcohol fuels policy position. The absence of clearly and fully defined policy in this area is a major reason for the publication of this compendium of papers.

When considering the Gasohol Study Group report it is important to recognize several other points. Instead of heavily emphasizing the production of alcohol fuel from farms, as it should have, the report stressed the potential of coal and wood for the production of methyl alcohol as an engine fuel. Findings and conclusions leading to this recommendation directly reflect the contributions of two members with ties to the Mobil Oil Corporation which has a large stake in its patented process to produce synthetic gasoline from methanol, a process which is still being developed for commercial application at a West German plant financed under a $30 million contract between DOE, the West German Government and two West German firms. The cost is being shared on a one-third basis by the two governments and the two firms with Mobil providing the catalyst valued at about $7 million for the methanol to synthetic gasoline process. Under the terms of the contract, Mobil will retain ownership of the catalyst which is essential to the process as well as exclusive rights to provide it or license its production. Mobil will also have first option rights for use throughout most of the world of any inventions developed in the course of constructing and operating the pilot plant. Should the process merit commercialization the company will hold a controlling position despite the fact that the operation is being largely financed by the taxpayers of the two countries. Although the contract does require Mobil to reimburse the governments, it is permitted to do so entirely out of the proceeds from the process. In other words, Mobil

Oil, with first quarter 1980 profits of $1.3 billion representing a 208 percent increase over the same period in 1979, is in a virtually risk free position at the expense, for the most part, of the taxpayers of the United States and West Germany.

Aside from questions of propriety regarding the contract itself, these circumstances should be stated because of the continuing conflict of interest in DOE's efforts to develop alcohol fuels policy. Five members of the former Gasohol Study Group, including the two with ties to Mobil, have been appointed to the newly established nine-member DOE Biomass Panel policy advisory group. The two are Dr. David Pimentel of Cornell University, a paid consultant of Mobil Oil, and Dr. Paul Weisz, manager of Mobil's Research and Development Corporation. Pimentel, who functioned as chairman of the Gasohol Study Group now holds the same position on the Biomass Panel which will examine the broad range of renewable resource energy possibilities, including production of alcohol fuel. In effect, DOE, through the activities of the Biomass Panel, is seemingly providing itself with a second chance to produce a set of positive and realistic policy recommendations going to alcohol fuel. However, with the makeup of its membership, the product of the Biomass Panel regarding alcohol if not the full range of biomass fuels, would not appear to be promising. At the very least Secretary Duncan and the Energy Research Advisory Board should expand the membership of the Biomass Panel with persons who have a thorough knowledge of and hands-on experience with farm-based alcohol fuel.

OIL COMPANY CONTROL OF ALCOHOL FUEL

If the general direction of the Gasohol Study Group's policy recommendations were followed by DOE—and there is no firm assurance to the contrary in the long run—the nation would likely find alcohol fuel production mainly restricted to the efforts of giant oil conglomerates because coal- and wood-based methanol facilities, by their very nature, require large and costly plants which only such companies can afford. Beyond this, relatively few plants would be constructed and the end product of those plants, either methaol or synthetic gasoline, would remain under the distribution and marketing control of the existing, highly centralized oil industry. That industry, of course, would continue its main line of business, the production and sale of gasoline and diesel fuel. In effect, the price of methanol and synthetic gasoline would be locked—stepped with the ever rising price of petroleum derived gasoline and diesel fuel. Apart from these disadvantages and the attendant serious air, water and land pollution problems of methanol produced from coal, methanol has less Btu value than farm-based eythol alcohol and causes engine and fuel system problems that are not associated with the use of ethanol.

ECONOMIC IMPACT OF SMALL SCALE PRODUCTION

A solid government policy and program commitment to full-scale production of ethanol, on the other hand, presents the opportunity to establish hundreds of thousands of relatively inexpensive, quickly built, efficient on-farm and small scale rural community alcohol production facilities and a marketing system which could directly compete with the sale of petroleum-based fuels. The nation could be provided with a real and economical alternative to continued dependence on multi-national oil companies, many of which have longstanding partnerships of one kind or another with OPEC.

Equally important, comprehensive development of farm-based alcohol fuel may provide the option the agriculture community desperately needs to check the appalling loss of family farms throughout the nation. Some 3,700 family farms a month are disappearing from the map of rural America as they fall victim to market forces over which their owners have no control. Unless this trend is halted, big business, as it has in so many other areas of the economy, will control the production of much if not most of the nation's food. Corporate farming has already displayed its talent for high cost inefficiency which translates into less food at higher prices for all consumers. Absent a turnaround, we can look for more of the same on a massive scale.

Farm-based alcohol fuel production represents the opportunity to establish a major industry with the potential of ushering in a new economic era for rural America while enhancing the food producing potential of the farm sector.

All of the protein contained in corn used to distill alcohol fuel remains available in the form of distillers grain for livestock production purposes following distillation. Only the starch from which alcohol is distilled is removed. With its high concentration of easily digested, meat building protein and the elimination of starch, distillers grain represents a superior and highly marketable animal feed. Moreover, experimental efforts make it apparent that distillers grain can be processed to produce a nutritious food for human consumption. Thus, both food for animals and people can be produced while manufacturing alcohol fuel. The prospect of a food-fuel tradeoff in the production of alcohol can be entirely eliminated through the use of high carbon alternative crops which will allow for continued production of corn at levels adequate to meet all demands. In considering this point, it should be recognized that the production of alcohol from corn in no way threatens to deprive people of less developed nations of needed food. Virtually all of the corn now exported is purchased by industrialized nations for the purpose of supplementing their domestically produced livestock feed stores. Poor nations do not have livestock industries and therefore have no need to import feedgrains.

On-farm and rural community alcohol fuel production facilities offer the fastest and least expensive way of generating a significant initial volume of fuel. Facilities can be in place and producing within a matter of months with the same efficiency that applies to large scale plants. The nation's decentralized dairy industry with its thousands of farms which supply milk for local consumption and processing indicates the pattern on which small scale alcohol fuel production and distribution systems can be established. Not only would the nation's farming sector become independent of gasoline and diesel fuel, it would do so with the resources grown and constructed in their own areas.

As the small scale aspect of the alcohol fuel industry grows and matures, it will promote the location of new business and manufacturing enterprises to rural America, attracted there by the next door availability of dependable, reasonably priced alternative liquid fuel. This in turn means the creation of hundreds of thousands of new jobs and an improved standard of living in regions of the country which have experienced chronic economic depression. Within two decades, farm-based alcohol fuel can play a major role in making the entire nation totally self-sufficient in its ability to meet its liquid fuel requirements.

It is an achievable goal. This compendium presents convincing proof of the road we must take to reach it.

Figure 1

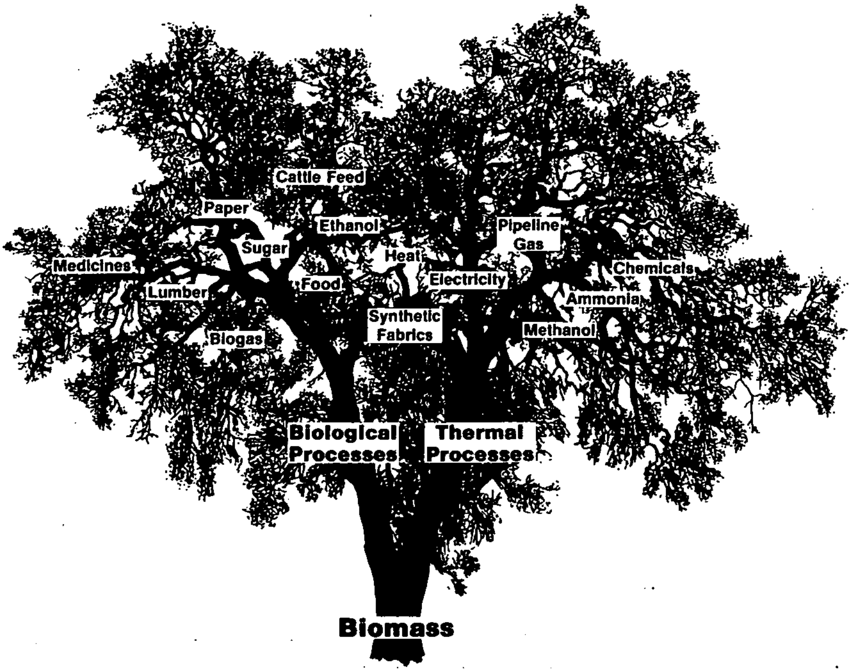
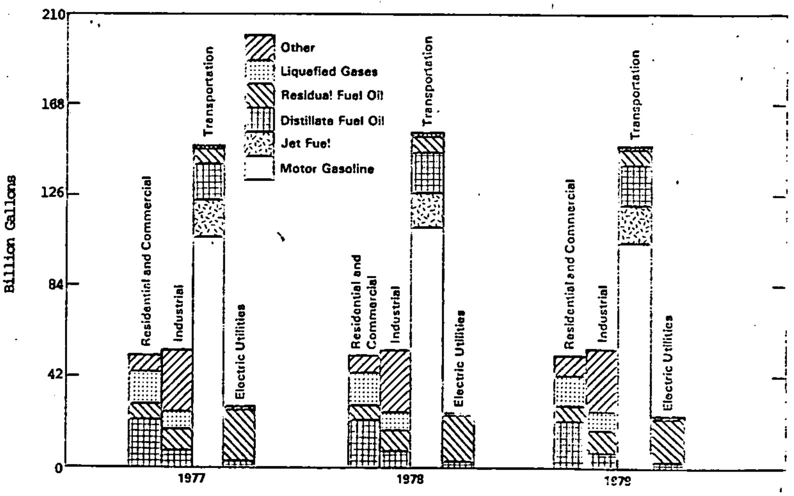


Figure 2

REFINED PETROLEUM PRODUCTS SUPPLIED BY TYPE AND TO END-USE SECTORS



In 1979, motor gasoline accounted for 71 percent of the total petroleum products supplied to the transportation sector. Distillate fuel accounted for 41 percent of the total petroleum products supplied to the residential and commercial sector. In the electric utilities sector, residual fuel accounted for 87 percent of the total.

Source: Energy Information Administration, "Annual Report to Congress, 1979, Vol. 2"

THE TECHNICAL POTENTIAL FOR ALCOHOL FUELS FROM BIOMASS

By Richard Carlson, David Freedman, Neil Jacobstein, Jim Kendall, Robert Schneider, and Holly Winger*

A. INTRODUCTION

In 1973, the Center for the Biology of Natural Systems began a five year analysis (supported by the National Science Foundation) of ways to reduce the dependence of U.S. agriculture on petroleum-based imports. Our research showed that with appropriate changes in farm production patterns fossil energy consumption in crop production could be cut by 60 percent. This reduction could be accomplished largely by eliminating use of indirect energy inputs (inorganic fertilizers and pesticides), with an 11 percent drop in crop revenue but no reduction in net economic returns per acre, since the decrease in input costs compensates for the loss in revenue (Lockeretz, *et al.*, 1978).

In 1978, our research efforts turned to ways of reducing U.S. agriculture's dependence on direct petroleum inputs. At the outset, we assumed that with adoption of energy conserving farming practices and on-farm production of energy, farmers could *at best,* totally eliminate their own dependence on fossil energy inputs. We have since discovered that this assumption was too conservative. Indeed, our present research suggests a new concept: U.S. agriculture as a net producer of significant quantities of renewable liquid and gaseous fuels, without reducing the supply of food or livestock feed for domestic consumption or export.

This report makes a preliminary technical assessment of the ultimate potential for alcohol production from agricultural and forestry biomass sources using biological conversion processes. Our basic concept of integrating renewable fuel production with other production activities leads to our estimate that in 2000 some 150 billion gallons of ethanol and butanediol could be produced in the United States (see Figure 1). Alcohol could completely replace gasoline as the nation's primary liquid fuel. Some three billion gallons could be produced with surplus grain and food processing wastes; by shifting several million acres from soybean to corn production another seven billion gallons of ethanol could be produced; by planting additional acres in sugar crops, such as sugar beets, another 40 billion gallons of ethanol could be produced; conversion of cellulose in wood, crop residues and municipal wastes could further add 40 billion gallons of ethanol; finally, conversion of the hemicellulose in the same cellulosic material could produce 60 billion gallons (ethanol equivalent) of butanediol, which mixes more easily with gasoline than ethanol does.

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B. U.S. FEED CROP-LIVESTOCK SYSTEM

Alterations in Carbon to Nitrogen Ratio

We approached this idea by attempting to construct a cropping system, based largely on the land available in Midwestern agriculture, that would significantly increase the carbon content of the crop—beyond that needed, together with the crop nitrogen—to support the present output of livestock and grain for export (Carlson, *et al.* 1979).

Figure II compares the current crop system with an alternative system based on a rotation of corn, sugar beets and hay, that would considerably increase the potential for alcohol production. Thus, as shown in Figure II, the current crop system provides livestock with about 172 million tons of carbon and about eight million tons of nitrogen per year. In contrast, the alternative crop system developed in our study, based on a corn-sugar beet-hay rotation and the expansion of crop land by 10 percent, would yield about 267 million tons of carbon and about nine million tons of nitrogen per year (Commoner, 1979).

In the proposed scheme nearly all of the corn and sugar beet crop is fermented to produce ethanol. Since ethanol contains carbon, but no nitrogen, this process reduces the residual material to about 179 million tons of carbon per year, while the nitrogen content of the stillage residue is maintained at nine million tons per year. Since the stillage residue from alcohol fermentation is palatable feed for livestock production, the alternative scheme contains enough carbon and nitrogen constituents to support as much livestock production as the current crop system.

The carbon to nitrogen ratio referred to in Table I is for the normally harvested portion of the plant, rather than its total biomass. Including the total biomass of the plant would increase its carbon to nitrogen ratio, but low digestibility and palatability limit the use of agricultural residues for livestock feed.

Based on the equation for ethanol fermentation, $C_6H_{12}O_6$ [glucose] = $2C_2H_5OH$ [ethanol] $+2CO_2$ [carbon dioxide], two-thirds of the 95 million "excess" tons per year of carbon (i.e., that beyond the amount needed to support the present output of livestock) could be converted to ethanol by fermentation of the crop starch and sugar. As Table II shows, this amounts to about 35 billion gallons of ethanol per year, or about one-third of the present U.S. gasoline consumption, based conservatively on the low crop yields of the 1974–76 period. (Corn, for example, averaged only 82 bushels per acre during those years, compared to subsequent years' yields of more than 100 bushels per acre.) Bused on normal weather conditions and slightly improved yields in the future, grain and sugar crop yields would allow ethanol production to surpass 50 billion gallons per year by the year 2000, or nearly half of the present U.S. gasoline consumption.

Figure I shows significant disparities among several energy studies in their estimates of alcohol production potential between 1980 and the year 2000, based on use of grain surpluses and food processing wastes (category A), shifts of soybean acreage to corn production (category B), and shifts to sugar crops (category C). For 1980 and 1985, the relatively small differences among these studies are due largely to different assumptions about how much of the total biomass harvest goes into alcohol production. In 1990, the shift to sugar crops which dramatically increase carbon production causes the CBNS estimate to considerably outstrip the office of Technology Assessment (OTA) estimate or the Energy Research Advisory Board (ERAB) estimate. The DOE Alcohol Fuels Policy Review estimate includes sugar crops at a minimal level. CBNS' estimate of agricultural ethanol production in 2000 climbs to 50 billion gallons per year based mainly on sugar crops. OTA (seven to 10 billion gallons) and ERAB (800 million gallons) continue to ignore sugar crops, and DOE (12 billion gallons) includes limited sugar crops based on sweet sorghum which yields ethanol, but less livestock feed per acre than sugar beets (Carlson, *et al.*, 1980). Each of these three studies constrained the amount of alcohol that could be produced by assuming a trade-off between food and fuel production.

Changes must be made in cropping patterns, in livestock feeding patterns and in the use of crop residues, if ethanol production is to be sharply increased. The practical changes required to make these alterations are well within the demonstrated flexibility of the agricultural system.

Cropping Patterns

The increase in soybean production after World War II is a particularly good example of the rate and extent of change possible in the U.S. crop mix. Between 1949 and 1969, more than 30 million acres of soybeans were brought into production (see Table III). And in the last decade, another 30 million acres have been added, bringing the total harvested soybean acreage to over 70 million acres for 1979. The shift from corn to soybeans was important for livestock productivity because soybeans contain almost five times as much protein as corn.

A second example of changes in cropping patterns is the recent rapid growth in sunflower production. Stimulated by a demand for polyunsaturated oil, sunflower production grew from less than 200,000 acres in 1969 to more than five million acres in 1979.

Ethanol production from corn could be achieved by replacing soybeans with corn and forage crops. There are virtually no agronomic barriers to substituting corn for soybeans. However, the yield of ethanol per acre from corn is considerably lower than from various sugar crops.

Sugar beets are an attractive alternative because of their relatively high yield of ethanol plus livestock feed coproducts per acre (see Table IV). Unlike sugar cane growing conditions appear to be favorable to sugar beet cultivation on essentially all land presently devoted to corn and soybeans, based on considerations such as precipitation, temperature, and soil slope, composition, and pH (Roller, 1975). Pest problems, particularly with nematodes, can be avoided by rotating sugar beets (one year in four) with grain and forage crops (Johnson, *et al.*, 1971). Since sugar beets have been grown on as many as 2.5 million acres, there would be very few problems with disseminating crop production knowledge, or providing planting and harvesting equipment to growers.

The capacity of U.S. industry to keep pace with these changes by timely provision of ethanol conversion equipment is also illustrated by the soybean example. Few problems were encountered in supplying soybean processers with equipment for crushing, oil extraction, and protein meal drying. Although concern has recently been expressed about the shortage of fermentation and distillation equipment, this is only a very short-term problem. It is generally recognized that a large-scale (e.g., 20–50 million gallons per year) ethanol production plant can be constructed within two to three years. On-farm units can be custom built in several months. And perhaps most significantly, factory assembled units suitable for on-farm and cooperative-scale application can be constructed by the thousands each year. For example, Solargizer International, Inc., of Bloomington, Minn., is contracting with Winnebago to build prefabricated alcohol plants capable of 500,000 gallons of anhydrous ethanol output per year.

Thus, agriculture is flexible enough to make the necessary changes in the crop production system, and industry is likewise flexible enough to respond to the new demands of agriculture.

Livestock Feeds

Livestock producers will be faced with significant changes in the composition of feed rations, if major shifts in the U.S. crop mix are accompanied by significant ethanol production. Past changes in livestock rations—from primarily range feeding, to use of more and more grain, and then to supplements of high protein soybean meal and inorganic urea—demonstrate the flexibility of livestock feeding. Several factors will influence the adaptability of livestock rations to include stillage and other coproduct feeds from ethanol conversion.

First, we have assumed that to achieve the same livestock output as the current U.S. feed system, any alternative must be capable of providing *at least the same* level of major nutrients to both ruminants and non-ruminants. Specifically, the same output from fermentation coproducts of metabolizable energy and digestible protein (without increasing the intake of fiber or dry matter) is needed as is presently supplied from feed concentrates. This is a relatively conservative assumption since it appears that the fermentation process actually improves the feeding value of certain nutrients by changes—such as increasing by-pass protein—which are not totally reflected in the amount of major nutrients (Poos and Klopfenstien, 1979).

Second, the feeding of fermentation coproducts to livestock is already a well-established practice. The grain coproducts are typically fed to livestock either in the wet form, as whole stillage, or in the dried form, as distillers dried grains and solubles (DDGS). Feeding of whole stillage (five to ten percent solids) with forages to dairy and beef cattle is a common practice in parts of Kentucky, Tennessee and Virginia, where small beverage alcohol distilleries are in close proximity to farms (University of Tennessee Agricultural Extension Service). Feeding of DDGS is preferable because it greatly reduces the moisture intake of the livestock. The Distiller Feed Research Council has develpoed a wide array of alternative feed rations using DDGS derived from corn, for virtually all types of livestock.

In the livestock feed system proposed in our work, many more animals would be fed fermentation coproducts, but the percentage of coproducts in animal feed would be no larger than in generally accepted agricultural practice. For example, Distillers Feed Research Council has dairy and beef rations in which corn DDGS amounts to as much as 39 percent of the total dry weight fed. In poultry rations, as much as 20 percent corn DDGS can be fed, providing the proper lysine level is maintained. Even if as much as 50 billion gallons of ethanol are produced from agricultural crops and all of the fermentation coproducts are fed to domestic livestock, the levels specified above are not exceeded.

Critics of ethanol production such as Secretary of Agriculture Bob Berglund (1979) have noted DDGS cannot be fed to non-ruminants because of its relatively high fiber content. This problem can be avoided by separate production of distillers dried grain (DDG)—the fibrous portion of DDGS—and distillers dried solubles (DDS). DDS is very low in fiber and has been used successfully in non-ruminant livestock feed rations. The relatively higher fiber content of DDG does not present a problem in ruminant livestock feed rations. Separate production of DDG and DDS is a common practice in large-scale ethanol production plants.

Thus, there appear to be no major barriers to increasing the number of livestock which receive fermentation coproducts as a part of their ration.

Crop Residues and Net Energy

Crop residues play an important role in the implementation of the large-scale ethanol production system proposed in our research. In present farm practices, crop residues are left in the field primarily because of their value in reducing soil erosion. As ethanol production increases, we assume that crop residue will be valued as fuel for the conversion process for the following reasons:

(1) Crop residues are renewable and locally abundant and, therefore, are not prone to rapid price escalation or supply disruptions.

(2) Boilers fueled with crop residues require only minimal air pollution equipment for control of ash emissions; sulfur emissions are essentially zero.

(3) Equipment is now commercially available for collecting and directly combusting most every type of crop residue. As demand increases for this equipment, additional cost efficiency improvements can be expected.

(4) In addition to direct combustion boilers, crop residues can be converted to a low-Btu gas ("syngas", produced by pyrolysis) which can easily be used in standard natural gas or fuel oil boilers. Efficient gasification technology is rapidly approaching commercialization, even at the on-farm unit size.

(5) Farm practices such as planting winter cover crops and minimum tillage can be used to prevent increases in soil erosion which otherwise might be expected with higher removal rates of crop residues.

(6) Use of crop residues will ensure that the ethanol production process is a substantial net energy producer, by as much as 500 percent.

This last point is probably the most important and deserves additional explanation. Until recently, critics of ethanol production have argued that ethanol production results in a large net loss of energy. For example, Peter Reilly (1978) of Iowa State University concluded that for each gallon of ethanol produced, 108,000 more Btu of energy are consumed than produced, resulting in a 56 percent net energy loss (see Figure III). Analyses such as these usually made at least one of three errors (Reilly made all three):

(1) Process energy requirements for fermentation and distillation were based on data from energy inefficient beverage alcohol plants, rather than modern facilities producing fuel-grade ethanol.

(2) The livestock feed coproduct was either ignored or credited on the basis of its combustible value, rather than its feeding value relative to the feedstock from which it was produced.

(3) The Btu value of ethanol was based only on its heat of combustion, thereby ignoring its value as an octane booster (yielding savings in gasoline refining) and its overall superior performance as a transportation fuel with respect to miles per Btu.

As shown in Figure III, recent government studies no longer repeat all of the above errors and therefore have concluded that the net energy gain in ethanol production is at least zero to five percent (ERAB and AFPR), and possibly as high as 61 percent (OTA). The variations in these estimates stem primarily from the fact that DOE's Alcohol Fuels Policy Review (AFPR) and ERAB do not include a credit for ethanol beyond its heat of combustion, while OTA credits each gallon of ethanol with 41,120 Btu for refinery savings in producing gasohol and 17,600 Btu for improved miles per Btu in gasohol.

Most important is the fact that all three of these major studies conclude that ethanol production is a substantial net producer of liquid energy (118 to 206 percent) when the conversion process uses a low quality solid fuel. By assuming the use of coal for processing heat, these studies calculate the net energy balance based only on high-grade fuels (liquids and natural gas) to arrive at gains exceeding 100 percent. In other words, the coal input is not included in the calculation because of its comparatively low quality.

Use of a low quality fuel in the processing plant is more rational than use of high quality fuels such as fuel oil or natural gas. However, the principal fuel for generating process heat should be crop residues, not coal. Although coal may have several site specific applications, its use in general is undesirable because of its nonrenewability, the increasing cost of controlling emissions (particularly sulfur) and the uncertainty of supply for smaller users. And in the longer-term, the total social cost of using coal is undoubtedly higher than relying on renewable crop residues. Since residue removal for providing distillery heat costs little in additional farming energy inputs (including additional inorganic fertilizer energy), it offers a substantial payoff in renewable net energy gained by ethanol production.

In contrast to the energy balances reported by ERAB, AFPR, and OTA, our research indicates that the net energy gain in ethanol production is actually closer to 500 percent (see Figure III). Our analysis differs from the others in these ways:

(1) We assume as intensive a use of crop residues as can be expected without increasing soil erosion above present levels. On the energy input side of the balance we include with the crop cultivation energy

and the energy required to harvest and transport residues. A small energy investment in residue collection yields a large amount of biomass available for boiler fuel. For example, one Btu spent on collection of corn stover yields enough biomass to provide about 50 Btu of process heat.

(2) We calculate net energy gain using an incremental systems analysis: As a starting point, we determine the energy inputs to crop production destined for domestic livestock feed. We then calculate the additional energy inputs required for producing an alternative crop mix designed for ethanol *and* livestock feed production. Finally, net energy gain is stated as the ratio of petroleum energy replaced by ethanol output (including oil refinery and vehicle fuel efficiency savings) to the incremental energy inputs required by agriculture for a new crop mix plus the fossil fuel required for operating ethanol distilleries. As the results show, a small addition to farming energy input can yield a large output of ethanol if the appropriate crop substitutions are allowed. (For additional information on this analysis, see Carlson, 1980.)

Thus, as long as crop residues are the major fuel for conversion of biomass to ethanol, the net energy balance in ethanol production will be decidedly positive.

Cost of Ethanol

Critics argue that although limited production of agricultural ethanol may be tolerated because of strong farmer interest in fuel self-sufficiency, total output should be limited to only a few billion gallons per year because other liquid fuels can be produced at a lower cost from abundant fossil resources such as coal, oil shale, and tar sands. As evidence, critics often point to the current wholesale price of ethanol—now about $1.65 per gallon, compared to wholesale gasoline at $.85 per gallon—and the extent to which ethanol is subsidized by the federal government and several states.

To determine whether ethanol from agriculture is cost-effective it is necessary to recognize the following points:

(1) The current wholesale price of ethanol is substantially higher than its profitable manufacturing cost because of subsidies to gasohol retailers and the inability of producers to keep pace with demand. A state-of-the-art analysis by Raphael Katzen Associates (1979) indicates that ethanol can be produced profitably from corn at $2.30 per bushel for $0.89 1.16 per gallon in 1978 dollars. Because the ethanol industry is presently being subsidized—for whatever reason—the existing price of ethanol is greater than its actual cost of production by the federal road tax rebate subsidy of $0.40 per gallon of ethanol, plus various state subsidies.

(2) Without subsidization ethanol would cost slightly more than $1.00 per gallon according to most recent studies. Given that ethanol has only two-thirds the energy content of gasoline, critics charge that even if cost estimates are based on modern production techniques, ethanol is more expensive than wholesale gasoline since two-thirds of a gallon costs about $0.60 to produce. Here it must be noted that ethanol's market value stems not from its energy content, but from its ability to perform work—to propel vehicles—and its octane-enhancing characteristics when blended with gasoline. The precise data are still lacking to fully qualify these advantages. However,

OTA has estimated, these two additional values may amount to $0.35–0.45 per gallon of ethanol, thereby increasing its competitive market value to around $1.00, or roughly equal to its cost of production.

(3) In considering the long-run and dynamic consequences of alternative liquid fuel supply strategies, the cost of renewable alcohol fuel needs to be compared to the cost of synthetic fossil liquid fuels. As Figure IV shows, estimates made during the 1970's on the cost of ethanol produced from corn have been stable, even though more recent estimates account for air pollution control equipment, minimal waste water and energy conservation plant design. In the future, the cost of ethanol can be expected to remain fairly stable because new cost-reducing innovations are continually being developed. Since the construction time for ethanol facilities is four or five times shorter than for synthetic fuel plants, second or third generation ethanol design technology should more accurately be contrasted with the present synthetic fuel technology. Since our estimate of how much alcohol fuel could be produced from biomass (both agriculture and forestry) without reducing food supplies is very large, this means that biomass feedstocks will remain constant in cost no matter how much alcohol is produced. In addition, some of the new technical innovations will allow more abundant and cheaper cellulosic feedstocks to be used.

The cost trend for methanol derived from coal, however, has been escalating exponentially over the same time period. As more environmental and worker health and safety protection measures are incorporated into the conversion plant's capital and operating costs, and as the price of coal rises, the price of methanol must also increase. In all likelihood, based on experience with the chemical industry, nuclear power, and other large complex technologies, capital and operating cost estimates can be expected to continue to rise.

(4) Finally, after accounting for the long-run internalized, private costs of competing liquid fuels, the remaining social damage costs of each alternative must be considered. For ethanol produced from crops or agricultural residues, the OTA and ERAB reports emphasize that serious environmental damage may result from energy farming. First, they assume that more residue would be removed and row crop acreage expanded to marginal land, exposing the soil to the elements. Soil losses in the United States are large and increasing, according to the Soil and Conservation Service. Second, they assume that energy crop production would result in more intensive use of fertilizer and pesticides. This would consume more scarce petroleum in farming, as well as causing more pollution and health damage. Yet our analysis shows that ethanol production from agricultural crops need not involve expanding row crop land to marginal soils. What is required for ethanol production is a reorganization of tillage practices on *existing* row crop land, replacement of row crops such as soybeans with high-carbon crops such as sugar beets, and the full use of fermentation feed coproducts in livestock rations.

This does not mean, however, that alcohol production cannot be expanded to marginal lands in environmentally benign ways. For example, interplanting of tree crops yielding annual sugar pod crops with forages would allow for alcohol production without exposing the land to erosion. Also, forage crop-to-ethanol and -methanol technologies are currently under development. Cultivation of forage crops from marginal lands does not present a problem of environmental deterioration, reducing soil erosion to virtually zero.

It does not necessarily follow that no more crop residues could be removed from the land because soil erosion is a serious and worsening problem. First, changes in crop mix induced by ethanol production would probably result in somewhat more residue production, allowing more to be harvested with the same amount left on the land. Secondly, if more forage production is forthcoming from an increased carbohydrate price, hilly and marginal land can be better protected from soil erosion. Thirdly, and most importantly, numerous studies have shown that conservation tillage practices (i.e., a primary tillage tool other than the moldboard plow) allow considerable residue removal while greatly *reducing* soil erosion from that of conventional land preparation. Conservation tillage need not also imply liquid fuel-saving *minimum* tillage, although this would be an added benefit (see, for example, Phillips, *et al.*, 1980).

Finally, energy crops such as sugar beets need not result in any more fertilizer or pesticide application or pollution than corn. Following corn in a rotation sugar beets can utilize nitrogen which has leached below the corn root zone due to sugar beets' deeper roots (which also make it more drought resistant). Pesticide application recommendations for Midwest corn and sugar beets are nearly identical. So increased biomass yields need not result in proportionately higher farming inputs. Careful examination is required on a crop-by-crop basis.

Although environmental damage costs to agriculture from energy farming can be easily alleviated, some of the potential environmental damages created by synthetic fossil fuels will be very expensive or impossible to control. For example, the damage to the world's climate from CO_2 build-up is a serious consequence of fossil fuel burning—especially synthetic fuels—but not of biomass fuels since the carbon released is quickly recycled into growing plants. The destruction of Western lands and the socio-economic consequences of boom towns are difficult to internalize into the private costs of synthetic fuels development.

C. EXTENSIONS OF THE FOOD-ENERGY INTEGRATION APPROACH

Detailed empirical evaluation of the food-energy system integration approach has been limited to considering only domestic livestock and feed crop production. Our present research also has not included a detailed exploration of the implications of advanced or second-generation alcohol conversion technology, and the entire problem of providing both food and alcohol to developing nations. In the sections that follow, we extend the basic scheme to use biomass to produce both food and energy to additional research areas including: other energy crops in the United States, food and fuel from lignocellulosic sources, U.S. grain export substitution, and world agriculture.

Other Energy Crops in the United States

The geographical focus of biomass research at CBNS has been Midwestern U.S. agriculture, where the sugar beet appears to offer maximum potential presently to produce both ethanol and feed products. In the near future commercial varieties of fodder beet, a close relative of the sugar beet with up to 50 percent higher yield, or sugar beet-fodder beet hybrids may be used to increase productivity (Earl and Brown, 1979). Another prospective energy crop for the Midwest region is white potato varieties which are too coarse for human consumption, but which yield twice as much biomass as conventional edible potatoes. Such yields would make the ethanol production per acre nearly equal for sugar beets and potatoes. Potatoes offer advantages over sugar beets because weed control is easier without herbicides, pest problems are generally less severe, full emergence is easier to achieve over a variety of weather conditions and the crop can be stored longer than sugar beets. Development of other energy crops, such as sweet sorghum, sweet sorghum-grain sorghum hybrids, or Jerusalem artichokes, for the Midwest could have the additional benefits of decreasing annual ethanol and feed output fluctuations because of adverse weather or pest conditions for a particular crop, and could alleviate the declining productivity associated with the present tendency towards monoculture.

For stony, wet, or steeply sloped land in the Midwest, South and East, interplanting of tree crops which produce sugar pods, such as the honey locust, with forages for hay or pasture holds considerable promise in the near future (Santamour, 1978 and Zarger, 1956). Presently marginal row crop land, pasture and hay land, and woodlots could be converted to this intercropping system. Forage yields may not decline significantly, and they could actually increase with proper grass species selection because of shade protection afforded by the trees during the hot, dry late summer season (Zarger and Lutz, 1961). On hilly land this crop system could virtually eliminate soil erosion on land currently devoted to row crops. Because so much land is presently in noncommercial forest and pasture, a very large aggregate ethanol and feed production potential exists for tree crops, even assuming modest yields per acre.

Food and Fuel From Lignocellulosic Sources

While there is considerable disagreement over the desirability of using agricultural crops for alcohol fuel production, there appears to be general agreement that cellulose—from agricultural and forestry residues, and municipal solid waste—is a very attractive feedstock because of its abundance and *apparent* minimal interaction with the food-fiber-fuel system. Differences in analysis usually arise about the quantity of cellulose which can be removed from cropland without creating undue soil erosion or fertility problems, the cost of harvesting and transporting residues, and the determination of which alcohol conversion process is closer to commercialization: a biological or a thermochemical process.

According to DOE's *Report of the Alcohol Fuels Policy Review*, by the year 2000 it may be possible to produce as much as 41.8 billion gallons of ethanol (3.3 quads), or 154.7 billion gallons of methanol (9.3 quads), from 549 million tons of wood and forestry residue, 278 million tons of agricultural residue, and 115 million tons of municipal solid waste. These quantities of alcohol fuels are substantial, but because the analysis fails to consider the principle of asking how food, fiber, and fuel production can be integrated, the following two interactive factors were not taken into account.

First, it must be recognized that yeast is an economically important coproduct of lignocellulose to ethanol conversion. Wolnak (1979) estimates that five percent of the sugar produced by cellulose hydrolysis is converted to recoverable yeast cells during fermentation, which amounts to 0.68 pound of dry yeast per gallon of anhydrous ethanol. Recycling of yeast to the fermentation process would reduce the recoverable yield, but this is not a widely accepted practice due to the increased risk of contamination. Given this conversion yield of glucose to yeast and DOE's estimate of ethanol production from cellulosic biomass, the production of yeast would be 14.2 million tons of 40 percent digestible protein feed. This amounts to 100 percent of the protein consumed by U.S. livestock in 1977 from soybean meal (USDA, 1978). Such a large input to the high-protein feed market could allow 22 million acres of cropland devoted to soybean production to be used for additional ethanol production from high-carbon energy crops, producing an extra 9 to 11 billion gallons of ethanol. In turn, the feed coproducts of these energy crops would produce additional livestock feeds.

Second, it must also be recognized that hemicellulose is a major constituent of lignocellulosic biomass, as shown in Table V. In the process of hydrolyzing cellulose to glucose (a six-carbon sugar), hemicellulose is broken down into pentoses (five-carbon sugars). According to a study by Arthur G. McKee Co. (1978) for DOE, 100 pounds of dry corn stover can yield 32 pounds of glucose and 45 pounds of pentoses. The glucose is converted to ethanol; the pentoses have two potential uses: (1) dried, they can be used as a high metabolizable energy livestock feed; or (2) using a bacterial fermentation process, about 129 gallons of butanediol can be produced per ton of pentoses. Butanediol is a four-carbon alcohol which mixes more easily with gasoline than methanol or ethanol, and it has a heat of combustion which is intermediate between ethanol and gasoline. Thus, for every gallon of ethanol produced from corn stover, a coproduct of about 20 pounds of livestock feed or 1.3 gallons of butanediol can also be produced. Similar yields can be expected from other types of lignocellulosic biomass.

Figure I shows that OTA, AFPR and ERAB include estimates in their analyses of ethanol production from cellulose (category D), but all fail to consider the potential for butanediol production from hemicellulose. Addition of this factor in the CBNS analysis (category E) more than doubles the total alcohol output from the same lignocellulosic biomass resource base.

Thus, recent reports on energy production from cellulose which prefer the methanol process over the ethanol process on the basis of almost three times greater energy output from the thermochemical methanol route have failed to consider the yield potential for yeast, and for either additional livestock feed (pentoses) or alcohol (butanediol) from the biological process. The assumed independence of food and fuel production when using cellulose biomass as the feedstock does not necessarily exist.

U.S. Grain Export Substitution

The calculations presented in section B assumed that cropping changes were made only on cropland currently devoted to domestic livestock feed production. Production of all grains and soybeans for export was assumed to remain unchanged. However, additional potential for alcohol production is possible if our original constraint is related to one of maintaining the same level of nutrients for export. The following considerations illuminate this potential:

About one-fourth of total harvested cropland is devoted to production of the three major U.S. export crops—corn, soybeans and soybean meal, and wheat, which are produced roughly in the proportions 2:1:1 by weight (USDA–FAS, 1980). Virtually all of the exported corn and soybeans are used for feeding livestock in other developed nations. Wheat is used mainly for direct human consumption, but a surprisingly large amount—20 percent—of total world production in 1978/79 was fed to livestock (USDA–FAS, 1980). Given that about three-fourths of our total grain crop exports end up as livestock feed, appropriate changes in U.S. export crop production patterns could yield additional ethanol for domestic consumption plus livestock feed coproducts for export containing equivalent levels of metabolizable energy and protein to existing exports. Once again, we can see the potential for ethanol production without interfering with livestock feed production so long as we are willing to consider the flexibility of the U.S. agricultural system to adopt new practices based on integration of food and fuel production.

Even with U.S. exports earmarked for direct human consumption (a large proportion of which goes to Japan and other developed countries), some potential for fuel and food coproduction may exist. In a modern "biomass refinery" ethanol plant, high-protein (60 percent) gluten meal can be separated from the starchy portion of the grain prior to fermentation. The gluten meal can then be used as a nutritional supplement in a wide variety of prepared foods, and the starch can be used in ethanol production. Such separation processes also yield an edible oil, and an oil cake suitable for livestock feed (Process Engineering Company, 1980). However, a limiting factor on direct food coproduct production is that high income people prefer to eat protein in animal product form, while the world's poor cannot afford to pay for processed foods incorporating high-protein vegetable supplements.

International Agriculture

Many people share a valid humanitarian concern over the consequences for world food production of a substantial program to use agricultural crops for energy, in the United States or elsewhere. This "food versus fuel" viewpoint was forcefully expressed recently by Lester R. Brown (1980): "Production of fuel from food crops will permit the affluent of the world to continue driving cars while the less developed countries pay higher and higher prices for food." However, it cannot be simply concluded without a close technical and economic investigation that consuming agricultural crops for production of fuel ethanol will necessarily result in less food availability for the poor. After several distorted or omitted points in Brown's analysis are clarified, the outlook appears much more optimistic.

First, Brown claims that hunger, soil erosion, deforestation and desertification are all evidence of a global shortage of food production resources. While these conditions are evidence of maldistribution of income and misallocation of resources in specific countries, they cannot be taken as evidence of global agricultural resource scarcity. Indeed, the numerous studies of world agricultural resources arrive at the same conclusion: world physical resource capacity is sufficient to produce several times more grain than is likely to be demanded through the year 2000 (Clark, 1970; Buringh, *et al.*, 1975; Revelle, 1976; Chou, *et al.*, 1977; Rojko, *et al.*, 1978). This amount is adequate for even the most pessimistic of the U.N. population scenarios, stability at 16 billion in 2135. In contrast, Lester Brown (1974) has argued that equilibrium at six billion is achievable.

Second, Brown claims that increases in food imports are evidence that a country's nutritional level has deteriorated. However, rising food imports are not necessarily a signal that a country is less able to feed its people. The fact that a country can *afford* to increase its food imports is generally evidence that incomes and nutritional standards are improving. The most obvious example is Japan, the largest importer of U.S. grain. More recent examples are our most rapidly growing food export markets: Korea, Taiwan and The People's Republic of China. Increases in food imports, especially since the demise of Public Law 480 concessional sales, are just as likely to be a sign of economic progress than an omen of future scarcity for the importing country.

The success of Japan, Korea, Taiwan and China in feeding their people suggests the third point ignored by Brown's analysis: the world food problem is not a production problem but an employment problem. Among the developing countries these have been outstanding in providing productive employment to the majority of the population. This has been accomplished through successful land reforms, the promotion of labor-intensive agricultural techniques, and massive investment in the agricultural sector. Given access to productive resources—land, roads, irrigation, projects, agricultural extension services, etc.—new farmers can decide whether to directly produce food or to produce cash crops to pay for their food purchases. With income to make their food demand effective in the market place, the employed bid up the price of food which in turn makes investment in the agricultural sector more attractive. Land does not get developed simply because people are hungry. Hunger must be accompanied by economic or political power to bring about the necessary investment. In the absence of political or economic power, a condition that characterizes the world's hungry, an alternative path is through the development of energy crops.

The tremendous effective demand of the world's automobile owners for gasoline could begin to induce the use of land, labor and other resources to develop the agricultural infrastructure in the world's land surplus countries rather than generating OPEC and oil company profits. This development process could open up massive new areas of cropland and improve the yields of existing cropland, with the potential to employ millions of those presently nutritionally deficient, and to provide them with resources to produce both food and fuel.

FIGURE I

ESTIMATES OF ALCOHOL PRODUCTION POTENTIAL: 1980-2000

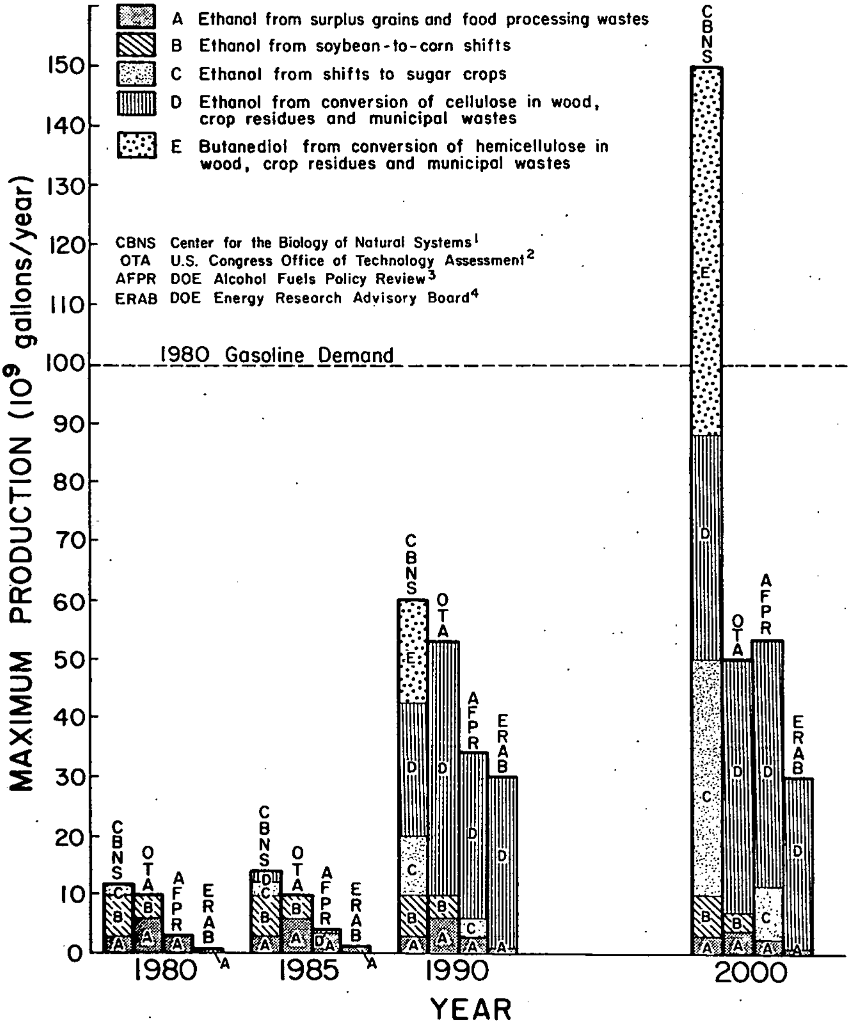


FIGURE I.—*Sources*

1. CBNS (Center for the Biology of Natural Systems): These estimates are derived from Richard Carlson, "Integrated Food-Energy Production Analysis," testimony before the Joint Economic Committee of the U.S. Congress, Subcommittee on Energy (St. Louis, Missouri: Center for the Biology of Natural Systems, Washington University; March 17, 1980) and from unpublished data derived from the CBNS model of optimal agricultural systems for production of food and energy.

2. OTA (U.S. Congress Office of Technology Assessment): These estimates are from *Gasohol: A Technical Memorandum*, Office of Technology Assessment (Washington, D.C.: U.S. Government Printing Office; September 1979). Category A resources include food processing wastes and spoiled grain, with no new land brought into production and with minimal crop substitution. The following resources are split between Categories A and B: An additional 4-6 billion gallons possible from i) new potential cropland and conversion of cropland pasture to grow feedstocks (land *not* needed for food, feed, fiber = 30 million acres); ii) use of set-aside and diverted cropland (p. 29). Another 3-5 billion possible if DDG produced is substituted for soybean meal, allowing some soybean acreage to go into ethanol feedstock production (p. 30). Finally, note that A and B are reduced in 2000 because OTA states that less than 10 billion gallons would be produced after 1990 because of increased competition for land for food production (p. 30). For Category D, OTA also estimates that at least 43 billion gallons of ethanol could be produced from cellulosic material (p. 31). Where a range is indicated, the midpoint is indicated in this figure.

3. AFPR (DOE Alcohol Fuels Policy Review): U.S. Department of Energy, Assistant Secretary for Policy Evaluation, *Report of the Alcohol Fuels Policy Review* (Washington, D.C.: U.S. Government Printing Office; June 1979). Category A includes 210 million gallons per year which could be produced from available surplus waste grains, with no use of any set-aside acreage (p. 47). In addition, another 240 to 450 million gallons could be immediately produced from food processing wastes (p. 46 and 47). Finally, Category A includes another 2.84 to 3.05 billion gallons which could be produced if: i) all set-aside acres could be used, ii) no allowance were made for a USDA reserve margin for grain, iv) no change were allowed in food/feed supply or exports (pp. 45, 46). Category C includes: i) for 1985, 150 mm from sugar cane, 260 mm from sweet sorghum (p. 46); ii) for 1990, 720 mm from sugar cane and 2.95 billion from sweet sorghum; iii) for 2000, 720 mm from sugar cane and 8.3 billion from sweet sorghum (p. 46). For 1990 AFPR estimates that 34 billion gallons of ethanol could be produced from cellulosics (Category D), including 20.2 billion gallons from wood; 11.3 billion gallons from agricultural residues; and 2.5 billion gallons from Municipal solid waste (MSW). For 2000 APFR estimates that 41.8 billion gallons of ethanol could be produced from cellulosics, including 25.8 billion gallons from wood, 13.3 billion gallons from agricultural residues and 2.9 billion gallons from MSW.

4. ERAB (DOE Energy Research Advisory Board): The DOE Gasohol Study Group (David Pimentel, *et al*) "Report of the Energy Research Advisory Board on Gasohol" (manuscript, Washington, D.C.: U.S. Department of Energy; April 29, 1980). The ERAB report estimates that before 1985 ethanol production will be limited to 200–300 million gallons per year from Category A materials, assuming no oil or gas is used in distillation. After 1985, the maximum potential for producing ethanol from grains (Category A) will be 800 million gallons per year, based on using 9 million tons of surplus grain. ERAB estimates that after 1990 methanol from coal or ethanol from cellulose will become major fuels (pp. 10, 13) with the advent of cellulosic technology. They estimate that category D (cellulosic conversion) resources could include: 70% of the corn residue from 20% of corn land, and 43% of residue from 25% of land in wheat; wood forestry residues; and 60 million acres of forestland converted to fuel wood farms, yielding a total of 18.6 billion gallons of ethanol (p. 26).

FIGURE II

CARBON TO NITROGEN RATIO IN PRESENT AND PROPOSED U.S. LIVESTOCK FEEDS

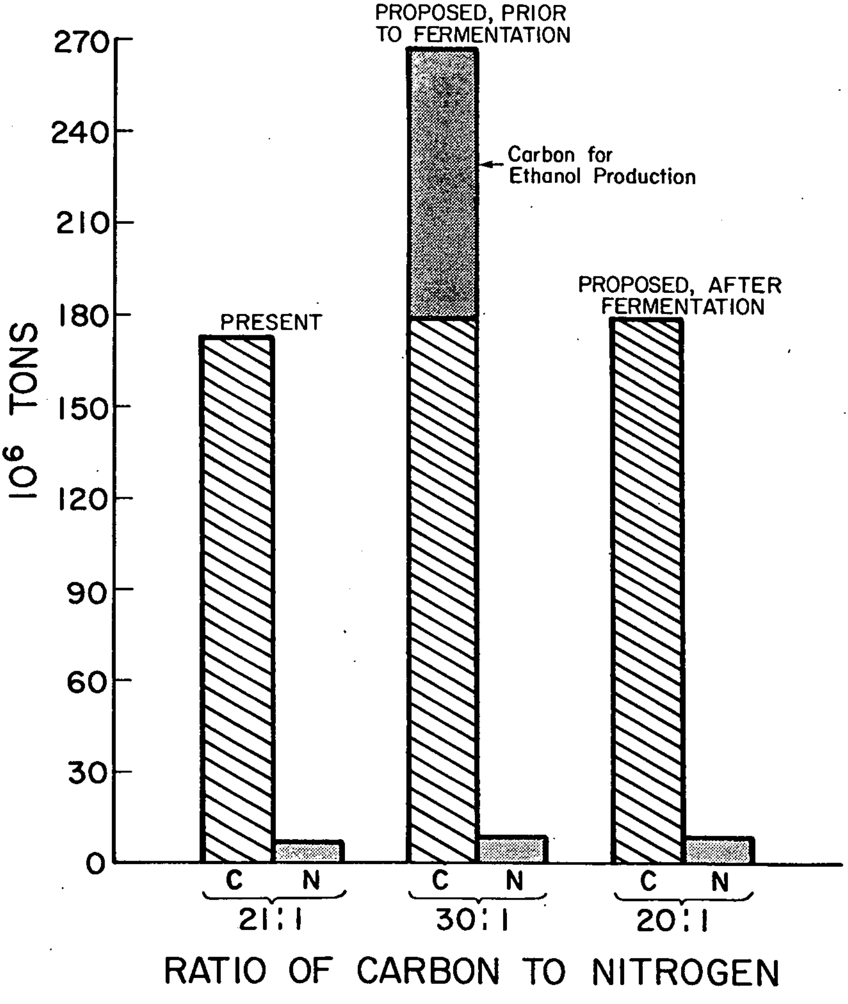
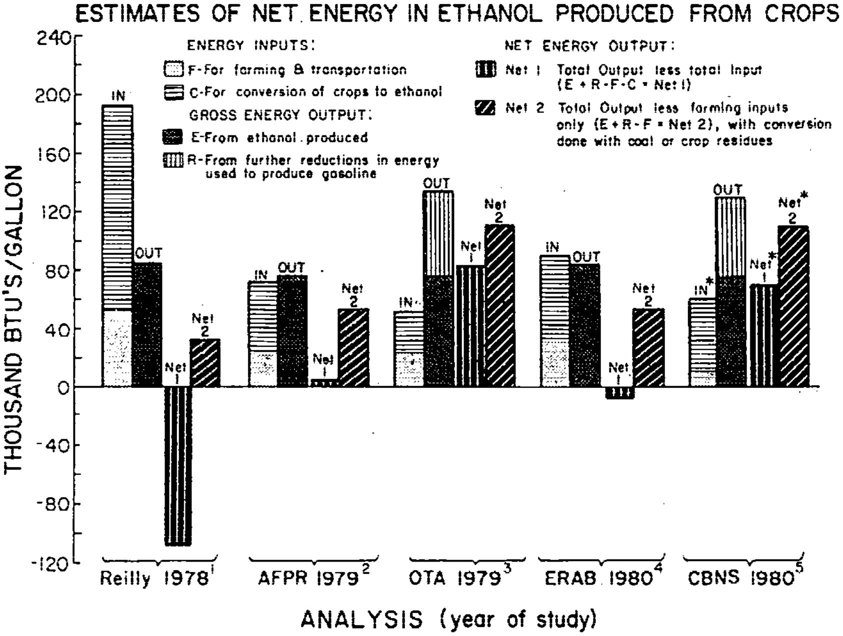


FIGURE III



*The CBNS analysis is based on the increment in energy used in a new cropping system to produce crops for conversion to ethanol, and thus differs from the other analyses cited here. See sources below for further details.

FIGURE III.—*Sources*

1. Reilly, 1978: Reilly, Peter J., "Economics and Energy Requirements of Ethanol Production," Department of Chemical Engineering and Nuclear Engineering, Iowa State University, January 1978. This study did not allocate any credit to farm energy consumption for the distiller's grains coproduct in the energy input/output estimates (pp. 5, 7). The conversion energy component is high (140,000 Btu's/gallon), which reflects the range of estimates commonly associated with inefficient brewing technologies, rather than with state-of-the-art fuel alcohol distilleries.

2. AFPR, 1979: U.S. Department of Energy, Assistant Secretary for Policy Evaluation, *Report of the Alcohol Fuels Policy Review* (Washington, D.C.: U.S. Government Printing Office; June 1979). A farming energy credit of 11,800 Btu for the distiller's grain product was deducted from the total farming energy estimate of 36,980 Btu to get the amount shown in Figure 3.

3. OTA, 1979: U.S. Congress, Office of Technology Assessment, *Gasohol: A Technical Memorandum* (Washington, D.C.: U.S. Government Printing Office; September 1979). The OTA study adds energy credits to ethanol as follows: 42,120 Btu are added to account for the refinery credit resulting from ETOH's octane boosting properties and the refinery energy saved in not producing the gasoline replaced by ETOH fuel. As a further credit, 17,600 Btu were added to reflect an estimated 20 percent increase in mileage per Btu of ETOH used (p. 16). A credit for farming energy input to distiller's grains of 10,530 Btu was deducted from total farming energy input estimated at 33,930 Btu.

4. ERAB, 1980: The DOE Gasohol Study Group (David Pimentel, *et al.*), "Report of the Energy Research Advisory Board on Gasohol" (manuscript, Washington, D.C.: U.S. Department of Energy; April 29, 1980). The estimated farming energy input to distiller's grains was 11,000 Btu, and was deducted from the total farming energy estimate of 45,000 Btu. A refinery energy credit of 8,000 Btu reflects reduced energy input to refining gasoline replaced by ETOH fuel (p. 25).

5. CBNS, 1980: These estimates are derived from Carlson, Richard, in Testimony before the Energy Subcommittee of the Joint Economic Committee of the U.S. Congress on "Integrated Food-Energy Production Analysis" (St. Louis, Missouri: Center for the Biology of Natural Systems, Washington University; March 17, 1980), CBNS-AEP-12. As noted on Figure 3, the CBNS method for computing energy inputs to farming for energy crops differs substantially from the other methods cited there. The CBNS approach is based on a systematic analysis of agricultural production patterns which has described an alternative system of cropping which would increase production of energy crops without reducing the production of vegetable protein for livestock. Hence, the CBNS energy analysis is based on the amount of energy needed to obtain the *increment* in crop output, above current levels of agricultural production. This explains why the CBNS estimate of farm energy use is less than half that of the other studies cited above.

FIGURE IV

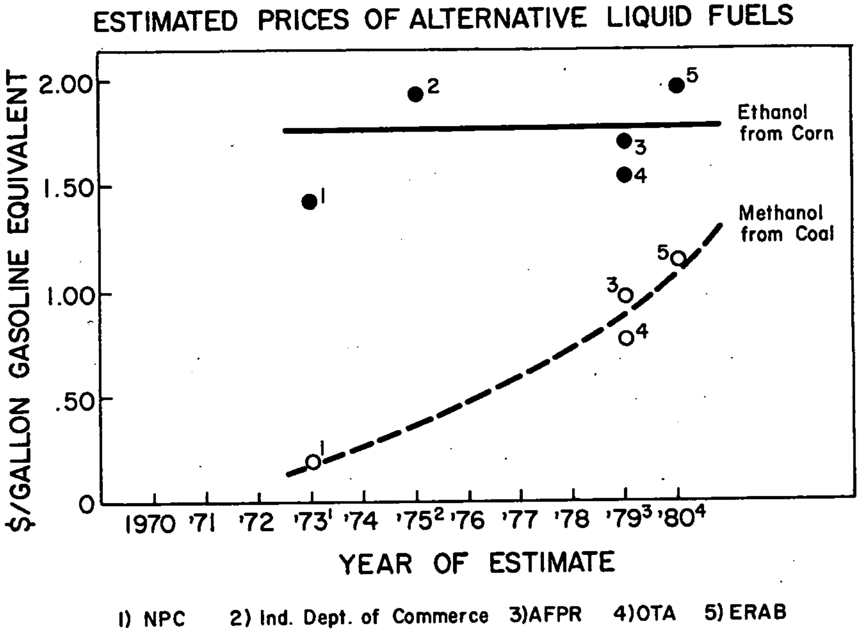


FIGURE IV.—*Sources*

All costs are expressed in current dollars, as of the date of the study. Method for computing gallons of gasoline equivalent: 1 gallon of typical gasoline has 115,400 Btu; 200 proof ethanol (ETOH) has 75,670 Btu per gallon, 200 proof methanol (MEOH) has 56,560 Btu per gallon. On a gasoline equivalent basis:

1 gal gasoline = 1.525 gal ETOH = 2.040 gal MEOH

No energy credits are included to account for the increased energy value/Btu for ETOH and MEOH which can result from their octane boosting and improved milegae properties as gasoline substitutes. Source of Btu values: *Alcohols: A Technical Assessement of Their Application as Fuels* (Washington, D.C.: American Petroleum Institute; July 1976), p. 8.

1. NPC: National Petroleum Council, *U.S. Energy Outlook: New Energy Forms*, A Report of the New Energy Forms Task Group of the Other Energy Resources Subcommittee of the National Petroleum Council's Subcommittee on U.S. Energy Outlook (Washington, D.C.: National Petroleum Council; 1973). 1973 methanol estimate based on coal costing $3.50 to $15.00 per ton in 1973 dollars (pp. 161–165). Ethanol cost includes 1973 corn feedstock cost (at $2.00/bu, or $.74/gal with 1 bu yielding 2.7 gallons ethanol, and a conversion cost of 10.2¢/gal; a correction factor for profit margin and marketing expenses of 15¢/gallon has been added in this figure and a credit for distiller's grains sale is taken (p. 78, 79). Source of ethanol cost estimate: Dwight L. Miller, "Corn and Its Uses," National Corn Growers Association, April 5, 1972; updated to May 1973.

2. Ind. Dept. of Commerce: Long-Rock J. V., *Grain Alcohol Study*, manuscript prepared for the Indiana State Department of Commerce, July 1975. Credit is taken for sale of distiller's grains, Esteraldehyde fraction fuel, fusil oil and CO_2 coproducts; a 20 percent profit margin is included (pp. 10, 11).

3. AFPR: *The Report of the Alcohol Fuels Policy Review*, U.S. Department of Energy, Assistant Secretary for Policy Evaluation (Washington, D.C.: U.S. Government Printing Office; June 1979). The ethanol cost estimate is based on a discounted cash flow return of 15–20 percent, and a 50 million gallon per year plant capacity with coal providing process heat (p. 72). The methanol cost estimate reflects an average cost (in 1978 dollars) of coal, a 15–12 percent discounted cash flow return, and a plant capacity ranging from 650 to 723 million gallons per year (p. 72).

4. OTA: U.S. Office of Technology Assessment, *Gasohol: A Technical Memorandum* (Washington, D.C.: U.S. Government Printing Office; September 1979). Ethanol estimate refers to a 50 million gallon per year plant and a 13 percent return on investment, coal supplies process energy, and includes the cost of drying the distiller's grains coproduct. The corn feedstock cost was estimated at $2.44 per bushel—an average of 1974–1977 prices (pp. 20, 21 and 22).

5. *Report of the Energy Research Advisory Board on Gasohol*, prepared by the DOE Gasohol Study Group (manuscript, Washington, D.C.: U.S. Department of Energy; April 29, 1980). The ethanol estimate given is an average of a low estimate given in the text (p. 14) and a high estmiate presented in a later figure (p. 28). Sale of coproducts and a return rate is not included in the higher estimate for manufacturing costs associated with a coal-fired, 50 million gallon per year conversion plant. The conversion technology is defined as the best potentially available through 1985. The methanol estimate derives from Stanford Research Institute data for 1978 and 1979, and averages the cost for lignite and bituminous coal. A 15 percent discount rate was used for a plant producing 735 million gallons per year of methanol.

TABLE I.—CARBON AND NITROGEN BALANCE

Crop	Carbon (10^6 tons)	Nitrogen (10^6 tons)	C/N
Current system:			
Soybean meal	4.4	1.9	2.3
Grain	38.8	1.6	24.3
Silage	16.0	.5	33.3
Hay	49.2	2.7	18.2
Pasture	63.9	1.4	46.5
Total	172.3	8.1	21.3
Alternative system prior to fermentation:			
Grain	69.8	2.9	24.3
Sugar beet, roots	68.5	1.9	36.6
Corn cobs	15.7	.17	93.0
Hay	49.2	2.7	18.2
Pasture	73.9	1.4	46.5
Total	267.1	9.1	29.5
Alternative system after fermentation:			
Grain stillage	19.2	2.9	6.9
Beet stillage	12.8	1.1	11.6
Beet pulp	18.0	.8	21.9
Corn cobs	15.7	.17	93.0
Hay	49.2	2.7	18.2
Pasture	63.9	1.4	46.5
Total	178.8	9.1	19.7

Source: National Academy of Sciences, "Atlas of National Data on United States and Canadian Feeds" (1972). Percent carbon calculated on the basis of nitrogen-free extract, ether extract, and crude fiber; percent nitrogen calculated from crude protein.

TABLE II.—LIVESTOCK NUTRIENT PRODUCTION

Livestock feed	Land (10^6 acres)	Dry matter (10^6 tons)	Digestible protein (10^6 tons)	Total digestible nutrients (10^6 tons)	Ethanol (10^9 gal)
Current food system:					
Soybeans	21	23	10.7	19.9	
Grain	76	95	8.8	103.5	
Silage	14	38	1.7	26.4	
Hay	61	123	12.9	73.8	
Pasture	84	148	13.8	100.2	
Total	262	427	46.2	323.8	
An example food and fuel system:					
Beet stillage	40	36	4.0	27.3	16.2
Beet pulp		44	2.0	33.1	
Grain stillage	115	59	15.8	64.6	18.8
Corn cobs		34	0	17.1	
Hay	61	123	12.9	73.8	
Pasture	84	148	13.8	100.2	
Total	300	444	48.5	316.1	35.0

Sources: U.S. average crop yields and livestock feed consumption from cropland (excludes range and permanent pasture for 1974-76 (years of low grain yields) in USDA, "Agricultural Statistics, 1977." Digestible nutrients of feeds from Frank B Morrison, "Feeds and Feeding," 22d ed. (Clinton, Iowa: Morrison Publishing Co., 1959).

TABLE III.—U.S. HARVESTED ACREAGE OF CORN, SOYBEANS, AND SUNFLOWERS, 1924-78

Year	Corn (10^6 acres)	Soybeans (10^6 acres)	Sunflowers (10^6 acres)
1924	100.4	0.4	--
1929	97.8	.7	--
1934	92.2	1.6	--
1939	88.3	4.3	--
1944	94.0	10.2	--
1949	85.6	10.5	--
1954	80.2	17.0	--
1959	81.9	22.6	--
1964	65.4	30.8	0.04
1969	63.1	41.3	.19
1974	76.9	51.3	.55
1979	79.4	70.5	5.41

Sources: USDA, "Agricultural Statistics, 1978" for 1924-64 for corn and soybeans. USDA, "Agricultural Statistics, 1979" for sunflowers 1964-74, and corn and soybeans for 1969-74. USDA, "Crop Production, 1980," for 1979.

TABLE IV.—REPRESENTATIVE ETHANOL AND STILLAGE YIELDS FOR SELECTED FEEDSTOCK CROPS [1]

Feedstock crops	Ethanol (anhydrous gallons)		Stillage (dry matter)	
	Per fresh weight ton	Average per acre	Pounds per fresh weight ton	Average tons per acre [2]
Sugar crops:				
Sugar beets [3]	22	420	100	1.00(3.95)
Sweet (sugar) sorghum [4]	15	280	220	2.05
Sweet (syrup) sorghum [4]	13	340	240	3.14
Sugar cane [3]	15	623	200	4.00
Jerusalem artichokes [5] (branching tuber)	21	480	100	1.14(4.68)
Fodder beets [6]	18	950	115	3.03(?)
Starch crops:				
Corn [7]	93	225	580	.70
Sorghum [7]	93	135	540	.39
Wheat [7]	93	95	620	.33
Potatoes [3]	23	280	76	.46
Sweet potatoes [3]	34	190	92	.26

[1] These data are to be regarded as approximations only; significant variations can be expected depending on the feedstock composition, the efficiency of conversion and recovery of products, and crop yields. For the starch crops, the yield data are generally based on practical experience, usually of the beverage alcohol industry. For the sugar crops, the yield data, as cited in the recent literature (see sources listed below) are typically calculated from the crops' fermentable sugar content, since very few fermentation tests have been done as yet with these crops.

[2] Numbers in parentheses also indicate the additional yields of crop dry matter (e.g., sugar beet tops) which can be used for livestock feed, but is not directly involved in the ethanol conversion process.

[3] Source: Portola Institute. "Energy Primer." Friche-Parks Press, Inc., Femont, Calif. (1974).

[4] Source: Nathan, R. A. "Fuels from Sugar Crops," DOE Critical Review Series. NTIS No. TID-22781 (1978).

[5] Source: Stauffer, M. D., et al. "Jerusalem Artichoke." Agriculture Canada, CDA Research Station (March 1975).

[6] Source: Earl, W. B., and Brown, W. A. N. "Alcohol Fuels from Biomass in New Zealand—The Energetics and Economics of Production and Processing," Alcohol Fuels Technology Third International Symposium, pp. 1-12, Asilomas, Calif. (May 28-31, 1979).

[7] Source: Solar Energy Research Institute. "Fuel from Farms—A Guide to Small-Scale Ethanol Production," SERI, Golden, Colo. (1979).

TABLE V.—TYPICAL COMPOSITION OF CELLULOSIC RESIDUES

[In percent]

	Corn residue [1]	Tall fescue [2]	Softwood
Cellulose	38	34	42
Hemicellulose	26	25	25
Lignin	11	8	28
Other [3]	25	32	5

[1] Harvested in late October; cellulose and hemicellulose content are higher in residue harvested earlier; content varies from year to year.

[2] Harvested at feeding stage.

[3] In crop residues this includes proteins, minerals, and soluble sugars.

Source: Ladisch, M. R. "Fermentable Sugars from Cellulosic Residues." Process Biochemistry: 21-25 (January 1979)

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UTILIZATION OF BIOMASS IN THE U.S. FOR THE PRODUCTION OF ETHANOL FUEL AS A GASOLINE REPLACEMENT

By John D. Ferchak and E. Kendall Pye*

Part I. TERRESTRIAL RESOURCE POTENTIAL

ABSTRACT

With relatively minor adjustments in the agricultural sector, large additional amounts of starch derived from feed corn, surplus and distressed grain, and set-aside land could presently be used for ethanol production. The quantity of ethanol that could be produced would be sufficient to replace anywhere from 5 percent to 27 percent (5.5–30 billion gallons) of present gasoline requirements. Thus, the ethanol requirement for total gasohol use (10 percent in the U.S.) could be met in the short period of time required for facility construction with no evident impact on food production. Increased supplies of ethanol will make feasible the introduction of ethanol fueled engines. High-yield sugar crops planted on new acreage could provide an additional 10 billion gallons of ethanol by the year 2000; conversion of the waste biomass from this crop to ethanol could also add substantially to this amount. Utilization of novel cellulose conversion technology can provide fermentable sugars from municipal wastes, agricultural and forest wastes, and ultimately, highly productive silvicultural operations. The wastes alone could yield over 36 billion gallons of 192° PR ethanol-fuel by the year 2000. Fast-growing woody species from silviculture are expected to yield a conservative average of 10 oven-dry tons per acre per year, convertible to 710 gallons of ethanol in a process that has 37 percent yield. Advantages over sugar/ starch crops include year-round harvesting, and use of marginal acreage. Commercial forest land presently suitable for silviculture is about 100 million acres in large tracts, plus 200 million acres in small private tracts. The potential additional yield of ethanol from lignocellulosic biomass appears to be well in excess of liquid fuel requirements of an enhanced efficiency transport sector in the United States at present mileage demands. No conflict with food production would be necessary.

INTRODUCTION

Strong support for the development of ethanol for use in "gasohol," a blend of 10 percent ethanol with gasoline, as a means of reducing dependence on foreign oil, is now evident in the United States. The ethanol is to be derived from plant material (biomass), and therefore is a renewable resource.

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There is major controversy surrounding two critical areas in the use of biomass for liquid fuel production. First, the size of the biomass resource base and therefore its potential contribution to liquid fuel needs is questioned. The quantity and sources for ethanol production will affect the relative effort to be made, the substrate of choice, and the degree of liquid fuel self-sufficiency attainable. Secondly, the energy balance, or whether the energy derived in the form of ethonol is negated by the overall energy demands in its production, is a focus of concern. The first point is analysed in this paper whereas the second is considered in a separate paper.[1]

Of the biochemicals present in biomass, those which are sugars or polymers of sugar molecules (polychacharides) can serve as substrates for fermentation into ethanol. These include the soluble sugars (fructose, glucose, sucrose, etc.) found, for example, in fruits, sugar cane, and beets; and the sugar polymers—starch, cellulose, and hemicellulose. Starch (amylase, amylopectin), a natural form of energy storage in plants such as corn, potatoes, and cassava, is easily converted back to the simple soluble sugar, glucose. However, cellulose and hemicellulose, combined with lignin, are a plant's structural material (the woody portion), which has evolved to be strong, enduring, and resistant to parasitic attack. Conversion, therefore, is more difficult, although processes are now being developed for commercial production of sugars from the cellulose and hemicellulose fractions (holocellulose). Sugars from all of the above sources can be fermented to ethanol.

POTENTIAL DEMAND FOR ETHANOL FUEL

Present Department of Energy scenarios evaluate U.S. potential fuel usage of ethanol only as an extender for gasoline, in a 10 percent: 90 percent blend. Not only might this emphasis be incredibly myopic, it also requires 200 proof ethanol, since any water present would separate out when mixed with gasoline (although "coupling" agents are now being marketed to stabilize mixtures of gasoline and 190° PR ethanol [2]). An alternative approach is to use engines designed for hydrous ethanol, which would not require the anhydrous form, allowing a saving in the requirements for ethanol distillation, together with easier small scale production and less difficulty in handling and storage. Automobiles with such engines are now being marketed in Brazil by Fiat, Ford, Volkswagen, General Motors and Chrysler, at the same prices as gasoline powered vehicles. Thus, if the U.S. market were able to offer ethanol as an alternative fuel to gasoline in sufficient quantity and availability, the automobiles to use it would be available at entirely competitive prices. As with diesel engines, even a small number of ethanol engines would establish the market. For example, only 41,000 diesel cars were sold in the U.S. in 1977, rising to 271,000 in 1979. Just as with diesel fuel, if a small percentage of filling stations initially offered the ethanol fuel alternative, an adequate market could develop. Additionally, demand by localized industrial users which fuel at central locations, such as power and telephone companies, the postal department, or the military, would allow the use of fleets of all-ethanol fueled vehicles. To accomplish this would require the coördination of agricultural supply, processing facilities, and distribution network. Such a scheme may evolve from the private sector. However, the Brazilian approach of government sponsorship may provide a model for more rapid development.[3]

U.S. consumption of gasoline as motor fuel for 1979 was 108 billion gallons, or 40 percent of total petroleum products demand. In addition, about 12 billion gallons of diesel fuel for highway use are consumed, mostly by the trucking industry.[4] Estimates of future consumption vary widely, with conservation and efficiency playing crucial roles. A recent analysis in the United Kingdom foresaw automobile specific fuel consumption potentially decreasing 70 percent by 2025, while predicting a doubling of passenger car travel.[5] Overall delivered energy in the transportation sector would decrease by 2025 to 45 percent of its 1976 level, while sustaining a large increase in economic activity. In the U.S. federally mandated fuel efficiencies for automobiles of 50 miles per gallon or more by the year 2000 have been suggested. Coupled with an inevitable expansion of the public transportation sector, such efficiencies could result in a decline in overall liquid fuel demand for transport even with significant expansion of activity.

Although we will not attempt to estimate future liquid fuel needs, it is necessary to evaluate how much ethanol could potentially be produced in the U.S. to determine whether sufficient quantities can be made available for three possible demands: first, as a gasoline extender (about 10 billion gallons/year required for a 10 percent mixture); second (and this would be simultaneously compatible with the first), as a separately used fuel in ethanol engines (on a scale comparable to diesel fuel for transportation); third, as the only available liquid transportation fuel (the question here is, what is the maximum production possible?).

In considering the total terrestrial biomass potential in the U.S., we have attempted to find out how much ethanol could be made available, first of all from utilization of starch and sugar crops without interference with food production, and secondly from sources requiring new technology—primarily cellulosic substrates.

TERRESTRIAL BIOMASS POTENTIAL

The contiguous 48 states of the U.S. occupy about 5.8 percent of the total world area (Table I).[6–11] 500 million acres are classified as commercial timberland by the U.S. Forest Service, and not legally withdrawn from timber harvesting.[12] Most of the commercial forest land is not presently utilized for production, as is cropland, except for the industrially owned area. Of the cropland, about 70 million acres are used for corn production, yielding an average of 87 bushels per acre in 1976. Total corn production for 1976 was 6.3 billion bushels, or 176 million tons (35.7 bu=1 short ton=2000 lbs).[13] It is estimated that an equal or greater quantity of corn stover (stalks, cobs) is left as agricultural waste. Other acreage includes wheat (66 million acres), soybeans (58 million acres) and sorghum (14 million acres).

Starch and Sugar Potential

An examination of end-use of grains reveals that most corn is only indirectly utilized for human consumption. Only 8 percent is used directly for human consumption, beverage alcohol and seed; 57 percent goes for animal feed (U.S.), 27 percent is exported (also mostly for animal feed), and 8 percent is in reserve (1976 figures).[13]

The fact that so much corn is used for animal feed has led to a novel suggestion for alcohol production. [14, 15] Corn is primarily starch, and about 2.6 gallons of anhydrous or 2.8 gallons of 192° PR ethanol can be made from a bushel (56 lbs). Cows need the protein in corn, but being ruminants, can utilize cellulose for energy in addition to starch (non-ruminants would require starch or sugars). If the corn were first used for alcohol production (i.e., the starch extracted and fermented), the residue would be a high protein product, equivalent to what is now commonly sold as DDG (distillers' dried grains). This high protein mash would not need drying if used locally as feed, thus eliminating an energy expensive step, and could be supplemented with corn stover or other cellulosic waste to replace the extracted starch. Methods of pretreating the cellulose could increase its digestibility from an untreated 45 percent up to as much as 90 percent, or comparable with the original starch.

An interesting aspect of substituting distilled fermentation mash for corn is that beef cattle seem to thrive better on it. Therefore, less total grain production for feed would be required for the same cattle weight if some of the corn feed were directed into ethanol production and the resulting high-protein mash residue returned to the feed troughs.[16]

Lipinsky[14] estimates that 1.7 billion bushels of corn are used just for cattle feed alone in the U.S., which could be used to produce about 4.8 billion gallons of 192° PR alcohol. If all the corn was similarly processed, exclusive of the 8 percent used for human consumption and seed, 16.2 billion gallons of alcohol could be produced (Table II). Major advantages of this proposal are that no disruptions of agricultural production are required; the technology for starch conversion is well established and facilities could be implemented within a year; the substrate has been collected and stored and is available year-round (allowing maximum use of plant facilities); the cost for substrate is low (since the corn was already grown and purchased as feed, and the only additional cost is that for replacement of starch with cellulose); the only energy requirements are for starch hydrolysis, fermentation and distillation, and possibly treatment of stover for feed; and the quantity is sufficient both to make an immediate impact on oil imports and to begin the development of an infrastructure for the transition to an ethanol-based transportation sector.

While corn starch could make a significant contribution to overall ethanol production, other carbohydrate crops such as surplus grains, sugar cane, sorghum, beets and potatoes have been suggested. Certainly surpluses and/or spoilage (i.e., "distressed grain") from these and other crops would provide excellent substrates for local production of ethanol by small entrepreneurs, farmers' cooperatives, or agribusiness, developed on a case-by-case basis. Such small-scale and localized operations could eventually add substantially, e.g. upwards of a billion gallons per year, to overall ethanol production.

More importantly, high-yield sugar crops—sugar cane, sweet sorghum, and sugar beets—can potentially make a major contribution to supplying ethanol needs. A recent study from Batelle-Columbus Laboratories concluded that large tracts of new acreage could be brought into production in the Southeastern, Delta and Southern Plains farm regions in a program that could achieve production of more than 10 billion gallons of anhydrous ethanol by the year 2000.[17] It was estimated that as much as 50 million new acres are potentially available for sugar cane or sweet sorghum production. The actual amount of land required will of course depend on the crop and productivity. Lipinsky[18] estimates that to produce 10 billion gallons of ethanol, 21 million acres of highly productive sugar crop land (at 3.5 T/a of fermentable sugar) would be required, as compared to 38 million acres of land in grain with high productivity (100 bu/a).

Sweet sorghum is a potentially promising crop. It grows in a wide range of climates and latitudes, and has yielded 2.6–3.6 T/acre of sugar in various test locations, plus 6.0–8.5 ODT/acre of residual biomass.[18]

Another possibility is the use of land that is now classified as idle, set-aside, and marginal acreage. Estimates of the land available range up to 150 million acres.[11] Cropland withheld from grain production under USDA programs varies yearly, with a recent peak in 1972 of 62.1 million acres.[19] In 1979, the agricultural subsidy to farmers to let 31 million acres of cropland lay idle was about 2.3 billion dollars. The money paid for idle land could instead be used to stimulate biomass production for fuel, becoming an investment rather than a subsidy, with far greater economic value. In a recent study, the Midwest Research Institute determined the excess amount of corn, wheat and grain sorghum which could be available for ethanol production by the year 2000, if produced only on the current cropland base with no USDA production restrictions, assuming modest and accepted increases in productivity.[20] Their conclusion was that on the average there will be sufficient grain available above food, feed and export requirements to produce approximately 3.8 billion gallons of ethanol per year.

This estimate may be unduly conservative. For example, present surplus acreage in the U.S. is not less than 30 million acres and may be as high as 150 million acres. Cultivating surplus acreage and taking 60 million acres as an average, then corn grain production (or sorghum, etc.) at a yield of 60 bu/a (75 percent of the 1976 national average) could be converted to 8.7 billion gallons of ethanol (net).

A significant development that could increase biomass feedstocks is an incipient tendency in the U.S. towards greater consumption of foods of vegetable origin, with a decline in meat consumption. Since direct human consumption of grains is from 8 to 15 times more efficient in protein utilization than the consumption of grain-fed beef, large areas of the cropland used for animal feedstocks could become available. One estimate is that up to 100 million acres of cropland would be set free, if present trends continue to the year 2020.[21] Corn grain from this quantity of land at average yields would give a net production of over 19 billion gallons of ethanol; if the crop were sweet sorghum, the net yield from sugar could be over 30 billion gal/ yr.

Thus, Table II indicates that current land and modified agricultural practices could produce in excess of 30 billion gallons of ethanol from starch and sugar crops annually for fuel use by the year 2000.

Lignocellulosic Conversion

At this point, having considered sugar and starch biomass resources, it is necessary to turn to cellulosic substrates and new conversion technologies to expand the base of renewable resources available for ethanol production. These resources are to be found in agricultural, forestry, and urban wastes, and in deliberate generation of biomass through silviculture. The potential is enormous.

Several different processes are currently being developed to convert woody substrates into soluble sugars for fermentation.

The technology is feasible and rapidly moving toward commercialization. Both acid and enzymatic methods are being studied, along with several approaches to pretreatment of the substrate.[22]

In order to calculate the amount of ethanol obtainable from lignocellulosic substrates, we will assume an enzymatic hydrolysis process with an average hydrolysis efficiency (wt. fermentable sugars/wt. holocellulose × 100) for the holocellulosic fraction of 80 percent, which is generally accepted as an attainable process goal. In practice this will vary according to substrate and degree of pretreatment. Fermentation efficiency can be taken as 90 percent of theoretical (the theoretical fermentation weight ratio of ethanol from glucose is 0.51:1). Overall process yield (wt. ethanol/wt. holocellulose × 100) is taken as 37 percent. Thus, one ton of of holocellulose will produce 117 gallons of 192° PR ethanol.

Higher efficiencies than these estimates have been reported. One process achieves quantitative yields (99 percent hydrolysis of cellulose to glucose) from agricultural residues using available cellulase enzymes and a new organic solvent pretreatment method.[23]

A recent evaluation of the process developed by Gulf Oil Chemicals Corp. indicated that it was technically feasible with an overall process yield of about 43 percent.[24] One dry ton of feedstock (two-thirds municipal solid waste and one-third pulp mill waste) containing 57 percent cellulose would yield 75 gallons of 190° PR ethanol.

Potential From Waste

Estimates of organic waste annually accumulated in the U.S. exceed 1 billion dry tons, out of a total net biomass production of 5 billion tons. A recent study for DOE indicated that 421 million tons are currently generated as agricultural residues, rising to almost 560 million tons by the year 2000.[25] The study estimates that, of this total, 278 million tons could potentially be available for alcohols feedstock by the year 2000, with most of the rest diverted to soil conditioning. Another 116 million tons of feedstock could come from MSW (70 percent of total MSW generated). If used for ethanol production at the given efficiencies, the cellulose and hemicellulose fraction (~50 percent) from 278 million tons of agricultural residues would yield about 16.3 billion gallons of 192° ethanol. The amount of collectible forest residues and waste presently available is about equal in energy value to the agricultural residues.[26] Assuming the same relationship to the year 2000, forest residues and waste have the potential of contributing roughly an equivalent additional amount of ethanol. The energy content of MSW, as fermentable sugar, is estimated as 0.6 that of low moisture residues;[31] therefore MSW could provide another 4.1 billion gallons. Thus, available waste alone could yield up to 36.6 billion gallons of 192° PR ethanol by the year 2000, or enough to replace 34 percent of current levels of gasoline consumption (assuming 1:1 volume equivalence [1]).

Moreover, if a program such as that suggested by Battelle-Columbus Laboratories to bring new acreage into sugar cane production were implemented, large quantities of bagasse would be generated. Production of 10 billion gallons of 192° PR ethanol per year would require about 70 million tons of sugar. From this sugar cane, which average 42 percent sugar on a dry weight basis, [27] a bagasse residue of 97 million tons would be left. If sweet sorghum were used, (31 percent sugar), the residue would exceed 150 million tons. Bagasse contains about 33 percent α–cellulose and, based on analysis of other grasses, [28] about 26 percent hemicellulose and 8–11 percent lignin. If 25 percent of the bargasse remained with the soil and the remainder were utilized for ethanol production, then the average 120 million tons of bagasse residue could yield another 5.2 billion gallons of ethanol.

In the total process for the conversion of biomass to ethanol fuel, the only required point of liquid fuel input is the agricultural operation. [1] Thus, it is more correct to estimate a net production per acre per year based on subtracting this requirement from the gross liquid fuel potential. Using the data base of Pimentel *et al.*, [29] for corn of 32 gallons of gasoline per acre per year, and assuming a worse case that the "gasoline" specified is diesel fuel (equated on a Btu basis with ethanol), then about 54 gal/yr of ethanol fuel is required per acre for corn, and 77 gal/yr for woodchips from silviculture.[1] This adjustment has been made in Table II where indicated.

Silviculture

The largest terrestrial biomass resource in the continental United States is 500 million acres of commercial forestland, most of which is presently underdeveloped. About 300 million acres are believed to be available for energy production. Of this, about 100 million acres are estimated to exist as large tracts of land which meet site, climate, and precipitation requirements for deciduous species for silviculture. [30] In addition, many small plots would also be available, perhaps operating on a cooperative basis. Virtually all is privately owned and not currently used. An interim goal suggested by DOE is that 10 percent of the total available acreage (about 30 million acres) be planted in the next 10–15 years as a first effort. [31]

One of the major advantages of silviculture for liquid fuels production is the option of continuous year-round operation for both harvesting and processing, so that the detrimental factors of long-term storage and/or short-term operation inherent with sugar or starch crops are eliminated.

New methods of silviculture for this purpose are very promising. These tree farms will consist of rapidly growing species, such as poplar, sycamore and eucalyptus, planted at close spacings and harvested at appropriate short rotations with coppicing (leaving roots and stumps for further growth).[32] Lower limit yields of 5 oven dry tons per acre per year (ODT/a/yr) are commonly quoted.[32, 33] Actually, the "current" level ranges from 5 to 12 ODT/acre/yr [34] and a "future" range of up to 20 ODT/acre/yr might be achieved through genetic improvement and advanced crop and land management practices.[35] A yield of 10 ODT/yr on a sustained large-scale basis is a reasonable projection.[30, 36] If a processing plant were incorporated into the silviculture farm, transportation costs would be negligible. Fertilizer requirements are kept low, since nitrogen-containing crops are not necessarily harvested. Also, plant processing wastes, which would be rich in nitrogen and other nutrients, would be returned to the soil (in large-scale production, the quantities generated would be expected to overwhelm the market for high-protein animal feed supplements).

The composition of hardwood trees varies, depending on age and species, but generally falls within the range of 50–51 percent glucan, 16–26 percent xylan, 16–24 percent lignin, and 8–12 percent other organics and 0.5 percent ash. For calculations, we use an average estimate of oven-dry tree composition as 34 percent cellulose, 27 percent hemicellulose, 18 percent lignin, 9 percent residuals, and 12 percent water.[37] Therefore, the holocellulosic fraction from one oven-dry ton of wood substrate can yield about 71 gallons of 192° PR ethanol, 360 lbs of lignin, 280 lbs of unhydrolyzed sugar polymers (which can be used as feedstock for anaerobic fermentation to methane and subsequent animal feed supplement) and 180 lbs other organics (which may have commercial significance). About 420 lbs of CO_2 will also be generated, either to be vented, made into dry ice, or reutilized in greenhouse farming.

The agricultural ethanol fuel requirement for production of 10 ODT/acre/yr of wood chips is estimated at 77 gal.[1] Thus, assuming an average silvicultural yield of 10 ODT/acre/yr, we could expect to produce 633 net gallons per acre/yr, or from the 31 million acres initially recommended for cultivation by DOE, about 19.6 billion gallons of 192° PR ethanol fuel per year. Without extrapolating to all available commercial forest acreage, it is clear that the potential for ethanol fuel production just from the sources listed above argues for a major investment in commercialization where presently feasible, and in R. & D. for technologies that are still immature.

Nor have we exhausted the possibilities for novel use of land and biomass. For example, swampy areas could potentially be used to grow crops such as cattails, a nitrogen-fixing plant, whose starch production alone could yield 5 ODT/acre·yr plus an equivalent amount of residue.[38] Brackish or saline water used to irrigate poor, non-agricultural land in areas such as the Southwestern U.S. will support certain species, such as *Tamarix aphylla*, (Athel tree), which has been shown able to yield an average of 14 ODT/acre·yr of woody biomass.[39]

Marine and freshwater plants such as seaweed and water hycinth are being investigated for use in methane generation.[40] Aquaculture of this sort may one day contribute to the production of alcohol fuels. The contribution of potential sources such as these is difficult to estimate, yet they may eventually make major contributions to liquid fuel production. We have not attempted to include such sources in our estimates, only because it is beyond our scope, not because of any foreseen limitation in their potential.

DISCUSSION

The processing of woody biomass holds great potential for the production of liquid fuels and chemical feedstocks on a continually renewable basis. This potential is in excess of that required to achieve transportation fuel independence in the U.S., if current trends continue.

In exploring just the terrestrial resource potential in the U.S., several points have become evident. Firstly, there is sufficient potential from presently available sources of starch, derived primarily from feed corn, surplus and distressed grain, and set aside land, to support a large-scale ethanol fuel effort that could supply 5.5–27 percent of present gasoline fuel needs. This could include use both as gasohol and as an independent fuel. Secondly, implementation of innovative cellulose conversion technology will permit utilization of vast tracts of marginal and forest acreage, in addition to huge amounts of waste biomass. Disposal of this waste biomass, presently a major environmental problem, would find an attractive solution. Thirdly, the theoretical limit of potential biomass resources for liquid transportation fuel exceeds foreseeable demand. Therefore, the extent of future production will largely be limited by other factors, such as price competition with other available stored energies (e.g., hydrogen or electricity). These conclusions are supported by an estimate recently made for the U.S. Dept. of Energy which projects that almost 42 billion gallons of ethanol derived from lignocellulosics alone could be achieved by the year 2000, plus another 12 billion gallons from sugar and starch.[19]

The potential for liquid fuel independence based on biomass resources extends even to countries such as the Federal Republic of Germany, despite the high population density and the lack of surplus land. A recent study concluded that a developed agriculture/forestry/fuel system, utilizing primarily wastes from current underproduction, might produce enough liquid fuel to cover the long run demands of the whole transport sector.[41]

An argument against biomass-derived fuels development has recently been made, suggesting that ethanol from biomass will result in direct competition with food production, further depriving the world's poor of adequate nutrition.[42] This possibility is highly speculative, and does not take into account the alternative effect that depletion of petroleum reserves will have on food production, nor does it analyze the root causes of malnutrition.

Countries such as India have had their agricultural output directly influenced by rising costs of petroleum and fertilizer. Our analysis shows that no competition between lands for food and fuel is necessary in the U.S. The production and price of food could well be positively affected by the availability of biomass-derived fuels, in opposition to the effects of rising petroleum-derived fuel costs in the present situation. Thus, to what extent food and fuel production will be related is unpredictable.

Malnutrition today is not the result of insufficient world food production capacity, but ultimately of inequitable distribution of purchasing power. The problem is a moral one. Its solution is partly economic, but more so related to the evolving consciousness of our relationship to one another on a planetary basis. Thus, it is more likely that social injustice, and man's willingness to remedy it, will have far greater influence on hunger than the development of an agriculturally based fuel industry.

New concepts for biomass production using short rotation intensive silviculture could actually enhance food production. For example, our own work involves the use of wood chips from *populus* species, such as aspen, for ethanol production. The leaves and short stems ("slashings") from these trees have recently been shown to be superb cattle feed of high nutritional value, with protein concentrations of 24 percent or more. Consequently, growth of these on a large scale will provide both fuel and feed, thereby releasing crop land presently cultivated for animal feed production.

Indeed, if we do not rapidly develop alternatives to present and proposed fossil fuel energy sources, the environmental consequences that will result may overshadow the moral problems of food distribution. Problems of CO_2-induced climatic changes and uncontrolled acid rain destruction of cropland and water resources may prove far more intractable to short-term solution and thus, in the long run, far more detrimental to the global fulfillment of human needs.[43] Rather, an energy policy which employs a strategy of energy frugality and conservation based on utilization of benign, renewable, "soft technologies" seems to offer the greatest hope for the future.[44]

TABLE I.—*Breakdown of U.S. land area use in the contiguous 48 States for 1970*

Continental United States:	*Acres*$\times 10^{6}$ [a]
Commercial forest	[b] 500
Noncommercial forest	100–250
Harvested cropland	[c] 330
Idle cropland (1974)	[d] 50–150
Pasture and range	550–715
Urban	60
Other (swamp, sand dune, desert, bare rock, national and State preserves)	135
Total	1, 900
Total, world land area	32, 800

[a] Definition of certain land areas is not firm, resulting in overlap of estimates. Minima and maxima are given.

[b] Public or national forest constitutes 25 percent, private ownership is about 58 percent, and industrial holdings 17 percent.

[c] Reference [6].

[d] Stephens and Heichel [11] give total cropland as 427,000,000 to 472,000,000 acres.

TABLE II.—POTENTIAL BIOMASS FEEDSTOCKS FOR ETHANOL PRODUCTION BY THE YEAR 2000

Source	Amount	Ethanol fuel: Gallons$\times 10^{9}$ (192° PR)
Starch or sugar:		
1. Corn starch		4. 8–16. 2
(a) Cattle feed	1.7×10^{9} bu*	
(b) All production, less 8 percent	5.8×10^{9} bu*	
2. Sugarcane, sweet sorghum, sugar beets	20–50×10^{6} acres†	>10. 0
3. Set aside, idle or marginal land	60×10^{6}‡	**8. 7
4. Surplus, distressed grain, and/or local production		>1. 0
5. Other: (a) Change in dietary habits (more grain, less meat)	100×10^{6} acres (?)††	(?)
Cellulose:		
6. Agricultural waste (extrapolating present sources)	178×10^{6} tons	16. 3
7. Forestry waste	1. 6 quads (1977)	16. 3
8. Municipal solid waste	90×10^{6} tons	>4. 1
9. Bagasse (from 2)	120×10^{6} tons	**5. 2
10. Trees (633 gal/acre-year): ‡‡		
(a) Silviculture (DOE, year 2000)	31×10^{6} acres	**19. 6
(b) Remaining commercial forest:		
Large tracts	70×10^{6} acres	**44. 3
Small private acreage	200×10^{6} acres	(?)
11. Agricultural waste from 5(a)	725×10^{6} tons	(?)

*Yields for 1976.

† Proposed new acreage.

‡ Estimated presently available.

**Net yield. Direct liquid fuel requirements in agricultural production have been deducted.

†† Extrapolation of present trends to year 2020. [21]

‡‡ Yield of 10 DOT/acre.

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Part II. ENERGY REQUIREMENTS, WITH EMPHASIS ON LIGNOCELLULOSIC CONVERSION

INTRODUCTION

The point is often raised whether the energy inputs in the production of ethanol from biomass are excessive, essentially negating any benefit for our energy economy to be derived from its use as an alternative fuel. The question, "Is a net positive energy produced?," requires more than simply a yes or no answer. Rather, a disaggregated energy analysis involving fuel quality and end-fuel use for the overall process is necessary. This approach has generally been neglected. Fuel quality is an important non-quantitative factor. Liquid fuel, like electricity, is of "high quality," and generally is not to be compared in value on a Btu basis with "low quality" fuels such as sugar cane waste (bagasse), even though both can be used to produce steam. In the steps for producing ethanol from biomass, liquid fuel is not readily substituted in most farming operations involving vehicles, but energy for distillation can be obtained, for example, from agricultural residues, wood, coal, solar and geothermal sources, or even waste heat from power plants. Therefore, in addition to "process efficiency," which is the ratio of energy produced to energy required, it is also important to consider the *ratio of liquid fuel produced to the liquid fuel necessarily used in the process*. To aid in evaluating this input-output liquid fuel ratio, we have made an estimate based on published reports of the relative motor-fuel value of ethanol as compared to gasoline and diesel. Other aspects of ethanol fuel application and demand have been examined in the preceding paper.[1]

The energy balance for alcohol production involves the agricultural energy inputs (growth, harvest, and transport of the feedstock) and the processing energy inputs (pretreatment, hydrolysis, fermentation, distillation and co-product preparation) compared with the end-use energy substitution value of the products. Detailed analyses of energy usage have been made for some crops and processes. However, a comparative study prepared by the Mitre Corporation for DOE assessing the economics of ethanol production concluded that, among the studies reviewed using the same feedstock, process efficiencies showed wide variations.[2] Moreover, the more realistic criteria outlined above for energy balance evaluation were not used.

The largest potential resources are in lignocellulosic production and conversion. However, less data are available, since commercialization has not yet been achieved (at least in the case of enzymatic conversion processes) nor has silviculture been implemented on a large scale. We have emphasized lignocellulosic conversion in this paper because of its great potential, and have attempted to make energy estimates from the data available, given in comparison with data for starch and sugar conversion to ethanol.

FUEL VALUE COMPARISON OF ETHANOL AND GASOLINE

Comparisons of ethanol and gasoline are often made simply on the basis of heat of combustion, i.e., BTU content. While useful thermodynamically, such a comparison is also simplistic and not especially valid if we want to evaluate the potential of ethanol as fuel for internal combustion engines, a specialized end-use. Despite the greater complexity involved in establishing the latter basis of comparison, which includes engine efficiency theory and pragmatic engineering evaluations, we are nonetheless required to utilize this more difficult, controversial basis when our interest is engine fuel and not heat content. Only one recent study of biomass economics has recognized the necessity of this approach.[3] The authors did not, however, attempt to reconcile the many conflicting reports concerning the relative fuel efficiencies of gasohol and gasoline.

A number of studies, both practical and theoretical, have concluded that ethanol fuel, either used straight as 192° PR (96 percent) in a properly designed engine, or as a 10 percent blend with gasoline ("gasohol"), can achieve or better 1:1 volume equality with gasoline.[4–10] A 1:1 volume equality has been assumed in our analysis. As more precise ratios become available, calculations made concerning ethanol substitution for gasoline will require the appropriate correction factor.

Where necessary, replacement of diesel by ethanol fuel was calculated using BTU ratios, so that 1 gallon of diesel was set equal to 1.7 gallons of 192° PR ethanol. This estimate is considered to be quite conservative, since, in certain circumstances, much better ratios are possible. For example, a duel injection system for turbocharged diesel engines is commercially available, which uses a secondary tank with a 50/50 mixture of water and ethanol; in this system, 1 gallon of ethanol is able to displace 1.25 gallons of diesel, based on power equivalence of straight diesel vs. the mixture.[11]

SILVICULTURAL COSTS

The study by Pimentel *et al.*[12] for the production of corn, is often cited as a data source for energy inputs in agriculture. They selected corn as a model which typifies energy requirements in U.S. crop production, since it is intermediate in energy demand between the extremes of fruit production (high demand) and tame hay and small grain production (low demand).

Some of the difficulties in applying data from food crops to the energy input requirements for energy crops become evident. For example, fully half of the estimated total energy input went for chemical fertilizer production and application. Because of this, alternatives which affect considerable energy saving are possible. Pimentel *et al.* calculated that if manure were substituted, 38 percent of the total energy input could be saved (with no energy value attributed to the manure). Together with other measures, such as using machinery more efficiently and precisely scaled to the job for fuel conservation, a much higher output: input energy ratio could result. Thus, it can be seen that great variability is possible in overall energy output. This is further illustrated by comparison with the low agricultural energy consumption in Brazil.[13]

The direct liquid fuel use given by Pimentel *et al.* is 22 gal/acre·yr using chemical fertilizer or 32 gal/acre·yr using manure for corn, and 21 gal/acre·yr for barley or wheat. A recent Canadian study found a practical requirement of 32 gal/acre·yr for corn (using manure), and 21 gal/acre·yr for barley or wheat.[14] Heichel [15] has estimated the energy budget for producing a 100 bu/acre corn crop under conditions of conventional fertilization and tillage practices, and compared it to either minimum tillage or animal manure in lieu of conventional fertilization. The total cultural energy varied from $10{,}200\text{–}11{,}600 \times 10^3$ Btu/acre. Liquid fuel use for farm production and harvesting (including transport, drying and shelling) varied from 25 gal/acre for conventional practices to 53.5 gal/acre when manure was used.

Silviculture is a low demand operation. After initial soil preparation and planting, the first harvest does not occur for several years. Coppice growth from the stump and root system will then permit several further harvests without replanting. Harvesting can occur more or less on a continuous year-round basis, unlike the narrow seasonal requirements of annual species, so that idle machinery time and storage problems are reduced. No data base is yet established for silviculture, although some estimates are available.[16–18]

A major energy requirement in silviculture, especially in terms of liquid fuel, is the harvesting operation, during which the wood is chipped and delivered to a central location. Prototype mobile chippers have been developed and operated for this purpose. To produce one-inch long chips from greenwood, such a unit requires an average specific cutting energy of 261–441 HP sec/cu ft (184–310 BTU/cu ft), for mixed firs or post oak respectively.[19] Using the density of green hardwood whole-tree chips as 19–26 lb/cu ft, containing 33–53 percent moisture,[20] we can calculate that the energy requirement for chipping is in the range of 44×10^3–66×10^3 BTU/ODT. If this energy is derived from a diesel engine (35 percent efficiency), we will need 1–1.5 gallons of diesel fuel for chipping each oven-dry ton of wood.

Mobilization of this unit and two chip forwarders (transporters), assuming 0.5 and 1.0 gal diesel/ODT each, respectively, would bring the total fuel use for harvesting and on-site delivery (average round trip of 6 mi) to 3.5–4.0 gal diesel/ODT. An evaluation by Smith and Corcoran[18] of operating energy using more traditional, less efficient methods (felling→bunching→skidding, etc.) estimated a fuel requirement of 530×10^3 BTU/ODT, exclusive of off-site transportation. This is about 3.9 gallons of diesel fuel. Their fuel requirement just for chipping is 65.5×10^3 BTU/ODT, or about 0.5 gal of diesel. Thus, since our estimate for chipping of 1–1.5 gal diesel/ODT may be high, our calculations will be based on the lower estimated production requirement of 3.5 gal diesel/ODT.

This equipment was designed to harvest, chip and transport 20 green tons per acre and 1,500 acres per year, for a total biomass yield of 10,000–15,000 ODT/yr. The weight of the mobile chipper is 60,000 lb. The weight of two chip forwarders is estimated at 56,000 lbs, based on cost. The harvesting machinery is amortized over 5 years (working 1,5000 acres/yr). Repairs add another 6 percent of total machinery production. Thus the harvesting equipment requirement is about 17 lbs/acre·yr, or 637×10^3 BTU (1 lb machinery and repair$\equiv$ 3,979 BTU/yr[12]. Smith and Corcoran arrive at a comparable estimate of 572×10^3 BTU per 10 ODT for their system.

Standard farming equipment will also be necessary for routine operations of planting, cultivating, fertilizing, spraying, etc. However, some of these operations will normally be done at infrequent intervals (e.g., every 4–6 or more years). An energy value per acre of 25 percent of that for corn can be estimated and probably exceeds requirements, since harvesting energy is included in the calculations for corn and is evaluated separately here. This would add 11 lbs (420×10^3 BTU/ acre·yr) for machinery, for a total of 28 lbs/ acre·yr machinery input. This estimate of planting and cultivation energy coincides with that given by Smith and Corcoran (40×10^3 BTU/ODT).

Labor for harvesting is 6.5 man hours/acre·yr For the other operations it is taken as 2.2 hrs/acre·yr (25 percent of corn requirements). for a total of 8.7 hrs/acre·yr. This figure is not exceeded by other estimates, [17] and represents less than 1 percent of total energy input (a man hour labor$\equiv$2160 BTU[12]). See Table I.

Some fertilizer will come from processing residues.[21] However, it is possible that the nutrient requirements needed to maintain the productivity of short rotation tree farms will exceed the amount available from the residues. Other sources of nutrients have been proposed, such as manure, municipal sludges and sewage wastewater, or mixed plantings with nitrogen fixing species such as red alder.[16] Integration of silvicultural operation with algae ponds for fertilizer, to form a Photosynthetic Energy Factory, has also been proposed.[20] Such novel methods will be necessary to counter present trends of increasing reliance on chemical fertilizers, whose use may prove too costly for energy silviculture. For example, Smith and Corcoran [18] have placed chemical fertilizer requirements as high as 2.7 million BTU/ODT, which would greatly exceed the extraction energy costs of harvesting and shipping. Clearly, alternatives such as those suggested above must be employed to ensure economic advantage.

The energy required for applying to the land processing or other residues should be similar to that for manure, or 1.1 gallons of diesel per ton.[12] If we applied 5 tons/acre·yr (half the amount currently required in chemical fertilizer equivalents for corn production), this would require 5.5 gal diesel/acre·yr. Harvesting adds 35 gal diesel/acre·yr (at a yield of 10 ODT/acre·yr). Other operations would need 5.5 gal diesel/acre·yr, for a total requirement of 46 gal/acre·yr of diesel fuel. Converted to 192° PR ethanol fuel on a BTU basis, this would be a requirement of 77 gal EtOH/acre·yr, for production of 10 oven-dry tons of wood chips.

Other inputs would vary considerably, greatly affecting the final energy balance. Making a conservative evaluation, since our goal is to maximize energy productivity, we will add no additional chemical fertilizer. Seedlings, irrigation and insecticides/herbicides can be equated to that for corn (417×10^3 BTU/acre·yr),[12] as representative as a high estimate. Drying, electricity, and additional transportation (off-site) will not be considered necessary for the silvicultural operation, since it will be subsidiary to an on-site proceeding plant. Table I summarizes the various inputs for a typical operation.

It is seen that for silvicultural operations, the liquid fuel demand can amount to 80 percent of the total energy input. The estimated 77 gal/acre·yr of ethanol fuel required compares to a potential gross ethanol yield of 710 gal/acre·yr.[1] Total energy input was found to be approximately $7{,}685\times10^3$ BTU/acre·yr.

Processing

Processing requirements include substrate pretreatment and hydrolysis, enzyme production, fermentation and distillation, and co-product preparation. Pretreatment methods of woody substrates are in the R & D or pilot plant stage, so that energy expenditures must be estimated. The same holds true for enzyme production and cellulose hydrolysis. Energy inputs are well-known for the traditional fermentation/ distillation methods, but technological innovations promise to greatly reduce those requirements. Co-products evaluation adds an uncertain but substantial positive contribution to the overall energy flow.

The first step in processing—pretreatment—is energy intensive. Numerous pretreatment methods for lignocellulosics are undergoing study, including milling, steam explosion, alkali swelling, solvent delignification, and chemical solubilization of cellulose (e.g., acid hydrolysis).

Methods of steam explosion, and/or solvent delignification, [22] are promising for wood chips pretreatment. These methods enhance the recovery potential and value as a chemical feedstock of lignin. One process using steam explosion, being developed by General Electric Corporate Research and Development (GE/CRD) in Schnectady, N.Y., estimates direct costs for the energy of pretreatment at 3.37 cents/gal EtOH (steam+lab+utility).[23]. If we convert this cost into energy (taken as steam, the major input) using their conversion efficiencies (~49 gal 192° PR EtOH/ODT), the direct energy requirement for steam explosion per oven-dry ton of wood is about 600×10^3 BTU. Another steam explosion process, using higher temperatures and pressures for very short periods of time, has been developed by Iotech Corp.[24] The process as developed uses about 2000×10^3 BTU/ODT. However, this amount may be reduced by over 50 percent with increased efficiency and steam recycle.[25] Thus, we may estimate that the energy input for the method of steam explosion would be a maximum of 900×10^3 BTU/ODT. This value will be taken as representative of pretreatment energy requirements (Table III).

Another major energy intensive step has been ethanol recovery by distillation. About 61 lb of steam (57×10^3 BTU) is currently used industrially to produce one gallon of 190° PR ethanol ("spirits grade") from corn mash. However, this amount is significantly reduced in fuel-grade processes. One approach is to distill for fuel-grade ethanol (containing trace amounts of fusel oil and aldehydes) with a two column distillation system, instead of the usual five columns. Energy requirements then drop significantly. Vulcan Cincinnati, Inc., claims to have proprietary technology which will cut energy needs to 19 lb of steam per gallon of anhydrous ethanol from fermented mash.[26] In one process using continuous high-cell density production, vacuum flashpot and vacuum distillation, an energy requirement of 16.3×10^3 BTU per gallon of 95 percent ethanol is predicted.[27] Raphael Katzen Associates International, Inc., has now developed advanced distillation systems that require as little as 10–12 lb of steam/gal of hydrous (190° PR), or 15–18 lb/gal of anhydrous, ethanol, with a total processing energy requirement for corn to ethanol of 40×10^3 to 50×10^3 BTU/gal.[28]

In the distillation of ethanol from a 6–12 percent feed, most of the energy consumption occurs in distilling above 85 percent ethanol.[29] To lower energy requirements, the use of dehydrating agents or membranes to remove the remaining water after distillation to 80–90 percent may be feasible.

A novel suggestion is the use of starch or cellulose as a dehydrating agent.[29] Anhydrous alcohol could then be produced from a 12 percent alcohol feed with an energy requirement as low as 8.2×10^3 BTU/gal, or just one-tenth of the energy in the product.

Membranes are being studied for the same purpose. While still in the research stage, this technology demands attention because of the great potential for process energy reduction. For example, Gregor of Columbia University states that dewatering of fermentation stillage can be accomplished with membrane processes using less than 5 percent of the energy required by conventional evaporators.[30] He calculates that membrane technology could ultimately reduce overall process energy costs to less than one-fourth of their present value.

Other approaches to separation are also being explored.[31] These include consideration of new azeotrope formers, solvent extraction, and molecular sieves. An extraction process being developed for commercialization by Arthur D. Little, Inc., uses critical fluid characteristics of CO_2 to extract 190° PR ethanol from mash, with an energy requirement of 8×10^3 to 10×10^3 BTU/gal.[32]

It therefore is reasonable to conclude that either 192° PR or 200° PR ethanol can be distilled at a maximum energy cost of 18×10^3 BTU/gal with present innovative technology and for as little as 8.2×10³ BTU/gal, representing a process goal (Table III).

Alternatively, the use of 160–180° PR ethanol (80–90 percent) has been used to fuel tractors, [33] and may prove to be adequate for automotive use without further concentration. This would reduce distillation energy requirements. New engines designed for this purpose are claimed to operate even on 120° PR ethanol.[34]

Other process requirements include plant construction and machinery, labor, water and electricity, chemicals, and the energy of enzyme production, hydrolysis, fermentation, and by-product preparation. Process requirements from studies on alcohol production from molasses and corn [27, 35, 36] are shown in Table II, together with a recent study of cellulosic conversion.[37] These requirements will be considered in greater detail.

Cellulase enzyme production and/or recovery is an aspect of the process that is somewhat difficult to estimate. Chemically, the process is exactly analogous to amylase production for hydrolysis of starch. Enzyme is produced in a batch or continuous mode and introduced at a critical point to saccharify a pretreated and prepared glucose-polymer substrate. However, engineering design for the two processes differs considerably at this time, partly because of the lower specific activity, slower rate of hydrolysis, and lesser thermal stability of cellulases compared to presently available amylases, which have undergone extensive development over the last 30 years. Hence, significantly longer residence times and greatly increased amounts of enzyme are required for a cellulose hydrolysis process at present, which adversely affect process costs. For example, nutrient requirements for the Gulf process are prohibitively high (Table II). Research efforts to enhance the quality and quantity of cellulases has resulted in major improvements in specific cases. However, such efforts are relatively recent and at an early stage. It is expected that future work will greatly improve enzyme characteristics, hopefully to the point where enzyme-associated process costs for cellulose conversion will be comparable to that for starch conversion.

The evaluation is further complicated by the fact that no process is yet commercialized. Since several competing processes are in the research and development stage, variables will include not only the amount and activity of enzyme required, but also microorganism source (e.g., procaryotic or eucaryotic, anaerobic or aerobic, mesophilic or thermophilic), and enzyme recovery, if any.

One estimate by Wilke, *et al.*, [38] of enzyme production and recovery costs based on hydrolysis of corn stover by cellulase from *Trichoderma reesei* amounted to 39 percent of total production costs, exclusive of raw materials. In this process design, the steam requirement per gallon of ethanol for enzyme production was 9×10³ BTU, for hydrolysis, 16.3×10³ BTU, and for fermentation, 4.8×10³ BTU. However, they found it necessary to concentrate the sugar solution, requiring an additional 80.4×10³ BTU.

A recent detailed cost analysis has been made by Raphael Katzen Associates, [37] based on a pilot-scale operation developed by Gulf Science & Technology Company. The process involves the conversion, also by *T. reesei* enyzme, of a mixed cellulosic feedstock (composed typically of two-third municipal solid wastes and one-third pulp mill waste) containing 57 percent cellulose into 190°–200° PR ethanol at a yield of 75 gal/ODT.

Compared to a corn/alcohol plant, the Gulf process requires approximately 15 times as much electricity; fully 85 percent of the purchased electricity is for raw material preparation (3.7 kwh/gal EtOH). Also, although not specifically given, it can be estimated that an incredible 200-fold increase in nutrients and chemicals is needed, because of the demands during enzyme production (Table II). The result is that the Gulf process is also a single-cell protein factory, generating 534 tons per day of animal feed, in addition to 485 tons per day of ethanol. By using light ends, fusel oil, and biomass residue for steam and power cogeneration, the energy purchases are reduced to a low level, so that only about 0.055 gal of fuel oil (8×10^3 BTU) and 4.4 kwh of electricity per gal EtOH need be supplied from outside the plant. If we convert kwh directly into BTU, then a total of only 23×10^3 BTU/gal EtOH would be purchased for plant energy requirements.

These calculations illustrate a present point of contention in the energy balance question. The low values given for energy requirements can be deceptive if improperly presented (e.g., excluding energy requirements for nutrient production), and similarly, it can be misleading to emphasize the steam and power inputs to the basic process, which could easily be computed as amounting to 129×10^3 BTU/gal EtOH (using the commercial equivalent of 10×10^3 BTU of fuel oil per 1 kwh purchased electricity, and with no internal co-generation of power).

The total steam input for the process is 65×10^3 BTU/gal EtOH. Although the breakdown is still proprietary, it is believed that the steam requirement for enzyme production, hydrolysis, and fermentation does not exceed the Wilke *et al.* total of 30×10^3 BTU/gal EtOH. No sugar concentration is necessary in this process. We will use this figure as an upper limit requirement for these processing steps in Table III (3.d). The lower limit should approach the requirements of the amylase process, [36] not exceeding 12×10^3 BTU/gal EtOH, which we use as a lower limit estimate. We have estimated the chemical and electrical requirements in a range based on the requirements for corn processing as a minimum, [36] representing a process goal, and that given for the Gulf Process [37] as a current maximum (Table III).

The water requirement is a minor energy input, and is not evaluated in Table III.

An estimate of total purchased cost for plant facilities to produce 50 million gal EtOH/yr from cellulose waste is 98 million dollars (1979 value) excluding contingency.[37] If we assume that the cost of the chemical engineering processing equipment is about $2.50/lb for this size unit, then the total installation will weigh 39 million lbs. Assuming plant life of 29 years, the requirement becomes 0.055 lb of plant and equipment per gal EtOH produced, or about 3.5 lb/ODT of woody substrate. This converts to $\sim150\times10^3$ BTU/ODT for plant and equipment (Table III).

The economics of processing a lignin by-product steam are unknown. However, processes exist for solubilization of the lignin in a solvent such as butanol or ethanol. It seems that a membrane process could quite readily separate an ethanol-lignin solution.[25] Such a process would have a low energy requirement, as with other membrane processes. Lignin could also be separated by evaporation of the ethanol, a more energy-intensive process. If we had a 30 percent wt/wt solution of lignin in ethanol, the heat of vaporization to separate 1 lb of lignin would be about 905 BTU. If we increase this heat requirement by 50 percent for a practical estimate, then the lignin in 1 ODT of wood could be separated with approximately 490×10^3 BTU. We have used this estimate in Table III.

Co-Products

After removal of ethanol, two useable co-products are lignin and the fermentation mash containing the unhydrolyzed carbohydrate. An anaerobic digester processing this mash can be used to produce methane. From 1 ODT of wood, there would be left 280 lb of carbohydrate (as calculated previously), [1] which converts to about 1850 cubic feet of biogas at 50 percent efficiency.[a] This biogas has an energy value of ~600 BTU/cf or $1{,}100 \times 10^3$ BTU per ODT of wood processed (Table IV). About 740 cf of the biogas is CO_2, equivalent to 90 lb.

Lignin would amount to about 360 lb/ODT. Its commercial value is yet to be determined although numerous applications are possible.[39] It can be converted into benzene and phenol at up to 35 percent yield, with a residual fuel-oil (13 percent) and fuel-gas (29 percent).[40] It can be made into resins for plywood and wood-based structural materials.[25] It also has potential for the plastics industry. Its fuel value alone is significant. After pretreatment by steam explosion, lignin is readily removable and totally soluble in ethanol, and can constitute up to 40 percent by weight of the solution.[25] In such a condition, its direct (BTU) fuel value would exceed that of ethanol. The application of such a mixture for internal combustion engines has not as yet been evaluated. Such a use could greatly increase the amount of liquid fuel obtainable from biomass.

The most direct use of lignin is external combustion. Its direct energy value is high. For example, lignin from Douglas fir has a heat of combustion of 6371 cal/gm (11.5×10^3 BTU/lb).[41] Falkehag [39] gives a ΔHc for lignin of 12.7×10^3 BTU/lb.

If we use the lignin only for combustion, we have a fuel similar to powdered coal with an energy value of about 4300×10^3 BTU from 1 ODT of wood chips (Table IV).

We have not evaluated the utilizability of the extractives or residue fraction of wood. This extractive fraction, composed of resins, turpentine, and fatty substances, comprises about 8–9 percent of wood, and has a high energy content, "sometimes approaching 15,000 BTU/lb."[42] In certain cases, e.g., with Georgia pine, the extractive fraction will have marketable value.[43] Otherwise, as fuel, it will have a conservative heat value of $2{,}100 \times 10^3$ BTU/ODT.

A by-product often totally discarded in cost and energy estimates is CO_2. When included, its use for dry ice production is usually evaluated. Since it is the end-product of carbon catabolism or combustion, it has no absolute energy value. However, one potential application that needs greater attention is the use of clean CO_2 for the enrichment of air to grow crops in enclosed environments. The rate of photosynthetic fixation can be doubled when the concentration of CO_2 in

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[a] Based on theoretical gas production of 13.3 cf/lb volatile solids with $CH_4 : CO_2$ ratio of 60:49.

the air is increased from a normal 300 ppm to 1000 ppm. Increases of 50 to 100 percent in the dry weight of tomatoes, lettuce, fruit and trees is obtained in closed greenhouses with enriched air; with the use of plastic canopies in the field, yield increases of 50 percent for wheat, rice, barley, oats and cotton have been obtained.[44] The moist, warm, CO_2-rich vapor from fermentation process plants fed into adjacent greenhouses would allow year-round super-abundant production of valuable foodstuffs. In such a system, where normal CO_2-imposed growth limitations are reduced, the value of CO_2 becomes equal in cost or energy value to the added productivity. This economic value might be considered as a BTU input on a balance sheet. Moreover, the additional waste heat and moisture, otherwise unusable, will have the value of whatever is displaced in ordinary greenhouse heating and irrigating requirements. Such an application calls for a detailed analyses to determine the costs and energy balances. While we have not attempted to evaluate it here, such a process, if incorporated, will no doubt enhance significantly the overall energy balance for ethanol production. Therefore CO^2 will draw a question mark in our balance sheet, awaiting future accounting.

Finally, process residues will be considered as fertilizer and returned to the soil. Fertilizer costs in Table I were evaluated only as additional liquid fuel for application. An overall energy balance is shown in Table IV.

DISCUSSION

Within broad limits, optimized conversion processes for the production of ethanol fuel from lignocellulosic substrates will generate substantial quantities of energy co-products in the form of biogas, lignin, and extractives which may allow a facility to be totally process energy self-sufficient if necessary. Moreover, the liquid fuel input critical to the overall process represents only a fraction of the output, so that the output to input liquid fuel ratio achieved is over 9:1. The liquid fuel input is needed exclusively for the operation of agricultural equipment.

The often neglected by-products of CO_2 and low temperature heat may play a role in enhancing the overall process economics. Utilization of these products in a controlled atmosphere agricultural operation would significantly increase yields either of food crops or further biomass for fuel.

In the short term, a lignin by-product may find more lucrative uses as a chemical feedstock, rather than as a process fuel. In this case, larger amounts of process energy would be derived from alternative sources, either fossil or renewable. Coal and peat are the obvious low quality fossil fuels that could be used to generate high quality alcohol fuel. However, the negative consequences of environmental pollution associated with their use, if unresolved, should direct us to seek less injurious alternatives, such as solar or geothermal energy.

The total thermal energy for an ethanol producing facility could be derived from geothermal energy on an economically competitive basis with fossil fuels in certain parts of the country.[45]

Solar collectors have the potential to become a major source of process energy. A demonstration system is being developed under DOE sponsorship at the Lone Star Brewing Co. is San Antonio, Texas, to supply steam at 350° C, 125 psi.[46] The system is designed to supply

60 percent of the process load, based on 30×10^3 BTU/yr per sq ft of collector surface. The total system cost, including collector, storage, and installation costs, in mass produced large installations is expected to be $20 per sq ft of collector.[47]. Thus, if a plant such as that described by Emert *et al.*, [37] which required 23×10^3 BTU per gal additional process energy, used a solar collector system with a cogenerating unit (operating at 75 percent efficiency), then an area of 4.5 million sq ft (100 acres) and a 90 million dollar capital investment (exclusive of land) would be required. The acreage involved represents less than 0.2 percent of a silvicultural plantation supplying a 50 million gal/yr ethanol facility. The energy produced would displace 20 million gallons per year of fuel oil (or other fossil fuel equivalent).

Given the escalating cost of fossil fuel, an investment in solar equipment would appear to have a relatively short payback period, perhaps less than five years. Assuming a 20-year life, it would be an environmentally attractive, financially sound alternative to dependence on purchased energy, which is generally derived from fossil, or perhaps nuclear, fuel. The problems associated with those sources of increasingly unstable supply, rapidly rising costs, and environmental threat, would thus be effectively reduced or eliminated.

TABLE I.—ESTIMATED ENERGY INPUT FOR SILVICULTURE

[Per acre-year, with yield of 10 ODT of wood]

Requirement	Amount	Btu×10³
Labor	8.7 hr	19
Machinery (amortized)		1,049
Harvesting	17 lb	
Other	11 lb	
Liquid fuel		6,200
Diesel	46 gal	
Or ethanol	77 gal	
Seeds, irrigation, insecticides/herbicides		417
Total		+7,685

*Includes nonchemical fertilizer application.

† By comparison, Heichel [15] has estimated total cultural energy for corn in the range of $10{,}200\times10^3$ to $11{,}600\times10^3$ Btu/acre-year.

TABLE II.—ESTIMATED PROCESS REQUIREMENTS FOR PRODUCTION OF 1 GAL OF ETHANOL* BASED ON STUDIES FOR CORN (A), (B), MOLASSES (C), OR LIGNO-CELLULOSIC SUBSTRATE (D)

	Arnold & Kremer (A)	Katzen Associates (B)	Cysewski & Wilke (C)	Emert et al. (D)
Direct labor (man-hours)	0.04	0.006	0.001-0.006	0.007
Water (gallons)	59	8	31–47	
Medium supplements † (pounds)	0.015	0.015		‡3
Electricity (kilowatt-hours)	1	**1.3	0.20-0.41	††6.4 (4.4)
Heat (Btu×10³)	103	‡‡41	21–32	††65 (8)

(A) Reference [35]. 1948 3,000,000 gal/yr plant.

(B) Reference [36]. Modern, 50,000,000 gal/yr plant.

(C) Reference [27]. Range represents comparison of processing modes, from vacuum distillation-cell recycle (most efficient, least expensive) through batch (most expensive). The latter had an investment cost only ⅓ that of the former.

(D) Reference [37].

*Anhydrous, except C (190° PR).

†Primarily inorganic ammonium.

‡Wilke, et al., [38] estimate ~2.8 lb/gal.

**The electrical requirement includes that for processing, cooking, and saccharifying the grain (9 percent), for amylase production (20 percent), and for DDG recovery (17 percent).

††( ) indicate actual purchase requirements for electricity and for fuel oil.

‡‡21 percent for stillage drying.

TABLE III.—ESTIMATED ENERGY REQUIREMENTS FOR PROCESSING WOOD CHIPS, WITH A YIELD OF 71 GAL ETHANOL (192° PR) PER ODT

Input	Amount/ODT	Energy/ODT (Btu×10^3)	Energy/gal EtOH (Btu×10^3)
1. Plant and equipment	3.5 lb	150	2.1
2. Labor	0.6 hr	1.3	0.02
3. Process heat:			
(a) Pretreatment		900	12.7
(b) Distillation		580–1,280	8.2–18
(c) Lignin recovery		490	6.9
(d) Enzyme production, hydrolysis and fermentation.		790–1,980	11.1–27.9
4. Electricity	86–420 kWh*	†300–1,460	4.2–20.6
5. Medium supplements	2–213 lb‡	40–4,260	0.6–60
Total			45.8–148.2

*The lower limit is derived from the requirement given by Katzen Associates [36] for 1 gal ethanol from corn, and the upper limit from that given by Emert, et al.,[37] for processing 1 ODT of lignocellulosic substrate to ethanol.

†Represents direct conversion to Btu, assuming onsite cogeneration of electricity with steam reuse. This value could increase by a factor of 3 for purchased electricity from conventional coal-fired generating stations (33–35 percent efficient).

‡Estimated at 20×10^3 Btu/lb from Heichel.[15]

TABLE IV.—ESTIMATED OVERALL ENERGY REQUIREMENTS AND FUEL PRODUCTION BY SILVICULTURE OF FAST-GROWING SPECIES

[Per acre-year, with yield of 10 ODT of wood; estimates are rounded off]

Operation	Liquid fuel (as 192° PR EtOH (gallons)	Direct heat and power (Btu×10^3)	Other (Btu×10^3)
Silviculture (product: wood chips)	−77	0	−1,500.*
Processing	0	−(30,000 to 61,000)	−(1,900 to 441,100).†
Products:			
95 percent ethanol	+710		
Biogas		+11,000	
Lignin		+43,000	
CO_2 plus low temperature (70°C) heat			(?).
Net balance	+633	(−6,000) to (+25,000)‡	

* Machinery; labor; seeds, etc. From table I.

† Plant and equipment, labor, medium supplements. From table III. The lower limit is an optimization, equal to the amylase process requirements. The excessive upper limit is derived from the nutrient requirements of the Gulf process, in which an estimated 5,000 lb of animal feed (primarily single-cell protein) would also be generated for every 10 ODT of woody feedstock.

‡ The extractive fraction of wood is not included in this estimate. Its potential heat value is 21,000×10^3 Btu per 10 ODT. See text.

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THE CASE FOR SMALL SCALE ALCOHOL FUEL PRODUCTION

By Don Patterson*

INTRODUCTION

Recent reports have questioned the advisability of launching a new alcohol fuels industry to displace substantial amounts of imported oil by using agricultural products.[1] Many reasons, all of which will be analyzed in this paper, are given to support this "go-slow" approach. Yet each of the studies has shortcomings due to a failure to consider the full range of significant issues or use correct and current information and complete research. If the wisest policy guidance is provided, access to and utilization of the fullest and most complete data base is essential.

This paper will look at each of the findings concerning farm-based alcohol, as presented in the Gasohol Study Group report. Alternative findings are given in support of the argument that farm based alcohol fuels, especially when produced by small scale units, can actually make a major contribution toward reducing our reliance upon imported oil. Information supporting these alternative findings will be developed in a manner that clearly shows the shortcomings of the commonly held assumptions about alcohol fuels.

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.

Fair and full analysis of the *potential* net energy return possible from an efficiently managed national ethanol production program (even including the energy required to grow the feedstock grain and assuming some use of oil or natural gas for process heat) results in the conclusion that net energy yields higher than 0.5 are possible. Higher yields are sustainable if the utilization of some solar process heat is possible and if major reductions in oil and gas use in the production process can be achieved.[2]

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[1] Studies include: Lester Brown, *Food or Fuel: New Competition for the World's Cropland;* U.S. Department of Energy, *Report of the Alcohol Fuels Advisory Board;* and Office of Technology Assessment, *Energy from Biological Processes* (forthcoming).

[2] This finding is based on monitoring of farm-scale alcohol facilities now in production. The plant which has played the largest role in developing the heat exchange technologies to the highest present operating efficiency was built by Darrel, Gene and Bill Schroder in Campo, Colorado. For more information, see Dan Jantzen and Tom McKinnon, *Preliminary Energy Balance and Economics of a farm-Scale Ethanol Plant*, published by the Solar Energy Research Institute, 1617 Cole Boulevard, Golden, Colorado, 80401, publication No. SERI/RR-624-669, April 1980.

For this level of net energy benefit to be achieved, the ethanol must be produced by relatively small-scale plants[3] so that large energy costs related to the transportation of feedstock grain as well as the drying and transportation of the by-product distillery grain can be mostly eliminated. Realization of the achievable net energy benefits in alcohol production depends upon: (1) Utilization of feedstock resources which are grown close to the alcohol production facility (i.e., within a minimum radius in relation to the plant's production capacity); and (2) the close proximity of a sufficient quantity of livestock that will be fed the by-product distillery grain in wet form.

Utilization of distillery grain in wet form enables the saving of approximately one-third to two-fifths of the total production energy costs if conventional drying techniques are used. Since such a large amount of energy is needed to dry by-product distillery grain for storage, handling, easy transporting, and delayed feeding, economic feasibility of the ethanol industry should not be based on production functions which require the drying of their by-product grain, even though some dried distillery grains will be needed, perhaps particularly for export markets.

Better certainly that a portion of the by-product be dried for export than that the nation commit the error of exporting kernel grain for conversion to alcohol by others in foreign countries. However, production incentives provided by federal policy should concentrate on production techniques which are capable of achieving maximum net energy efficiencies. In general, this is not yet happening.

The profitability of large-scale plants (such as are presently producing most of the nation's fuel ethanol) depends upon the dollar value of the by-product stream undergirded by state and federal tax incentives. Important net energy benefits are not being achieved.

Long range future net energy considerations in alcohol production require that international energy policy concentrate on establishing healthy local agricultural economies worldwide. Once trade in agricultural commodities (including alcohol) is based upon true production costs, including particularly net energy cost, present policies which favor the growth of export and import dependencies in many nations will be undermined.

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[3] The term "small-scale" as used in this context will refer to plants ranging in size from 100,000 gallons of annual production to one million gallons of annual production. Current cost data suggests that production efficiencies using plants of current design will be greatest in the range from 250,000 gallons of annual production to one million gallons of annual production. For plants below 250,000 gallons of annual capacity to be labor efficient, labor reducing automation will have to be incorporated into the design at an increase in capital cost. Further, these automated systems will have to be wholly reliable, and at present no claims can be made that standards of reliability will be met. No operating plant yet incorporates the level of automation necessary. Semi-automated plants are expected to be in operation during the summer of 1980; better data on their performance can be provided after the operation of these plants has been monitored.

For net energy efficiencies to be achieved, it is also necessary that the plants, whatever their level of annual production, maintain fairly continuous operation so as not to lose the benefit of heat levels within the system while it is operating. One hundred thousand gallons of annual production corresponds with a plant of roughly 15 gallons/hour operating on a continuous basis. Similarly, a plant of one million gallons of annual production corresponds with a production level of approximately 150 gallons/hour.

Control automation may also open up the possibility of cost effective production below 100,000 gallons of annual yield; however, no working models are yet available to show what might be possible at this scale. At low yields, without automation, labor costs create heavy overhead burdens. However, some farmers will explain that they have been "working for nothing for years producing grain, so what difference does it make if they want to turn to making alcohol without receiving a wage for their labor?" Clearly, no one should be discouraged from developing plants at whatever scale of operation they think they can make work. However, the role of federal policy and indeed of this review should be to reinforce the scale of operation which can yield a return to labor as well as to capital and management which is, at least, roughly equivalant to what other non-agricultural industries would require. Health cannot be restored to the agricultural sector if farmers continue to be willing to work for low wages just because that is "the way they have always done it."

Comparative advantages of trade can be expected to change in the near future as the result of a growing energy cost component on the trade balance sheet. Therefore, policies should concentrate on: (1) optimizing regional trade opportunities, (2) reducing existing incentives stimulating international trade in kernel grain when such trade is at the expense of American farmers who are effectively being driven to bankruptcy producing grain for export at less than their cost of production,[4] and (3) underscoring the advisability of moving high-protein by-products into international grain markets whenever possible.

Over time, economic and other considerations can be expected to cause high-protein distillery by-products to be substituted for kernel grain in grain export trade. Under the most likely scenario, dictated by transportation economics, the usable grain carbohydrate will be utilized for alcohol production near the grain harvest location.[5] U.S. national interest should most logically promote policies which are in harmony with this economic direction.

One of the major shortcomings to be noted in many reports lie in the tacit and quite American assumption that large-scale production functions are more efficient than small-scale. Because economies of scale are realized at high levels of plant production in some industries, Americans tend to assume that economies of scale will be realizable at similar levels of plant capacity in other industries regardless of differing cost factors. In ethanol production, net energy economies can be maximized in plants producing less than one million gallons per year and probably at present in plants producing as little as 250,000 gallons per year.[6]

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[4] U.S. grain export policy has been defended on the basis of the apparent belief by policy makers that price increases in the international market would result in loss of sales to other suppliers. This view is doggedly maintained by U.S. officials in spite of analysis showing that the United States, as the largest supplier of export grain, effectively sets a ceiling on world market price. Officials of other grain exporting countries have said that they would like to see the United States lift the price ceiling so that they can achieve higher prices for their grain exports as well.

Maintenance of low export prices is justified by the United States on the basis that low prices are needed to retain foreign market share which is necessary, so the logic argues, in order to maintain, on a continuing basis, export income which can help offset the national balance of payments deficit.

In contrast to this official logic is USDA-sponsored econometric analysis which reveals that increased export grain prices would result in a smaller volume of exports but a larger dollar return to help offset balance of payments deficits. This analysis shows that U.S. grain faces an inelastic demand curve in the international market (at least in the short run). (In this case, the short run might be 2 to 3 years and the long run would be anything longer than that.) And that the projected consequences of raising export grain prices would not be suffered. The shortcoming of the USDA econometric analysis and indeed of any econometric analysis based on market models lies in its inability to clearly predict the long range effects of policy changes.

[5] Over the longer term, the need to utilize land resources for the cultivation of biomass as an energy resource can be expected to displace land used now for pasture. Ultimately, both policy makers and markets may come to realize that meat production, particularly cattle production, is an inefficient way to produce protein for human consumption. No doubt, the protein value of distillery by-product grains enhanced with yeast products will be recognized as a superior source of protein for human nutrition, not requiring further processing through animals. Nutritional analysis points to the superiority of yeast food in comparison to other protein sources. Whatever final determination is made on this point by either nutritionists, market price changes, or consumer tastes, existing research also reveals that aqua-culture fish farming can be greatly more efficient in the production of tissue protein than can current animal agricultural systems. Although research work remains to be done, fish farming through using alcohol production by-products shows promising indications of economic efficiency.

In relation to the emergence of such patterns of agriculture in the future, recent studies showing the climatological implications of removing tropical rain forests to make way for cattle pasture in equatorial areas of the world has raised major international concern. The importance of biomass growth in relation to ecosystem maintenance, the protection of habitat, the production of oxygen, the maintenance of valuable weather patterns, and protection against encroachment of desert must season patterns of agricultural development.

[6] Net energy economies of scale are more pressing in reference to ethanol production than dollar economies of scale, and both need to be analyzed differently. Because of the dollar value of the by-product stream in wet milling, dollar economies of scale are reached in larger plants more than are industry-wide net energy economies of scale. The average cost curve reflecting dollar costs for the total industry is a compound curve with two minimum cost points, one relating to farm and rural scale production functions and the other relating to large-scale production functions designed to maximize the dollar value of the by-product stream. Both technologies are equally sensitive to increased transportation costs and therefore, the total industry's average cost curve rises steadily from its lowest cost point in response to feedstock transportation and by-product shipment costs. In contrast to the average cost curve reflecting *dollar* costs within the total industry the average cost curve reflecting *net energy* costs for the total industry is a simple curve with one minimum cost point, and this curve is similar in shape to the average cost curve for small-scale (less than one million gallons annual capacity) production functions.

The USDA Energy Office has released an analysis showing maximum economy of scale at thirty gallons per hour continuous production. Among other aspects, the curve depends upon the production system in use. Obviously, correct plotting of the curve depends upon correctly estimating a number of parameters and co-efficients relating to the the chosen technology. Reduction of labor costs through automation can be expected to change the shape of the curve.

From the standpoint of quick development of production capacity, the characteristics of the cost curve that result from USDA analysis, if the curve is even close to correct, are greatly to the nation's benefit. A large number of small-scale plants can be built much faster than can a smaller number of large plants. Fortunately, dependency on foreign oil imports can be reduced much faster using plants that are also maximally efficient; thus speed of construction and efficiency of production in the plants that can be built the fastest are harmonized to our benefit.

In relation to this analysis, one caveat needs clarification. From the standpoint of *dollar* cost/benefits as opposed to *net energy* cost/benefits, large-scale plants are more closely competitive with smaller plants because of the dollar value of the multiple by-product stream which, at present, large plants are better suited to produce.

Net energy considerations, taken alone, clearly favor smaller plants. The characteristics of comparative advantage between large and small plants can be expected to change as both strengthen their patterns of by-product utilization. One fruitful direction for large plants might be plant construction in conjunction with giant feedlots with provisions for handling large quantities of distillery grain in wet form. It would be interesting to learn if such a system could be competitive.

Smaller plants will undoubtedly be developing enhanced capability for more full utilization of a more diversified by-product stream while larger plants may have developed in this direction as far as they are capable. One problem now being worked on involves the economical utilization of presently unrecovered nutrient in excess plant waste water. In some farm-scale plants, as the by-product mash is squeezed to reduce excess moisture levels, the water which results is allowed to run down the drain or into a holding pond. The value of the nutrient in the waste water needs to be fully recognized and utilized. Unless care is taken, some of the best protein in the total by-product can be wasted.

Other possible areas of development are plentiful. Among them is the potential use of by-product carbon dioxide in conjunction with greenhouse agriculture and the use of by-product grains for aquaculture feedings of fish and other seafood as a means of gaining increased efficiency in the production of tissue protein. These developments arise from the greatly superior efficiency of fish farming over beef feeding as a means of producing protein food.

More beneficial uses for all by-product components as well as alternatives to livestock feeding are being developed as is the technology for economical anhydrous alcohol production in smallscale plants.

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 percent 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 percent of U.S. gasoline consumption.

This conclusion ignores the production capacity which could be developed if substantial national commitment were made to the construction of relatively small and rural community plants. It is not unreasonable to suggest that 800 one million gal/yr. plants or the equivalent of various sizes could be built within two or three years if the full commitment of resources, including credit availability and technical assistance were made available to the purpose. Plants of this size can now be built and put into operation in four months or less.

If the nation waits to achieve the same total production goals through large-scale facilities, lead times increase enormously. Present national economic peril based on oil import dependency cannot wait for large-scale production capacity to arrive on line. We must solve the immediate problem much sooner.

The net energy benefits achievable from small scale plants can even permit the toleration of petroleum or natural gas for process heat, although that option should be discouraged wherever possible. Use of lower grade fuels and solar process heat should be emphasized. While experience with solar process heat in alcohol production is still lacking, the feasibility of modest solar heat boosting is suggested as long as financing at lower interest rates can be made available.

3a. 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.

Most existing large-scale ethanol plants are not energy-efficient for several reasons: (1) They are too large to take advantage of transportation efficiencies in the provision of feedstock resources, (2) efficient management, transportation and feeding of by-product distillery grain is not possible, (3) the plant designs were developed for industrial and drinking alcohol at a time when net energy considerations were unimportant; process inefficiencies that were lost in the original plant designs cannot be cost effectively recaptured now through retrofit, and (4) large-scale plants depend upon the dollar value of the by-product stream (augmented through tax incentives) and not net energy benefits as the basis for defending their profitability.

As often happens, oligopolistic marketing strength or monopolistic market domination has been confused with production efficiency. If we are to establish sound long-term policy with respect to all energy systems, full analysis of true production efficiencies from the standpoint of total energy consumption must be accomplished and integrated into policy. As has been said, most fuel alcohol is currently being produced in plants that have been converted from industrial or beverage alcohol production and cannot easily adapt the necessary process heat recovery systems which will improve their net energy performance. New plants, both large and small, will be designed to achieve better net energy performance; but the larger plants still cannot overcome the high cost of transportation and by-product drying so that even when their net energy efficiencies are optimized, they cannot be as efficient as plants designed to be optimally integrated with feedstock production, livestock feeding, and perhaps also methane utilization in the immediate vicinity of the alcohol plant.[7]

Even though substantial process design achievements have been made already, additional improvements will be evolving at the margin. These can be expected to continue to improve the net energy balance sheet for optimally sized production facilities.

3*b*. 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.

This finding appears to arise from an understanding that substantial testing and review of the mileage performance of gasohol has not yet been accomplished. In fact, the results of numerous studies are available,[8] and reportedly, the Atlantic-Richfield Petroleum Company has been using ethanol as an octane booster in its gasoline for years without even informing the public of the practice. The achievement of mileage improvements depends on engine characteristics and tuning. In order to achieve full octane benefits engines must be tuned for the higher octane fuel.[9] While gasohol can be burned without any engine or carburetion modification, optimization of fuel efficiencies do require modest carburetion and timing adjustments (because of the higher octane of the gasohol available in the U.S. market).

In engines of the current design, further research is not needed to clearly establish these facts. However, greater research into the refinement of internal combustion engines to optimize alcohol combustion efficiencies could be helpful. On the other hand, the results of much existing research and development which has been done in this country and abroad has yet to be implemented or brought to the state where

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[7] The Mason-Dixon farm near Gettysburg, Pa., is an excellent demonstration of the interface between methane production and alcohol production at the farm scale of operation. The farm is presently generating 75 percent of its electric energy from a methane-fired generator. The methane, of course, comes from manure collected from the dairy barns. The waste heat off the generator will soon be mixed with corn grown on the farm to produce pure alcohol. The economics of such an integrated system, one which allows the farm to be virtually energy self-sufficient, are much better than if a digester or alcohol still was in operation by itself.

[8] For road and mileage tests of gasohol, see: Dr. William Scheller, *The Nebraska 2-million Mile Test*, Department of Chemical Engineering, University of Nebraska, Lincoln, Nebraska, 68688;

The Analysis of Gasohol Fleet Data, Technical Support Branch, Mobile Source Enforcement Division, Office of Mobile Source and Noise Enforcement, United States Environmental Protection Agency *Environmental Planning and Assessment for Highway Vehicle Use of Alcohol Fuels*, Transportation Energy Systems Section, Energy and Environmental Systems Division, Argonne National Laboratory,

F. B. P. Pinto of Ford of Brazil, G. K. Chui, R. D. Anderson, and R. E. Baker of Ford Motor Company Engineering and Research Staff, Dearborn, Michigan, *Brazilian Vehicle Calibration for Ethanol Fuels*.

[9] Brazilian officials are reportedly amused by the U.S. practice of mixing alcohol with regular and high-test unleaded gasoline. From their point of view the total octane levels achieved from these combinations are too high. The Brazilians save on refinery costs by mixing their ethanol with gasoline of much lower octane (70 to 73 octane). Through the use of ethanol they bring the total octane level up to that of our regular gasoline. This practice would seem much more sensible both from the standpoint of net energy and from the standpoint of gasohol utilization in engines that are optimixed for fuel of regular or unleaded gasoline octane levels.

commercialization is possible. As is often the case, more follow-through on existing research is needed and less initiation of new research.[10]

Practically speaking, no major innovations in combustion technology have been implemented in the United States during the last fifty years. U.S. manufacturers have even let foreign countries capture most of the initial comparative advantages from recent inprovements in vehicle design. Ethanol and gasohol should not be made to bear responsibility for a large failing in corporate and governmental research and developmental policy over this larger time span. Instead of wringing our hands and seeking scapegoats, we should recognize what should have been done years ago and start getting it done. A major commitment is needed so that valuable research developments can reach the point of market accessability.

To promote achievement of this objective, it may be valuable to identify some of the institutional barriers that have tended to impede progress. For example, a distressing tendency for industry funded research to concentrate on enhancing areas of established investment and avoid advancing ideas which threaten established markets can be cited. Even governmental research funds have tended too often to back up existing industry priorities rather than open up new frontiers which can be very promising in helping the nation to overcome its energy supply problems.

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

At the outset, this finding seems to contradict the established need to reduce net energy costs. Even though most major achievement of net energy savings can be accomplished with well-established, off-the-shelf technology, research directed at improving net energy benefits at the margin are well advised.

In general, this finding of the Gasohol Report arises from the fragmented way in which alcohol production systems are being analyzed. A conclusion such as the foregoing can be drawn only when dollar values are looked at outside of the context of an integrated review of the real values which underlie market prices. For example, distillery

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[10] Much work has been done in Brazil on the improvement of engine designs and the easy modification of existing engines for improved combustion of alcohol fuels. No doubt we can benefit from the research and development done in Brazil and in other countries as well. Additionally, a variety of as yet uncommercialized U.S. research and development can be pushed along so that it can become useful.

To provide a brief idea of what is known already about engine design for alcohol fuels, a quotation from Jack Freeman, Chairman of the American Petroleum Institute's Alcohol Fuels Task Force may be helpful:

"If you look only at combustion properties, the low molecular weight alcohols (methanol and ethanol) because of their wide flammability limits, high flame speeds, and low flame luminosity, unquestionably make superior fuels compared with petroleum derived hydrocarbons. At the same time, all of the nation's automobiles have been developed to burn petroleum fuels, and only new engines specifically designed for alcohol fuels could exploit these advantages. Generally, they are lost almost entirely in blends with gasoline."

This statement is quoted in the text of a speech delivered by Mart Marik, agricultural engineer with the Ontario (Canada) Ministry of Agriculture and Food, North Bay, Ontario. Marik spoke to the Ontario Cattleman's Association on February 21, 1980. His statements on alcohol burning engines continued:

"Alcohol engines are so similar to existing engines, that some engines can be modified to run on straight alcohol, giving the same mileage, convenience of starting, and overall performance as gasoline engines. The most advanced alcohol engines are high compression, fuel injected, spark ignition. Because alcohol burns with a cool flame, these engines will eventually be of the supercharged two stroke cycle.

"Primitive conversions retain the compression of the gasoline engine and thus use about 1.5 times more ethanol by volume, and have cold starting difficulty. Starting problems can be overcome and performance is superior to gasoline as a fuel. An improved primitive conversion uses high compression but retains the awkward cold starting features of a carburetor type of engine. Because cold starting is not a major problem in the climate of Brazil, and because the mechanics available to service the cars are relatively unsophisticated, this is the type of car now being manufactured by Volkswagen and by Fiat in Brazil to run on straight alcohol. These vehicles use about 1.2 times more ethanol by volume compared to similar gasoline powered cars.

"Because significant amounts of water can contribute to the mass of gases expelled, alcohol is a very efficient fuel for turbine type of engines. . . . Turbine powered vehicles are (therefore) a possibility."

by-product values may be distorted as the result of current market conditions. In general, the feed value of by-product distillery grain has been greater than its price. Therefore, direct utilization has resulted in better returns than are achievable if the by-product is sold. Assessment of value, therefore, must be made in relation to the ultimate product rather than in relation to an intermediate product which suffers from the absence of a sharply equilibrated market price.

When the economics are adjusted to properly reflect the true food and feed value of the by-product stream, the ethanol becomes actually itself the by-product of a process which improves the feedability, nutrition, digestability and utilization of corn and other grain products. Finally, the finding in question places too much emphasis on corn as the feedstock for alcohol production. Processes utilizing other feedstocks are developing rapidly. The promise for increased alcohol production from cellulosic waste may not be as far in the future as some have recently assumed.

5. 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.

Since the value of the by-product distillery grain is an integral product of the total operation, this finding would most appropriately be included as part of the preceding finding. Finding number 4 without the balancing contribution of finding number 5 gives a distorted impression of the economics of alcohol production. It makes it seem as if some producers might choose to exclude consideration of by-product values in their production decisions. No intelligent alcohol producer would make alcohol without considering the by-product as part of the process. Division into two separate findings makes it seem as if production input costs and plant by-product returns can be separated.

Ultimately, the alcohol by-product credit issue should be looked at not just in the context of other high protein supplements available as animal feed but in the total context of an overall policy which can give health and stability to the agricultural economy. Also considered should be the context of total international energy policy. Should not the merit of policy alternatives which are capable of reducing energy supply concentration, restoring competition, providing greater energy independence for citizens and nations and limiting dependency on major international corporate aggregates be reviewed for its own sake? The world has come to recognize enough insecurity about which nothing can be done; it certainly ought not seek to entrench additional insecurity from these sources if it does not have to.

Alcohol fuel provides a tool for protecting the stability and security of our food supply by making farms and rural areas energy self-sufficient. Additionally, farm alcohol permits the incorporation of valuable production economies into agricultural production processes so that the brutal inflationary trend in farm input costs can be offset. As cost pressures within agriculture can be relieved by the integration of these energy related production functions, the potential exists for actually relieving pressures for increased commodity prices. If farmers' costs decline because of new efficiencies in their total operation, then increases in commodity prices will not be so necessary for them to survive. Thus rising agricultural costs could mean less pressure for higher commodity prices if alcohol fuel and other energy related efficiencies are incorporated into the overall agricultural production picture.

Nevertheless, before holding out any hope for relative decline in commodity prices, the currently depressed state of American agriculture needs to be acknowledged. Profitability must be restored to agriculture and payment on the large and exponentially increasing agricultural debt must be made before prospects of relatively lower commodity prices should be held out.

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

From the standpoint of economists who favor free market allocation of resources and political philosophers who dream of Adam Smith's free enterprise economy, federal and state tax incentives stimulating alcohol fuel production may seem over-zealous. No doubt, the incentives arose out of a sense of over-dependence on a few suppliers of both foreign and domestic oil.

Artificial incentives favoring the construction of plants which are uneconomical in net energy terms, but which are made economical in dollar terms by virtue of tax incentives, were probably not intended by policy makers. Full understanding of the difference between net energy economies of scale and dollar economies of scale has probably not been achieved by most policy makers. However, with the nation facing a liquid fuel crisis of major magnitude, such failures are perhaps more to be tolerated than the failures of inaction that have frozen the decision-making process on energy issues for too many years.

Alcohol fuel production technology is the only means we have for producing additional liquid fuel in a hurry. Under this circumstance alone, policy makers can perhaps be forgiven for being a little more zealous in enacting incentives than some might prefer. Infant industry protections have been extended to virtually every other energy production technology in their time, including those that are now at the top of the energy industry. Incentives, grants in aid, government assumption of direct costs, liberal regulatory patterns, and other transfers of public benefit have been bestowed upon various energy industries that may ultimately have less longer term promise than alcohol and other biomass technologies. Biomass is, after all, renewable.

Infant industry protections have been widely used in many countries and in many fields to enable new and highly valued industries a chance to become established. Tax incentives are used to enable the establishment of a favorable market position with the understanding that marginally competitive environment will at the outset be insufficient to attract capital into the new industry.

If alcohol fuel tax incentives were sufficient by themselves to bring the most efficient production capacity on line without raising the possibility of other problems in some people's minds, fewer objections might be raised. The incentives would probably be more readily recognized as part of what government does to facilitate needed production.

The biggest problem, however, is one not mentioned in the recent gasohol reports: tax incentives alone are not sufficient to stimulate the construction of the alcohol plants which can give the nation the best net energy returns.

Since alcohol plants need to be built in conjunction with existing agricultural operations to be optimally efficient from a net energy standpoint, the current depressed state of the agricultural economy and the difficulty farm producers are having in forming capital under existing monetary policies is a matter of most pressing concern. No amount of tax incentive is capable of overcoming either the capital availability or the high interest rate problem; nor is any amount of capital availability a substitute for agricultural profitability. Farmers cannot borrow their way out of debt and they cannot help meet the nation's energy needs from the threshold of bankruptcy.

Ultimately, if the nation understood the importance of insuring the viability of the nation's most efficient food producers, not just because of the new role they can have in fuel production, but also because of their importance in restoring health to the American economic system, they would demand the restoration of fair agricultural income so that capital could be formed out of general agricultural profitability.

The national economy cannot be restored to health, nor can the ability to create capital be built, unless earned income can be generated in place of credit. Alcohol production can help farmers improve the efficiency and lower the cost of their agricultural operation, but it cannot get started when farmers have their backs against the wall just trying to survive. They cannot help solve the nation's energy problem in the most efficient way possible unless they can get themselves off of the daylight-to-dark farm production treadmill and out from under the brutal agricultural cost/price squeeze long enough to learn how to build and manage alcohol plants in conjunction with their total farm operations.

At best, alcohol production should be handled just like milk production: as a farm product which is picked up from the farm in a tank truck and sold in a local market. Accordingly, federal credit programs for alcohol plant construction give entirely the wrong emphasis. Instead of providing 90 percent of the funding for large-scale and ten percent for small scale, the emphasis should be precisely reversed. Like so many federal programs, the gasohol credit package provides funds for those economically strong operators who have the leverage in capital markets to help themselves without government aid and provides almost nothing for those who are in the weakest financial position at present, but who could do the most efficient job of alcohol production.

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

If ethanol from ethylene has been entering the gasohol market, it may be more the result of the market domination and price administration that results from oligopoly organization of the industry at present than it is the result of the present pattern of tax incentives. Tax incentives serve to reduce production costs, but the price observed in the ethanol industry today covers all calculable production costs and protects a considerable margin for profit as well. Therefore the non-competitive nature of the industry at present needs more to be addressed than the level of production incentives.

An even larger problem than that of ethanol from petroleum ethylene is the issue of imported ethanol entering the U.S. market in response to both incentives and oligopoly-administered prices.[11] The importation of alcohol in response to profit opportunities makes a mockery of international net energy considerations which ultimately should undergird all national and international ethanol production policy, indeed, all energy policy. As long as artificial and non-competitive conditions exist in the industry, U.S. interests would be well served through the imposition of import barriers. Tax incentives have been enacted, at taxpayers expense, to stimulate the growth of a domestic industry and reduce our dependency on imports. If these incentives are stimulating the importation of foreign ethanol, we are creating additional balance of payments pressure with a new fuel import and gaining no net improvement over the importation of petroleum. Indeed, depending upon price paid, our balance of payments deficits could be made worse through the importation of ethanol.

Ultimately, national and international energy import and export policy must favor ethanol production at a scale which is most efficient and eliminates long-distance transportation and other costs which not only introduce liabilities on the net energy balance sheet, but tend to bias other important economic considerations as well.

8a. 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.

This finding undermines its own conclusion. Clearly no finding can be sustained until the research which supports it has been accomplished. Current nuclear waste management problems press a similar case in point. An entire industry has been allowed to develop without having first done the research necessary to assure wise management of radioactive wastes. An industry has been allowed to launch itself without first producing answers to serious problems.

More importantly, the Gasohol Study Group's emphasis on large-scale ethanol production permits the awareness that any comparison between methanol and ethanol is based on worst case efficiencies for ethanol production. Since the Gasohol Study Group report itself does not address the most efficient scale of plant operation, any comparisons between ethanol production functions and other energy production systems would be unreliable. In addition, the externalities of both ethanol and methanol production functions must be researched thoroughly before valid comparative conclusions can be drawn. Health,

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[11] While Brazilian officials have stated that they are not developing their ethanol industry with exports even partly in mind, indications are that production has sometimes outrun storage capacity and utilization rates. Therefore, some Brazilian ethanol has been allowed to flow into the international market. This information has come out through conversations between Brazilian officians and U.S. visitors. See trip report, Energy Study Exchange, March 9–29, 1980. Trip leader, S. Mason Carbaugh, Virginia Commissioner of Agriculture and Consumer Services, Richmond, Virginia.

environmental and other external impacts of methanol utilization are at least potentially greater than are the impacts of ethanol utilization. Without going into a deep discussion of the technologies which might to be part of any methanol process and if the coal gasification technique is employed, a standard 250 million scf/day coal gasification plant cannabalizes 17,000 acre/feet of water per year. This water is permanently and forever removed from the natural cycle; it is not just borrowed for cooling as in a coal-fired electric generating facility.

8*b*. 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.

This finding would tend to make readers believe that no research in this area has yet been accomplished. In fact, a great deal of research on these issues has been done, and the importance of integrating ethanol production with food production in a way that improves the economics of agriculture as well as enhancing the quality of the food produced has clearly been established.

The finding hints obliquely at the so-called food/fuel conflict about which a great deal has been heard. Unfortunately most of it plays upon the fact that very few Americans, even those involved in scientific analysis of energy technologies, understand very much about the economics and the technology of agriculture. However, more will be said on this later. It is sufficient here to simply make some general observations.

Restoration of strength to the agricultural economy through provision of income opportunities for farms and rural communities can help provide a means not now available to help protect land productivity and environmental quality. The degradation of soil and topsoil loss that has resulted from poor agricultural management practices can be attributed in part to the lack of a secure price structure which allows farmers to project future income stability. In part also, the problem results from the continuing agricultural cost/price pressure which has caused farmers to cut conservation corners in the effort to protect their income levels.

While some farmers have exhibited bad management practices at the expense of wise soil conservation objectives, even when the income has been available to do otherwise, and while the responsibility for poor soil management practices is shared roughly equally among farmers of all types and sizes, farm tenancy arrangements do bear on the problem. As farmers have increasingly come to farm leased land and have been unable to own the land on which they farm (because of high land prices) there has been increasingly less incentive for farmers to take care of the land in the same way they would if they owned it. It is a fact that farmers will take better care of the owned land than they will of leased land, especially, if the lease is short term or subject to termination on short notice by the landowner. If farming enjoyed more profitability, farmers might still be able to own their farms and some of the soil management problem would be eliminated.

The addition of alcohol production to a well-managed farm operation can not only help improve the quality, feedability, palatability and digestability of grains utilizable in human and animal nutrition, but can also assist in providing the farm profitability resources which will enable land productivity and environmental quality to be better protected. Some people will always take advantage of resources to the detriment of long-term productivity and environmental quality, but this fact is not the most important economic fact to identify in relation to the establishment of public policy promoting or limiting ethanol production.

If ethanol production is concentrated in the hands of large operators using agricultural products, then farmers will continue to be, as they are now, at the end of an economic whip which over recent years has steadily driven them toward bankruptcy. Policy which helps to strengthen the family farm system and give farmers increased economic independence will do a great deal to improve the nation's economic and political durability during such critical passages as we are now enduring.

Policy which strengthens the continuing trend toward more concentrated ownership of the means of production and gives nonfarm sectors of the economy increased leverage in utilizing commodities that have been effectively taken away from farmers at cheaper than reasonable prices is not in the national interest. Ultimately, this nation will not be strengthened if yet another industry is allowed to grow wealthy through the utilization of cheap farm resources at the expense of American farmers.[12]

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[12] For more information on the impacts of ethanol production on agriculture, see also Donald Hertzmark Daryl Ray, and Gregory Parvin, *The Agricultural Sector Impacts of Making Ethanol from Grain*, published by the Solar Research Institute, 1617 Coal Boulevard, Golden, Colorado 80401, publication No. SERI/TR-352-554, March 1980.

This study is based in part on econometric analysis using the Agricultural Policy Simulator Model at Oklahoma State University. POLYSIM is an aggregate simultaneous equation model of the agricultural sector of the U.S. economy.

The authors explain:

"The driving force of the model is a supply and demand relationship for each of the crops included. This permits changes in the quantities and prices of the included crops to feed back on allocation of land and foreign sector demand. Government payments are also included in the model so that alternative types of subsidy programs can be considered. The major outputs of the model are farm income, crop prices, acreage of various crops, exports, total production, and retail meat prices."

Because of these characteristics of the model, the validity of the resulting simulation is hampered to the degree that commodity markets are incompletely responsive to supply and demand and in fact respond also to other factors such as the operations of large traders and the impact of unpredictable speculative activity on cash markets.

9. 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.

Certainly the utilization of cellulosic biomass for alcohol production has promise and clearly additional research and development work is necessary before production opportunities can be readily developed. However, progress is being made rapidly, and on the basis of work presently under way, it is unlikely that commercialization will have to wait until after 1985. Some preliminary and relatively small scale commercialization during 1981 is not unreasonable to anticipate.

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.

The phrasing of this finding suggests maximal conflict between food and fuel. Proper attention is not given to the nutritional role of distillery grain. Only the carbohydrate content of the grain is used for making alcohol; all the other nutrients remain in the grain by-product to be used as high-protein feed for as food for human consumption. Carbohydrate is the least difficult of food substances to replace from alternative sources. The balancing of the ration is not difficult to achieve and through the use of the grain by-products of alcohol production, food nutrition for animals and for people can be improved.

The accessability of the grain's basic food nutrition to digestion is improved as a result of the enzymatic treatment which releases the grain starches for alcohol production. In addition, the use of the grain as a fermentation medium allows yeast products to grow and thereby enhance both the vitamin and protein content of the grain by-product. Yeasts are among the most nutritional and best balanced sources of protein and B vitamins that are known. Such yeast foods have been used by natural food advocates for years; their beneficial qualities are well documented.[13]

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[13] The use of yeast in nutrition goes back to ancient Egyptian civilization. Reports of therapeutic use of yeast by Hippocrates are known.

Two heaping tablespoons (16 grams) of saccharomyces cerevisiae which is commonly sold as brewer's yeast by health food stores contain the following amounts of nutrients:

	Strength	MDR (percent)
Vitamin B complex factors:		
Vitamin B1	4 mg	400
Vitamin B2	4 mg	333
Vitamin B6	4 mg	(*)
Niacin	40 mg	400
Pantothenic acid	16 mg	(*)
Para-aminobenzoic acid	15 mg	(*)
Choline	60 mg	(*)
Inositol	60 mg	(*)
Vitamin B12	7.5 mcg	(*)
Biotin	55 mcg	(*)
Minerals:		
Calcium (carbonate)	240 mg	32
Phosphorus	190 mg	25
Iron	1.2 mg	12
Copper	0.37 mg	(*)
Magnesium (oxide)	150 mg	(*)
Potassium	320 mg	(*)
Zinc	0.9 mg	(*)
Manganese	0.1 mg	(*)
Sodium	30 mg	(*)
Amino acids:		
Isoleucine	456 mg	
Leucine	504 mg	
Lysine	584 mg	
Methionine	96 mg	
Phenylalanine	352 mg	
Threonine	384 mg	
Tryptophan	88 mg	
Valine	416 mg	
Alanine	440 mg	
Arginine	376 mg	
Aspartic acid	656 mg	
Cystine	72 mg	
Glutamic acid	1,224 mg	
Glycine	296 mg	
Histidine	120 mg	
Proline	320 mg	
Serine	312 mg	
Tyrosine	272 mg	

*This product is nutritionally identical to the yeast used in 95 percent of the alcohol production in the United States, according to a spokesman for Universal Foods, a major U.S. yeast manufacturer. It is nutritionally superior to high alcohol tolerant wine yeasts, but according to company tests will produce 13 percent alcohol beer equally as fast as wine yeasts which are also produced by the same manufacturer. Wine yeasts will produce a higher alcohol beer but it may take weeks to add two or three percentage points of alcohol content to the beer. Therefore, from the standpoint of the nutritional content of by-product distillery grain, the most highly nutritional yeast would be the best choice.

A natural food store flyer on yeasts quotes Dr. Holger Metz, a Ph.D. in biochemistry at the University of Marburg in Germany to the effect that the brewer's yeast cell is a wonder of nature, "it gives mankind one of the most complete, nutritious and valuable foods known." Dr. Metz is quoted to the effect that the yeast cell contains a "harmony of B vitamins working in unison in an undistorted state. The B vitamins thiamin, riboflavin, niacin, pantothenic acid, folic acid, PABA-choline, inositol, biotin, pyridoxine, B12, B15 (pangamic acid), B16, B17, orotic acid, and all the rest of the B vitamins known and unknown are metabolically available and easily usable by the human intestinal tract. One notices amazing results when taking this yeast over a period of time. Because these vitamins are in an undistorted state, and because they are tied up with all the essential amino acids and a great host of unessential amino acids, they aid in transporting vitamins and minerals to the cells. They nourish cell nuclei."

One point is important in relation to the feeding of yeasts. They must be dead in order for their nutritional benefits to be realized. Years ago, live yeasts were recommended as a food until studies showed that they survived the digestion process and actually extracted nutrients for their own growth during their passage through the digestion system. Instead of proving to be a nutritional benefit they were a net nutritional liability. In order that the yeast in distillery grain be killed, it must be subjected to temperatures of 80 degrees Centigrade for roughly ten minutes. In normal treatment through a stripper column, this requirement could be met. However, if a vacuum distillation were used, the requirement would not be met and therefore the nutritional serviceability of the wet distillery grain would be undermined. Animal studies on this question are needed inasmuch as live yeast may not survive as readily in animals as it does in humans.

The value of nutritional yeast in fish farming is even greater than it is for warmblooded animals, in that fish can handle a greater quantity of yeast that could fruitfully be fed into the fermentation batch and allowed to multiply during the fermentation process could be much greater than would be the case if livestock were being fed with the yeast. Under this logic, therefore, possibilities for faster fermentation can be explored in relation to fish farming.

As pressure increases on food production resources in the years ahead, more attention is expected to turn to the production of yeast for both human and animal consumption. While it is undeniable that the world possesses a finite land base for the production of biomass, whether that biomass is used for food or for fuel, it is also clear that for the next few years, at least, the world enjoys the opportunity "to have its cake and eat it too," to have both food and fuel and to have both better food and more efficient agriculture as a result of including fuel production in the equation.

Over the longer term, the question becomes one of providing proper management so that all needs are met as harmoniously as possible. In the long run, the world will have problems providing enough fuel from all available sources. The future need for careful management should not father present efforts to dampen or discredit any important alternative. Policy decisions must be made on their merits, and above all is the necessity for a steady hand in steering the course of policy. Ready arguments can be made that the use of other energy technologies pose even larger potential future problems than alcohol systems could if they are poorly managed.

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

Higher protein distillery grain is particularly well suited for beef and pork production. Alcohol plants built in conjunction with cattle feed lots and hog operations can increase the efficiency of meat production through the achievement of improved growth rates, improved ration balance and lower production cost. Milk production is similarly improved when distillery grain is incorporated in the diet. Studies have shown milk production increases when distillery grain is fed.[14]

It will take many years to build enough alcohol plants to utilize all the grain that could be fruitfully used for alcohol while at the same time improving the nation's livestock ration. It will be many years before necessary supplies of kernel grain could conceivably be threatened, but ultimately this is a management question. How long will the world feel it can afford the luxury of animal protein when it involves inefficient resource allocations in relation to high protein grains and aquatic species? It is easy to get cheap propaganda mileage by pointing to threats of reduced future beef supply, but responsible and objective researchers should be capable of reviewing the complexities of

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[14] See Information, Research Documentation, Research Bibliographies and Article Reprints available from The Distiller's Feed Research Council, 1435 Enquirer Bldg., Cincinnati, Ohio 45202, and The National Gasohol Commission, Suite 5, 521 South 14th Street, Lincoln, Nebraska 68508.

Both these agencies have been performing a library and distribution service for the alcohol fuel and distillery grain industries.

On the question of milk production, see the DFRC publication, *Make More Milk*.

Since findings against the beneficial value of distillery grain have been cited by members of the Gasohol Study Group, clarification of accurate findings is needed. Studies of the nutritional effect of distillery grain can be structured so as to fail to show beneficial results. If animals are fed nothing but distillery grain, production will fall. However, if the ration is properly mixed and balanced, production will rise. When production decreases occur, they happen in part because the salt levels in unmixed distillery grain are too high for palatability. For this reason, among others, the ration must be properly mixed and balanced.

New research directed toward reducing salt levels in distillery grain hold promise for future application. Processes involved also offer the possibility for improving the efficiency of alcohol production by reducing the amount of distillation which is required and by facilitating the removal of excess water from the by-product grain. (For more details on this research activity, see the work of Harry Gregor at Columbia University, New York City, New York.)

Apart from the possibilities opened by this vein of research, rations must be balanced to meet the needs of the particular livestock in question, with special attention to salt, oil, protein, nutrient and carbohydrate levels. When studies are based on a properly balanced total ration, the benefits of distillery grain have been clearly demonstrated. Studies conducted by researchers at the following places can be referred to for verification of results: Land o' Lakes Cooperative, Lincoln, Nebraska; University of Kentucky, University of Nebraska, and Iowa State University, Ames, Iowa.

the issues in greater analytic detail and with greater subtlety of perspective.

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

This finding unfortunately has a perhaps unintentional inflammatory quality and is not necessarily true at all. As with all agricultural production, everything depends upon how management is applied. Quite possibly the improved efficiency of agriculture resulting from on-farm alcohol production will give farmers additional income breathing space so that they do not have to squeeze increased production out of their land and take environmental risks in order to earn income in the short run. With the development of alcohol production on American farms, additional income can be made available to enable the improvement of farm management practices and the reduction of environmental pressures.

At present, federal farm policy is being managed to keep farm income depressed, in turn causing farmers to make up with volume what they are losing in margin. As income pressures have increased, farmers have too often implemented management practices which are less than ideal for the long-term care of the land resource.

Over the last twenty-five years, farm policy has been managed to maintain a continuing downward pressure on farm income, and as a result of this pressure, farms have gone out of business at the average rate of 2,000 per week. In 1952, the United States had roughly five million farms. Today, just over two million total farms are counted. Basically, federal government policy has said to farmers, "Get big or get out." To make up for declining margins of farm profitability, farmers have had to produce more volume, operate bigger equipment, and extend the hours of operation during the critical seasons so that greater volumes can be produced from ever increasing farm acreages. As this process has proceeded, the most aggressive farmers have come to take over or lease the ground of more and more of their neighbors. Many will admit now that they wish they had not gotten "suckered into" all the headaches of growing so large but that they felt forced to out of the need to survive economically and meet their payments. In many cases, land management risks have been taken to enable the expansion of gross income in pace with rising production costs.

The growing tendency has been for farmers to operate increasingly on leased land with farmers typically owning a smaller and smaller portion of the total acreage they farm. Under the pressure to produce higher volume to survive economically in the short run, less care has been taken to maintain the long-term productivity of the land. Additionally, farmers often have not taken the same precautions against soil erosion and other forms of soil degradation on leased land as they do on their own land. Often, especially if the lease is short term, farmers feel they cannot afford the cost of good management practices. The problem has been compounded by the termination of effective government cost-sharing conservation programs just when they are more needed than ever as a result of increasing farm income pressure. As the cost/price squeeze has continued over recent years, farmers have taken risks even with their own land in order to maintain cash flow.

Since 1974 when many young men from farm families borrowed heavily to try to get started in farming, there has been a relatively large group of high-cost farmers in agriculture. This group anticipated improved agricultural profitability as a result of the highly publicized analysis provided by then Secretary of Agriculture Earl Butz. As the Butz prognosis failed to materialize, these younger and highly leveraged farmers have been under particular pressure to make sure that yields provide enough income to cover costs. In the struggle to survive corners have been cut, but no mistake should be made; this is not the only group of farmers that is in trouble. Increasingly more and more farmers have taken various land management risks in recent years.

The economics of scale in agriculture allow farms to get only so big before they begin to get inefficient. The "stop" has been hit by working family farmers who are the most efficient producers of food.[15] The only farmers who can survive the present income pressures in agriculture are those who have non-farm cash flow against which to write off farm losses. This group can take better advantage of tax and investment credit breaks than can working family farmers who earn 100 percent of their income from farming. Also among the group that are better insulated from the existing pressures are foreign farmland buyers who can use benefits provided by tax treaty to out-compete American producers.

Ultimately, all these factors bear upon the larger economic and policy management difficulties in which the nation finds itself. Major national economic problems are arising from the instability and insecurity of the farm market and the steady farm income pressure maintained by federal commodity price policy. Agriculture is still a very large sector of the American economy. Even though relatively few people are directly employed in farming the fortunes of agriculture impact themselves deeply throughout the economy as a result both of the economic multiplier and the secondary impacts that result for the forty percent of the economy that is indirectly dependent upon the farm economy.

Alcohol fuel production and other biomass energy systems at best can become integral parts of wise farm management practice. These systems can help strengthen the position of the farm economy in the American system, helping farmers to gain improved income stability

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[15] Just as some Americans have tended to believe that larger plants must be more efficient for alcohol fuel production as well as for the production of other goods, so also have they tended to believe that larger corporately organized farms are more efficient in the production of food. Many times, also, the idea that "bigger is better" has been defended without consideration of the externalities associated with the particular production functions in question. In effect this has happened in agriculture. Through the availability of tax and investment credit programs which serve those with non-farm cash flow, the government has created a false incentive for production units to get larger than efficiency itself alone would dictate.

Working family farms operated by families that make the vast majority of their income from agriculture are America's most efficient food producers. They are also important to the health and stability of America's political, economic and social system, but unfortunately, as the result of the tax advantages and investment credits that are available to individuals and corporations with non-farm cash flow and diversified investment portfolios, non-farm investors can out-compete and gain increasingly strong position in American agriculture at the expense of family farm operators. In many cases, because these investors cannot farm as efficiently as family farmers, they simply buy land and lease it back to family farm operators. One of the anomalous aspects of the present situation is that profits can be earned leasing farmland today even though on average nationwide, farming itself is not profitable.

See Walter Goldschmidt, *As You Sow: Three Studies in the Social Consequences of Agribusiness*, Allenheld, Osmun, Montclair, New Jersey 1978 for more on the implications of concentrating control over farming.

For a short article on the importance of family farmers to efficient food production, see Jim Hightower, "The Case for the Family Farmer", *The Washington Monthly*, September 1973. Also of value is Hightower's book *Eat Your Heart Out*, Crown Publishers, New York, 1975.

A helpful USDA publication on the current trends in agriculture is Lyle P. Schertz and others, *Another Revolution in U.S. Farming?*, USDA, Washington 1979.

which will in turn enable them to manage their farm land with longer term objectives in mind.

Other countries in the world have found it necessary to manage their soil resources more intensively in order to maximize food production in the short term and take appropriate precautions so that long term food production is maintained. Just because this pattern of intensive management is not yet basic to the American farming system, policy makers should not allow themselves to be led into panic when faced with the need to manage agriculture with multiple objectives in mind. Is it not about time we came to consider land for the true value and importance it has, instead of treating it and the farmers who work it with the same throw-away spirit we treat so much else?

Instead of feeling threatened and projecting worst case scenarios which become self-fulfilling as a result of the policies they can father, the nation should examine the potential for positive benefits, seeking to understand how sound management policies can enable these benefits to be optimized.

In conclusion, it will be several years even at the fastest possible rate of plant construction before existing feedstock supplies are matched by alcohol fuel production capacity. During this time, technological refinements will be evolving and the techniques for making alcohol from cellulose will also be developing. While alcohol from grain can clearly continue into the distant future as one means of helping us address our fuel needs, perhaps the most valuable blessing it bestows lies in the assistance it offers in enabling us to restore health and self-sufficiency to farmers worldwide while at the same time strengthening the nutritive quality of grain foods. What should be perceived in this is the true reprieve it gives mankind from the Malthusian equation. The additional fuel we gain may ultimately be the least of it. Clear nutritional opportunities can be explored and developed through the use of distillery grain by-products. Enormous potential exists for changing the character of agriculture in positive and beneficial ways. Out of inability to perceive these potential benefits the nation should not fail to examine and explore the full horizon of possibilities. Most of this nation's corn crop presently is used for livestock feed. This is an enormous resource, and we simply must examine the best ways to achieve the best and most efficient nutrition from this total resource. The positive possibilities are very great. With proper management, the world can have food *and* fuel, and have better qualities of both.

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 contributions will probably be small, these small-scale units would offer a degree of family self-sufficiency.

This finding, of course, as can be seen from everything that has been said thus far, grossly underestimates the potential role of farm-scale and rural community or cooperative-scale (i.e., serving several farms) alcohol production in meeting U.S. liquid fuel needs. Wood-fired alcohol plants can play a significant role in the total picture, but perhaps the way to achieve maximum net energy production efficiency on the farm will be through the integration of alcohol and methane technologies. The waste heat from a methane-fired electric generating facility in turn can be used to fire the alcohol portion of the integrated operation.[16]

To stress again the main point which has been made throughout this response to the Gasohol Study Group's work, the only way that the United States will be able to efficiently and immediately reduce its dependency on foreign oil is by putting into production farm-scale alcohol plants in large numbers. Not only can net energy efficiencies be better achieved at this level of production, but ultimately dollar values can be optimized as well. The strength of the family farm in the American economic system can be defended, and total national production capacity can be enlarged much more rapidly than it can if larger scale alcohol plants are depended upon.

To the extent that alcohol and methane are integrated, farms can become net exporters of electricity as well as of liquid fuel. On-farm electricity needs can be met with the excess going into the grid, and all this can be achieved while also improving farm waste disposal practices, organic farm management practices, provision of bedding, field fertilization, manure handling, non-point source water pollution as well as livestock feeding programs.

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.

Variation in grain production in spite of weather problems is not nearly as great as it once was. With short-season varieties and equipment capable of seeding and harvesting vast areas in a short period of time, quick recovery from and flexible response to adverse conditions is more possible than has formerly been the case. Specifically, in corn areas, recovery from bad spring planting conditions has been seen repeatedly. Areas can be reseeded quite late and still produce bumper crops. Wider use of irrigation, though responsible for the creation of some new and previously unanticipated problems, at present permits many farmers to overcome the difficulties resulting from low rainfall.

Nevertheless, it is necessary to develop healthy farm economies worldwide in order that production can be assured in the future as food demands increase. The United States cannot expect to continue undermining foreign agricultural economies through the scale of underpriced grain exports and still expect to be part of a healthy and strong free world economy. We must start encouraging more food (and fuel) self-reliance in other countries. The United States cannot forever be the world's breadbasket any more than it can be the world's policeman or a rescue mission for the world's refugees.[17]

Variability in grain supply will have an impact on gasohol production only to the extent that alcohol production capacity approaches the limits of available supply. It will be many years before sufficient

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[16] See footnote 6.

[17] See Frances Moore Lappe, *Diet for a Small Planet*, Ballantine Books, New York City, 1971; Revised Edition 1975 for more full development of the issue of misappropriation of protein in the American diet and food production system.

alcohol production capacity exists to use all the grain available. In the meantime, recently increased on-farm grain storage capacity offers great flexibility with respect to both alcohol production and general grain supply stability. This increased storage capacity, together with alcohol opportunities and other new market possibilities, enables carryover stocks to be viewed more as inventories and less as surpluses.

Once available production capacity approaches the limits of available grain supply, alcohol production from cellulose will have started to take its place in the feedstock market. Utilization of cellulosic wastes could very well happen faster than has normally been projected. The necessary enzymes are now available; it is simply a matter of producing them at costs low enough to make the process economically feasible. The problem may be solved simply through the development of a market large enough to permit the achievement of economies of scale in enzyme production.

6. The pool of grain 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.

The use of distillery grain by-products of alcohol production for human food (as opposed to livestock feed) can fill a very important worldwide need. Carbohydrate is in relatively ample supply everywhere in the world, but good protein sources are not. The opportunity to make internationally available a good source of grain protein fortified with yeast products rich in amino acids and B vitamins can substantially benefit the effort to overcome malnutrition and worldwide hunger. Distillery grain products will make a very much more valuable way to feed the masses of mankind than will high starch cereal grains or relatively costly animal proteins. Not only will the digestability be improved but the nutritional balance for human consumption will be better, so much so that distillery by-product foods can be seen as enabling a giant step toward international food self-sufficiency quite apart from the potential for energy self-sufficiency that accompanies it. Ultimately, distillery grain could cease being used for animal nutrition altogether. All of the available supply could be switched to human consumption.[18]

Yet another alternative, mentioned earlier, would be to make use of distillery grains for fish inasmuch as fish culture is a much more efficient way to raise protein than is offered by beef, pork or poultry production.

As long as grain prices are so subject to management by large traders operating on both the cash and the future markets, the prospect of higher grain prices (driven up by growing grain demand) benefiting farmers may be substantially reduced. If such free market happenings were likely to occur, they would have been revealing themselves already. Under extreme conditions, no doubt increased demand will result in higher grain prices, but in recent years, considerable variation in the amount of available grain inventory has not brought any such effect.

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[18] See Frances Moore Lappe and Joseph Collins, *Food First: Beyond the Myth of Scarcity*, Houghton-Mifflin Co., Boston 1977 for discussion of the world's capacity to feed itself if existing abuses of land ownership and agricultural concentration are overcome.

The actions of grain traders continue to depress grain prices into a narrow band above the price floor established by government commodity loan rates. Increasingly also, while the market views carry-over stocks less as surpluses and more as security inventory, they continue to overhang the market nevertheless. Although the semantics have changed the effect is the same: grain prices received by farmers remain depressed.[19]

Even government purchases after the embargo on Russian grain sales had little impact on grain prices. This helps to show how little the market prices respond either to large purchases or changes in immediately available supply; although also a factor in the embargo related government purchases was the market psychology that this grain was not really going anywhere and could be called forth any time it was needed. The actual effect of the purchases was to bail out grain traders, freeing their cash position. Nothing was done for farmers who lost money on grain sales after markets were jotted downward by the embargo.[20]

One of the most serious issues that needs to be reviewed in relation to any finding about future grain demand and future prices on the international market involves the analysis of present U.S. grain exports on the economies particularly of Third World nations that do not protect themselves through the imposition of import quotas and tariffs. By exporting grain at less than the cost of production in order to help offset our own balance of payments' pressures, we have caused many countries to fall into a pattern of dependency on U.S. grain imports.

Unable to produce grain themselves as cheaply as they can buy it from the United States, this dependency has served to undermine the health of local agricultural economies in many nations. European countries and Japan have defended themselves against this occurrence by establishing high support prices to provide security for their own grain producers, but there are a large number of Third World nations that have not done similarly; as a result U.S. exports have served to undermine the health of their national economies by first undermining the rural economy.[21]

Just as the health and strength of our own national economy is dependent upon the health and strength of our agricultural system, so is this also true, and possibly even more so, in other countries. U.S. policies which have been shortsighted and have served to benefit a few grain exporting firms much more than they have benefited anyone else[22] have resulted in undermining the economic strength and stability of U.S. allies and especially Third World nations. It is as if we were operating our own Fifth column working to undermine ourselves.

Instead of building a strong free enterprise system in these countries, U.S. trade policy has been a major force undermining these very ideals

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[19] See Dan Morgan, *The Merchants of Grain*, Viking, New York City, 1979 for details about the operation of the major grain trading companies. This book is the first thorough treatment of the very secretive grain trading industry. The documentation is plentiful to show how the industry operates especially when one understands that it does not take a great deal of particular documentation to understand how grain markets work when the grain marketing industry is dominated by oligopoly and large traders are free to buy, sell and store commodities at will.

[20] See A. V. Krebs, "Of the Grain Trade, by the Grain Trade and for the Grain Trade", pp. 353-372, *Food For People Not for Profit*, edited by Catherine Lerza and Michael Jacobson, Ballantine, 1975 for more details on the way the USDA serves the graintrading industry at the expense of farm producers.

[21] A U.S. State Department official recently returned from Africa and described privately the impact of U.S. grain sales in Africa as dependency not unlike that seen in urban welfare projects in the United States.

[22] See again Morgan, *Merchants of Grain*, op. cit.

to which so much lip service is given. Short term expediency has gotten the United States into the problems it is now facing; if the situation is to be improved, policy planning and the understanding of policy implications will have to be improved.

Once policies that promote the growth of healthy worldwide agricultural economies have been established, supply and demand conditions in grain markets around the world will alter and the capacity to meet worldwide hunger needs as well as biomass fuel needs will improve. The world does not suffer from an insufficient capacity to meet its own food needs.[23] It suffers from policies which concentrate the control over food resources so that basic needs are made secondary to corporate controlled cash cropping; producers are enslaved to a production treadmill while profits accrue mostly only to a very small group.

To the extent that the finding of the Gasohol Study Group with respect to international grain demand and prices in the future is correct, it is correct because shortsighted policy choices by government and large business aggregates are able to manufacture an artificial reality within which the world gets turned upside down. Artificial imbalances are stimulated which tend to stimulate the growth of still larger imbalances, and natural forces which could help to re-establish equilibria are aborted.

Once the system is out of equilibrium, there is no wise and all-knowing hand operating in the process which can either bring it back into equilibrium again or bring it to a new point of equilibrium. Altogether too easily, the world can waltz off with Alice into Wonderland and return only when the entire fantasy crashes around its ankles.

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[23] See again Lappe, *Diet for a Small Planet*, op. cit., and Lappe and Collins, *Food First*, op. cit.

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