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FARM AND COMMUNITY SCALE
ETHANOL PRODUCTION

Task Force Meeting at IIASA on "New (Non-Traditional) Technologies for the Utilization of Agricultural By-Products and Waste Materials"

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FARM AND COMMUNITY SCALE ETHANOL PRODUCTION

Introduction

The objectives of this paper are to outline key issues in the production of ethanol at farm and community scales and to illustrate the paradigm used by the Michigan State University Agricultural Experiment Station and Cooperative Extension Service in approaching these questions. Inferences that can be extrapolated to larger scale production are discussed. The paper focuses on critical elements of biological and physical integration required to significantly improve the overall liquid fuel gain of the system and the economics of implementing such integrations.

Key Issues

The debate over the efficacy of ethyl alcohol (ethanol) production from feed grains has been extensive. On one hand, many argue that excessive feed grain supplies (or, capacity to produce feed grains) exists in North America and that these supplies should be used in the production of ethanol to reduce dependence upon imported oil. On the other hand, there are those who argue that ethanol production from feed grains results in no significant net gain in liquid fuel production and therefore cannot make a contribution to the problem. It's like planting a bushel of corn and obtaining a bushel in return.

MSU scientists began by asking, "If done properly, can ethanol production from feed grains result in significant *net* liquid fuel gain if the process is properly integrated and scaled?" Second, if net liquid fuel supplies can be enhanced, "Under what conditions is ethanol production for fuel economically viable?" Third, if production is economically viable, "What is the size of the market for ethanol and the by-product distiller's grains with soluables?"

"At what point, for example, will encroachment on the feed grain supply be sufficient to raise feed grain prices to the level where ethanol production is no longer economically viable?"

Unraveling the Issues

Energy Balance

Table 1 depicts the distribution of energy used in the production of corn including the energy embodied in the fertilizer, herbicides, and pesticides. Use of corn is assumed since it is the dominant feed grain in the United States

Table 1. Distribution of Energy Used in Corn Production[1]

Operation	Percent of Energy Used
Tillage	7.7
Fertilizer	53.2
Herbicide and Pesticide Use	3.0
Harvest	2.5
Drying	28.0
Transportation	5.6

[1]Sources: CAST (1977); DOE (1979); and USDA (1980). Percentages vary with soil management group, cultural practices, and management.

and the most widely discussed "near term" biomass candidate for ethanol production.

Table 2 depicts the energy balances for ethanol production on a "gasoline equivalent" basis, i.e., all energy flows are converted to the BTU's in a gallon of gasoline. If liquid fuels are used throughout in the production of corn, in the fermentation and distillation of ethanol, and in the drying of the by-product (distillers grains with soluables, DDGS) there could be up to a 0.3 gallons "gasoline equivalent" reduction in liquid fuel supply per gallon of ethanol produced, depending upon technology used [i.e. (.80 + .11 + .06) - (.40 + .90)]. However, if wood or coal are used in the ethanol production phase, as few as 0.3 gallons of "gasoline equivalent" per gallon ethanol is required [i.e., gasoline equivalent required for corn production].

Table 2. Energy Flows in the Production of One Gallon of Ethanol from Corn (Standardized to Gallons of Gasoline Equivalent)

Task and/or Product	Energy Required in the Production of Ethanol	Energy Supplied and/or Replaced in the Production of Ethanol
Energy Producing Tasks:		
Corn Production	.30 - .40	
Ethanol Production, including drying DDGS[1]	.35 - .90	
Energy Supply and/or Substitution Tasks:		
Ethanol (1 gallon)[2]		.80 - .90
By-Product Credit[3]		.11 - .12
Energy Saved in Refining by Octane Enhancement		.06

Sources: Adapted from Hawley and Grulke (1980) and DOE (1979).

[1]Vendors of new technology claim 0.35 - 0.40 is feasible with current energy recovery techniques. Liquid fuel use (gasoline, diesel, natural gas) is near zero for this phase if coal or wood is used.

[2]Assumes a 2 to 3% increase in thermal efficiency of combustion when ethanol is combined with gasoline at low percentages, e.g., 1 part ethanol, 9 parts gasoline.

[3]Energy released by producing distillers dried grains with soluables (DDGS) instead of growing and processing an equivalent "protein supplement" comprised of 52% soybean meal and 48% corn. The supplement has the same crude protein, 27% on an as-is basis, as DDGS (Cf. Black, Longabaugh, Jackson, Waller, and Weber, 1980).

If corn can be used in a high moisture form, 20 to 30% of the energy used in corn production can be eliminated. Further, if corn is grown in rotation with a legume or if interplanting with legumes can be achieved without sacrificing yield, an additional 20 to 30% of the energy required can be saved by reducing the nitrogen fertilizer input. If properly integrated, the transportation linkage to haul corn to the ethanol plant is eliminated if the ethanol plant is on the farm. If the ethanol can be used in the agricultural operations without being in anhydrous form, 20 to 30% of the energy used in distillation can be saved, and if the by-product can be fed on the farm the energy required for drying, which is 25 to 35% of the distillation and drying total, can be saved. Additionally, the transportation of the by-product from the ethanol plant to feed manufacturers and back to the farm can be eliminated. Under these conditions the potential energy gain in liquid fuels is as high as 7 gallons (gasoline equivalent) per gallon used in its production [i.e., (.90 + .12 + .06) ÷ (.30 x 112)]. That compares with a net gain of 3.5 in a well integrated, industrial scale plant [i.e., (.90 + .12 + .06) ÷ .30). Thus, potential liquid fuel gains do exist. The remaining questions are: "Is ethanol production from corn economic?" and "At what scale is it pracical to carry out the above elements of integration?" In principal the necessary elements of integration can be carried out at the farm and regional levels. But, "Can the small scale, higher gain systems compete economically with the lower gain, centralized systems?" There is a trade-off between energy and other resource costs, particularly capital and labor.

Size of Plant

There are substantial economies of size, particularly capital and equipment, in an ethanol plant. The investment per gallon in a community scale plant of 5 million gallons of ethanol per year is two to three times larger than of a 50 million gallon per year plant. Economies accure for labor and marketing also. Further, under certain conditions and volume levels the carbon dioxide that is produced during fermentation may become an economically viable by-product for manufacturing industries or greenhouses.

If the technologies required for improving net gains can be solved, "Will the resultant economic gain make the small scale plant potentially competitive with the large scale plant where economies of size prevail?" The answer to this question depends critically upon the energy gain of the plant in relationship to the cost of the energy required to operate the system. Since the real cost of conventional fuels will surely increase over time, the optimal design must be regarded as a moving target. The nature of trade-off of interest can be illustrated as follows.

The unit cost of the energy produced as a function of the gain, g, and the unit cost, X_f, of the energy used in the system can be easily shown to be

$$X_o = \frac{1}{g} X_f + X_c \, (E_o) \qquad (1)$$

where X_c (E_o) represents the non-energy costs of conversion per unit of output (e.g., labor, non-energy component of inputs and capital flows, interest). In general, the non-energy costs are a function of the design capacity, E_o, of the plant. They typically decrease with increased scale of operation.[1/]

The cost of energy used in the production system will differ from the cost of the energy produced by it; the difference

$$X_f = -(X_o + X_s) \qquad (2)$$

Equations (1) and (2) combine to give the cost, X_o, of a unit of the energy as a function of the gain, g, the price subsidy X_s and the pecuniary costs

[1/] A positive cost indicates expenditure and a negative cost indicates returns.

$x_c\ (E_o)$

$$X_o = \frac{1}{(1 - 1/g)} [X_c\ (E_o) - \frac{1}{g} X_s] \qquad (3)$$

The conditions under which conversion systems are ultimately competitive with the fossil fuels they complement occurs when $X_s = o$, i.e. when

$$X_o = \frac{1}{(1 - 1/g)} X_c\ (E_o) \qquad (4)$$

The coefficient

$$C = \frac{1}{(1 - 1/g)} = \frac{1}{m}$$

is appropriately called the coefficient of cost. It also is the inverse of the net energy gain $N = 1 - 1/g$ expressed as a fraction of the gross energy produced. It represents the factor by which the pecuniary costs (non-energy cost of conversion) must be multiplied to obtain the true cost of the energy produced. Stated another way, it represents the ultimate cost of energy relative to labor and other pecuniary costs for alternative systems in relationship to their respective energy gain coefficients g. As Equation (4) indicates, this coefficient is very high for low gain systems and approaches unity for high gain systems.

The relationship between cost of production, the scale of operation, the energy gain of the plant and the changing real costs of conventional fuels is illustrated in Figure 1 for three hypothetical, but representative situations. Note that a highly centralized plant (Case 1) having a gain of one may have neither the lowest operating cost nor can the product ever become competitive with conventional fuels it is intended to replace. The small scale highly integrated system having a gain of 5 may cost more to operate initially and may be less competitive with the large scale plant in the very short term and the medium scale plant in the medium term. But in the long-term, as the cost of conventional fuels continue to rise, it outcompetes the larger scale units because of its energy gain advantages.

$$X_o = \frac{1}{G} X_f + X_c$$

X_o = Unit cost of alcohol produced in 1980 dollars

X_f = Unit cost of conventional fuels in 1980 dollars

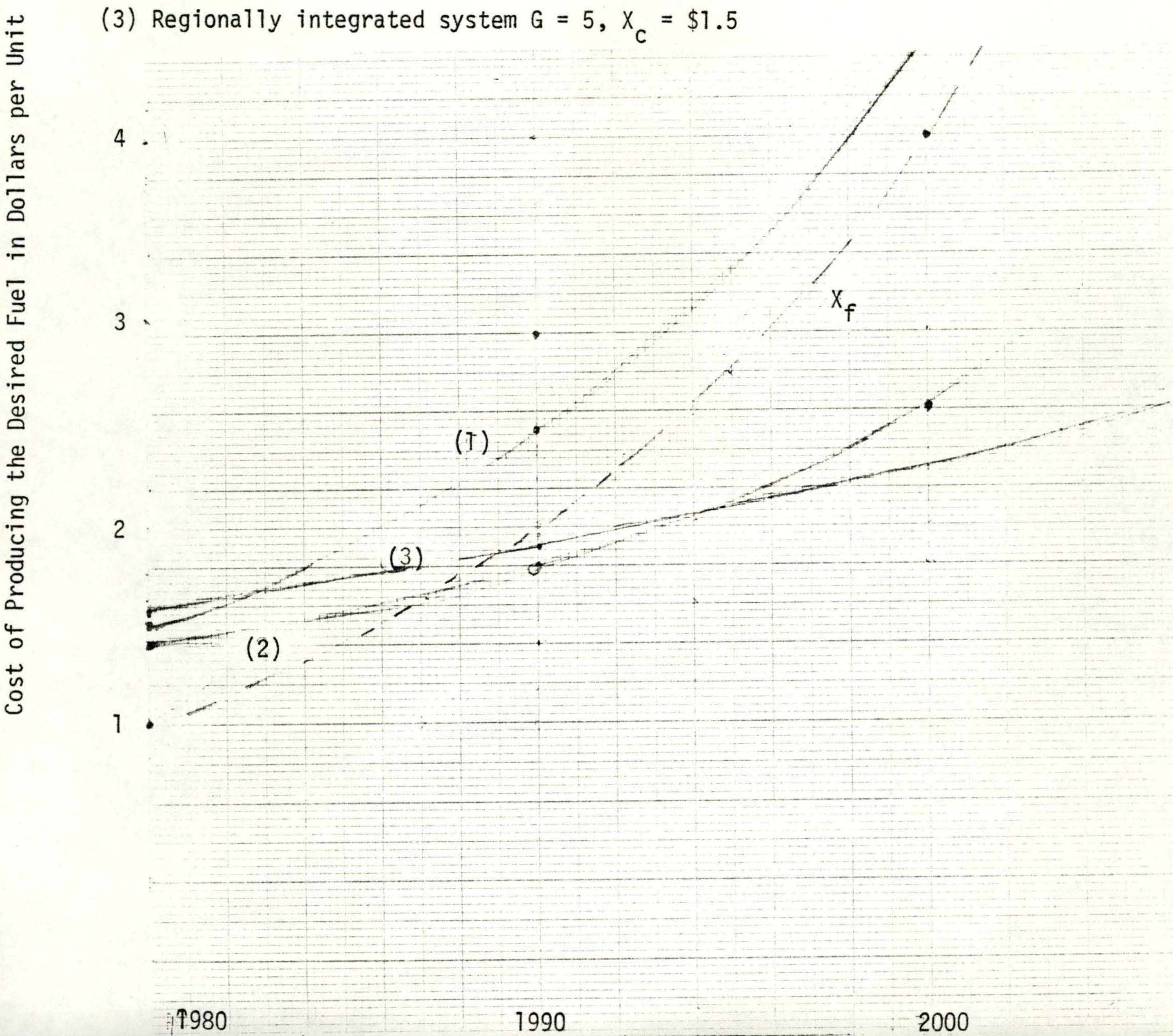
G = Energy gain of deployment system

X_c = Non-energy costs in dollars per unit output

(1) Highly centralized plant $G = 1$, $X_c = \$6.5$

(2) Medium scale plant $G = 2.5$, $X_c = \$1.00$

(3) Regionally integrated system $G = 5$, $X_c = \$1.5$



Research Paradigm

In an attempt to answer the above questions Michigan State University investigators initiated a comprehensive program in comprehensive design analysis pilot studies based on the flow diagram depicted in Figure 1 which identifies the essential components of the system and the linkages in an integrated biological/physical system. A model of this system was developed and evaluated with parameters corresponding to conventional technology and under our best estimate of what the parameters would be if research pertaining to unproven technologies were successful (Parsch et al, 1980; Jackson et al, 1980). Linkages, as can be seen, involve critical ties between feed production and livestock diets, in labor utilization across subsystems, in the relationship between fermented feeds and the presence of the protected protein by-product DDGS in the animal diets, of the relationship between protein balance from alfalfa versus DDGS in the animal diets, and the energy (in the form of fertilizer) required in the production of corn through its integration with legumes. It is only when each of these critical linkage issues is put in the context of the overall system that the potential technical and economic gains in one area can be evaluated against the potential losses in other areas of the system.

Research was divided into seven subsystems: 1) production of feedstocks; 2) steam generation from biomass (e.g. corn stalks, corn cobs); 3) preparation of feedstocks, cooking and fermentation of alternative feedstocks including dry (15% moisture) and high moisture (25 to 30% moisture) corn, sugar beets, potatoes, and fruit and vegetable processing industry waste; 4) distillation of ethanol from solution (including alternative end points); 5) by-product (e.g. distillers grains) handling, storage, and feeding; 6) utilization of ethanol; and 7) economics, management and energy balance analysis. The

The next section will outline research initiated in each of these areas, and some of the results to date.

Research Subsystems

Overview

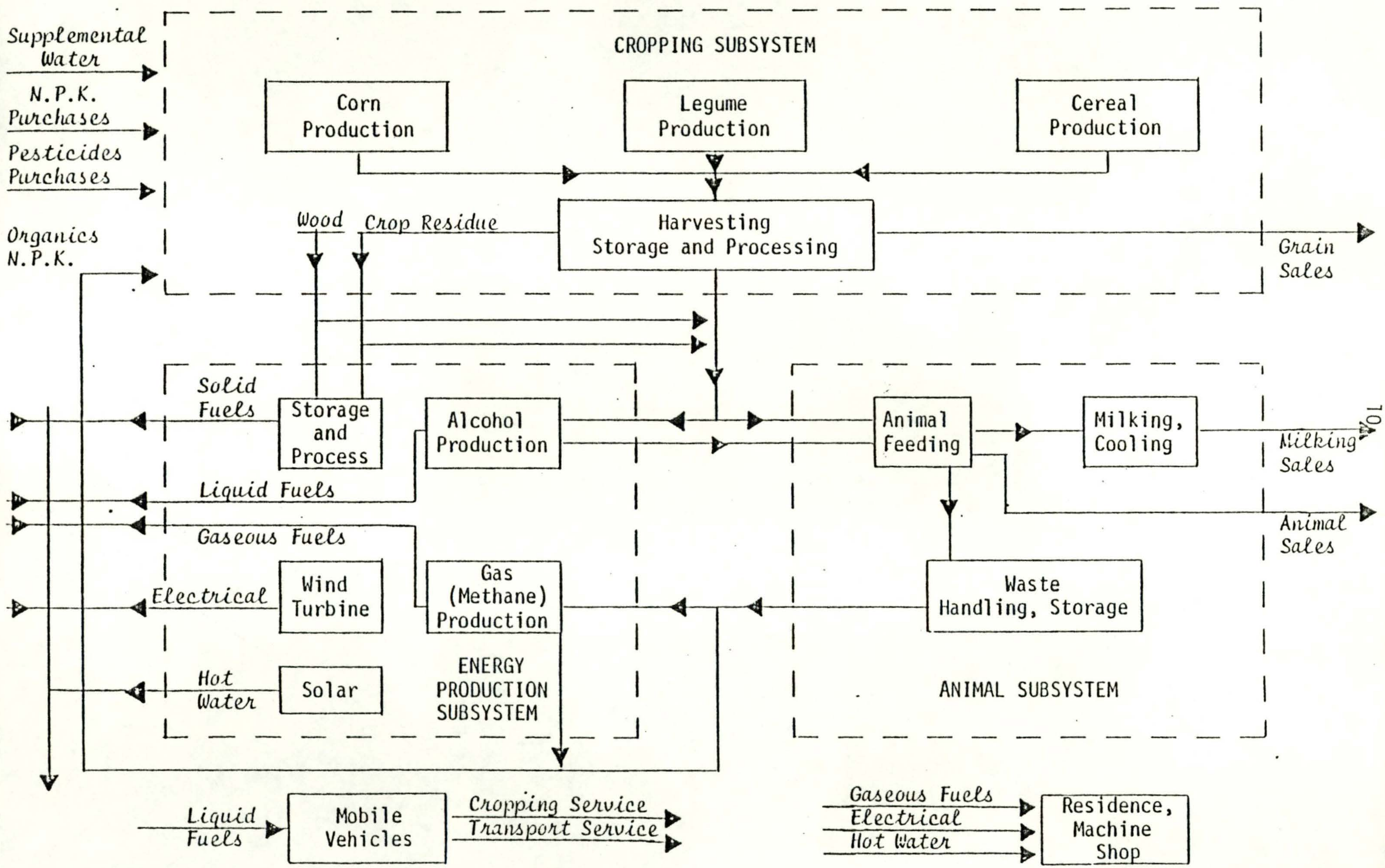
MSU scientists have taken a total systems design approach as contrasted to situation specific, research approach. Multi-disciplinary teams with participants from agricultural and chemical engineering, agricultural economics, animal science, crop and soil science and microbiology have developed a research philosophy that focuses upon the development of simulation models to permit inferences to specific situations based upon a knowledge of the overall system properties. Thus, experimental designs focus upon more than "treatment" effects; the estimation of subsystem and system model parameters is a primary objective. The "hardware," whenever possible, is highly controllable and has extensive monitoring capabilities, and control includes the ability to simulate the consequences of nonoptimal operating strategies.

The development of systems modeling capability facilitates commercialization since an ability exists to develop "good" design and management systems for site specific applications--a concept that is consistent with objectives of MSU's Cooperative Extension Service programs in technology and management development and transfer.

To illustrate the nature of this concept consider for example the livestock feeding subsystem. The unique protein characteristics of the byproduct of ethanol production from corn, distillers grains with soluables (DDGS), provides a focal point. MSU scientists, and others, have developed biological simulation models of the lactating dairy cow and the growing and finishing feedlot animal (e.g. Bergen, et al, 1978: Fox et al, 1977; Hlubik, et al, 1980; Waller, et al, 1979; Waller, et al, 1980). These

Figure 1

OVERALL SYSTEMS DIAGRAM



models were developed to: a) provide a framework for understanding biological system input/output relationships; b) obtain a better understanding of research needs; and c) provide a framework for development of site specific feeding systems including amounts to feed per day and economic implications. These models include explicit considerations of key characteristics of feedstuffs and include the impact of method of harvest and preservation on these characteristics. Through such models integration information from a wide range of experimental groups can be integrated into many site specific decision processes thereby extending the inferences and system design and management recommendations far beyond the sphere of MSU investigation.

The issue is not "Can DDGS be fed?" but "How can the dairy farmer and the feedlot manager utilize the DDGS to optimize its value?" Thus, technology transfer includes development of field calculator and time share computer models adopted from the research models, that can be used by feed manufacturer salesmen and by university agricultural extension agents when working with individual and small groups of farmers (Black and Fox, 1978).

Production of Feedstocks (intercrop etc.)

Energy Production

A number of institutions in North America are investigating alternative means of production of steam from biomass including direct firing and gasification. Dr. Srivastava of MSU's Agricultural Engineering Department, for example, is working on the development of gasification units that could use either corn stalks or cobs. Economic studies by Loewer, et al, 1980 indicate this practice will become economic by the mid 1980's if natural gas prices continue to rise at recent rates.

The ethanol production unit at the MSU Beef Cattle Research Center uses natural gas as an energy source for the steam boiler. The objective, however, is to obtain a controllable source with the ability to vary steam otuput in a known way for the cooking, fermentation and distillation phases. The final farming systems analysis, however, will include a simulation framework that integrates the work of Srivastava, and others.

Alternative Feedstocks

Michigan, because of its varied climate and soils, raises a wide range of commodities and is in the top five states in the United States in the production of 25 commodities. As a consequence, there are a large number of alternative feedstocks, including wastes from fruit and vegetable processing. Initial work was begun using 15 percent moisture corn as a reference, or standard, feedstock. The production scale (as contrasted to bench scale) production unit has been in operation for two months. Starch removal and conversion to glucose has resulted in 2.4 to 2.5 gallon (100% ethanol equivalent) per bushel of corn. That compares favorably, in a start up mode and with simple processes, with 2.6 gallons/bushel in the beverage alcohol industry. Initial work has begun on high moisture corn and the results look promising. The lactate which results from fermentation during ensiling reduces the potential yield, but this has been partially offset by the ease with which the starch can be separated from the corn kernel. Work is currently underway which focuses on the impact of alternative storage structures and management schemes on the extent of fermentation of high moisture corn, hence lactate production. Preliminary work, jointly with United States Department of Agriculture - AR, has considered sugar and fodder beets and sweet sorghum.

MSU facilities include bench-level fermenters as well as 500 gallon fermenters, a size that can be reasonably scaled upwards to make inferences to large scale systems. Initial research protocol is developed using the bench fermenter, with promising candidates then scaled upwards to the 500 gallon fermenter.

The fermentation and distillation processes have been studied from the point of view of "end point control" as contrasted to "time" control. Development of control mechanism which would permit an ethanol system to run under automatic controls, somewhat as a continuous flow grain dryer operates, is under consideration.

Distillation

Distillation design was coordinated with the ethanol end use design. Work has shown that ethanol can be used in turbo-charged diesel engines using alcohol injection processes at 100 proof (50% ethanol, 50% water). Thus, the distillation column was designed by Drs. Hawley and Grulke of the Chemical Engineering Department to permit stripping out 100 proof alcohol from the fermented feedstocks in the first phase. The column, a plated column, was designed to permit redistilling of the alcohol/water mixture to upgrade alcohol to as much as 190 proof. The column has glass walls which permits observation of its properties, and can be taken apart with plates restructured in a number of ways to test the efficacy of alternative design and management systems. Additionally, glass construction has proven exceptionally fruitful from a demonstration perspective.

One of our objectives is to work with ethanol production unit manufacturers on system design and management. Too, a system that can be used as part of an instructional program for farmers and operators of community scale ethanol production units is important.

Ethanol Use as a Liquid Fuel

The fuel subsystem includes three components. First, a simulation model of cash grain and livestock farms developed by MSU scientists is being used to develop load factors to better understand the conditions under which ethanol would be used. Second, a duel fueled diesel engine and a spark-ignition engine converted to use alcohol are being studied in the context of alternative loads and field conditions. These are taking place under the direction of Dr. Rotz of the Agricultural Engineering Department. Third, by understanding loads that will exist and by understanding the properties of ethanol under alternative fueling systems, the efficacy of alcohol as a fuel can be examined under the wide range of conditions which occur in Michigan agriculture, not just a particular single condition observed in a study. Results of duel fueling indicate a replacement of 25% diesel is possible under certain load conditions. An increase in therman efficiency with alcohol as a fuel has also been noticed.

By-product Use

The utilization of the by-product in high moisture form involves questions of storage and handling as well as feeding (stillage, prior to any separation, is typically 7 to 9 percent solids). Thus, the protocol was to develop and characterize handling and storage properties, particularly those that result because of the contamination that occurs in the practical operations of moving material through pipes, troughs, and other vehicles. Storage life that has been observed has ranged from as little as one day to as high as a week, depending on how the material was handled and whether it was done under lab or field conditions. The objective in the MSU study is to understand characteristics under field conditions, and to examine potential additives which might extend storage life.

Consideration of alternative separation systems is included in the project. Issues such as the utilization of distillers' grains versus distillers' soluables from corn are included here. Also, the properties of by-products from new ethanol sources such as fruit and vegetable waste are largely unknown.

Nutritional work begins with a biological model which provides focus on the subtleties of protein and energy metabolism, then involves individual animal in vivo studies to assess the parameters that are used in the biological simulation model, feedback updating the parameters of the biological model, and concludes with "feed and weigh" experiments based upon diets expected to optimize by-product nutritional properties. That is, feeding trials are designed based upon regimes predicted to be optimal by the biological model; these by-product diets are compared to well-known, standard diets, such as use of soybean meal or urea as protein sources. Data gathered include average daily gain, feed efficiency, and carcass quality.

Research, to date, has focused on biological model development and updating, including joint investigations with the National Research Council By-products subcommittee chaired by Waller, and animal dry matter and in vivo studies.

Economics, Management, and Energy Balance

The ultimate question is, "When integrated into a whole-farm context, what is the economic and social efficacy of alternative design and management strategies?" Concommitantly, what are the associated labor and management skills required for alternative degrees of farming system performance?

Relevance to Larger Scale Production Units

Energy Balances, Including Embodied Energy Flows Pre- and Post-Investigations

Many of the results from the smaller scale design and management systems are relevant to larger scale units. For example, the outcomes of feeding experiments using high moisture by-products are as relevant for community scale ethanol production units that are integrated into livestock production systems, as well as in smaller scale systems. High moisture corn feedstock investigations can be translated to any size of system. Work delineated the impact of storage systems is of relevance across all scales of operation.

Additionally, the pilot scale nature of the system at MSU is critical in the delineation of the ethanol production processes from new products that have not previously have been tried. The controllable nature and the highly monitored nature of the MSU system is particularly valuable here.

Conclusion

Institutional arrangements for successful research include the need for multi-disciplinary teams, controllable systems with adequate monitoring, and the ability to simulate from first principles and existing knowledge base to a wide range of alternative environments. MSU investigator's have found operation under that research philosophy is necessary for success.

Acknowledgements

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