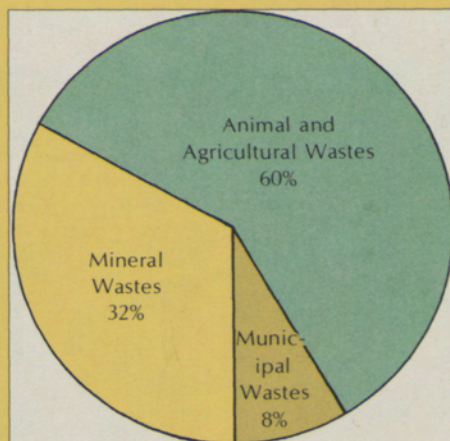


ENGINEERING

CORNELL QUARTERLY



VOLUME 12
NUMBER 1
SPRING 1977

USING OUR
AGRICULTURAL
RESOURCES



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Although the world population is certain to increase for the next twenty to twenty-five years, starvation is not inevitable, maintains Kenneth L. Robinson, professor of agricultural economics at Cornell. If population control is combined with agricultural expansion and improvement and if sufficient low-cost energy for fertilizer production is available, food production could increase at rates comparable to population growth.



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Engineering: Cornell Quarterly, Vol. 12, No. 1, Spring 1977. Published four times a year, in spring, summer, autumn, and winter, by the College of Engineering, Carpenter Hall, Campus Road, Ithaca, New York 14853. Second-class postage paid at Ithaca, New York. Subscription rate: \$4.00 per year.

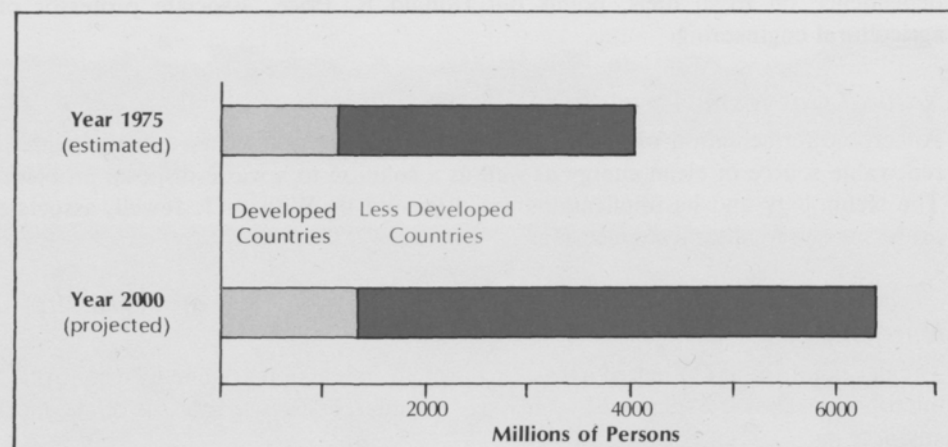
Opposite: A farmstead in the Finger Lakes region of upstate New York, near Cornell University.

HOPE FOR THE WORLD'S HUNGRY

by Kenneth L. Robinson

The world food situation is now somewhat less precarious than it was at the time of the World Food Conference in 1974. Reserves of both wheat and rice have increased, especially in the United States. Better crops in a number of chronic food-deficit countries also have helped to ease the tight supply situation. But a year or two of unfavorable crop seasons could reverse the situation once again; and while the threat of starvation for large numbers of individuals has been deferred, the problem of chronic malnutrition and seasonal food shortages remains for perhaps 10 to 15 percent of the world's population.

No one can deny the seriousness of the situation confronting the world over the next twenty to twenty-five years. In many developing countries, it will be necessary to double food production during this period if malnutrition and critical food shortages are to be avoided. Birth rates are already beginning to decline in most food-deficit countries, but not fast enough to bring down the overall rate of population growth, which now averages between 2 and 3 percent per year over much of Asia, Africa, and



Latin America. A sustained 3-percent growth rate will lead to a doubling of the population in less than twenty-five years. In many developing countries, approximately 40 percent of the population is now under fifteen years of age; most of those who will produce the next generation have already been born. Even if one assumes that current efforts to limit the number of children born to each family will be successful, the world's population will still rise from the present size of around four billion to more than six billion in the year 2000

Figure 1. Estimated world populations in 1975 and 2000. Nations grouped as "developed" are mainly countries in North America and Europe, the Soviet Union, Japan, Australia, and New Zealand. The data are based on United Nations projections as reported by Eric M. Ojala in Food Policy, Vol. 1, No. 1 (November 1975), p. 80.

(see Figure 1). Almost all of this increase (about 90 percent) will occur in those countries where there is already a precarious food balance. Providing the added food required for this incre-

“...food production can be increased at a rate that will match the growth of population”

ment in the world's population (plus some allowance for increased demand due to improvements in income) presents a formidable challenge. Very few countries, including the United States, have increased agricultural production over an extended period of time at the rate that will be required over the next twenty-five years to sustain the population and provide even a modest improvement in diets.

PROBLEMS OF CLIMATIC CHANGE, ENERGY SHORTAGES

Climatic changes and energy shortages could make the task of increasing food production even more difficult. Evidence of climatic changes is by no means conclusive, but it is possible that growing seasons could average a little shorter, and rainfall a little less in some of the important grain-producing areas of the Northern Hemisphere during the next ten to twenty years. Increasing variability in weather as compared to the 1960s (a relatively favorable period) could lead to temporary shortages and serious deprivation in the absence of substantial storage holdings.

A general shortage of energy, particularly of natural gas, could have a major impact on food production. The manufacture of critically needed mineral fertilizer currently depends on fossil fuel. In addition, increasing amounts of energy are used to dry crops. Nitrogen obviously can be obtained from the atmosphere, as was done before lower cost methods of producing ammonia and urea, based on natural gas, were developed, but the older process still requires substantial amounts of energy. Extraction of phosphate rock or potash and the conversion of these raw materials into fertilizer likewise requires significant quantities of energy. Without access to low-cost energy or some method of allocating natural gas supplies so as to ensure adequate feedstocks for fertilizer plants, it will be very difficult to meet future world food requirements.

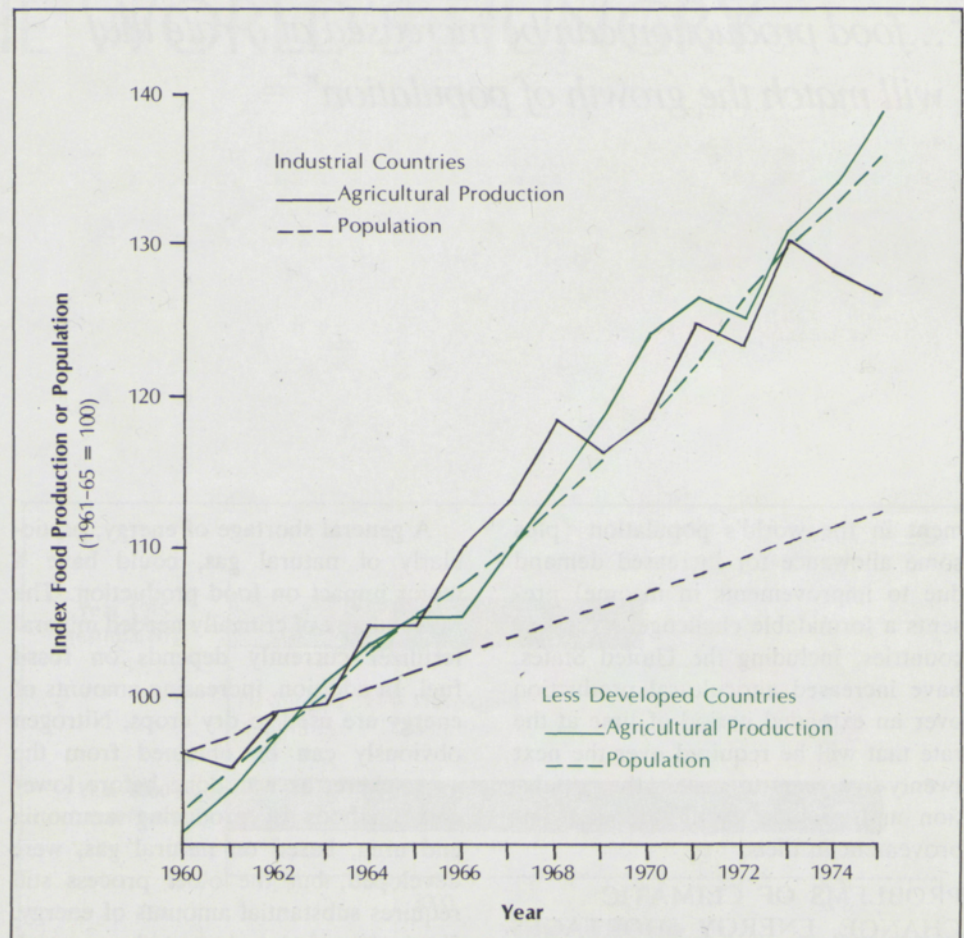
GROUND FOR OPTIMISM ABOUT THE FOOD SUPPLY

It is not difficult to visualize a sequence of events that could lead to critical food shortages. But starvation is not in-

evitable. Given sufficient incentives for farmers to increase output, government support for agricultural research, and an international commitment to develop and transfer technology appropriate for developing countries, plus some additional capital for investment in irrigation and fertilizer manufacturing facilities, food production can be increased at a rate that will match the growth of population over the next twenty to twenty-five years. Success is by no means assured, but there is more scope for increasing food production than is commonly recognized.

The gains in food production achieved by developing countries over the past two decades provide grounds for at least a moderate degree of optimism regarding the future. The record of such countries taken as a group is slightly better than that of the industrial countries (see Figure 2). Since 1960, total agricultural production in the developing countries has increased about 40 percent (as compared with a little over 30 percent in the industrial countries). This is slightly greater than the increase in population over the same period,

Figure 2. Food production and population of industrial and less developed countries from 1960 to 1975. The index numbers are calculated on the basis of 100 = the averages for the period 1961 to 1965. Source: U. S. Department of Agriculture, Handbook of Agricultural Charts (Agricultural handbook no. 504, October 1976).



permitting a modest increase in per capita food availability in most countries. There are, of course, significant exceptions. Per capita food supplies generally have declined slightly in Africa south of the Sahara, for example. In several countries, increased imports have been required to satisfy the food needs of urban areas.

Increases in domestic food production must be the chief source of supply for the developing countries, for international transfers of food (mainly in the form of grains) can provide only a

small part of their food needs. Currently, less than 10 percent of the total supply of starchy staple foods (grains and tubers or root crops) consumed in developing countries is obtained from imports of grain, and less than 2 percent is provided on concessional terms or donated as food aid. A few countries such as the United States, Canada, and Australia do have the capacity to provide additional food aid if necessary, but at best, this can meet the needs of only a small part of the world's population. Furthermore, too great a reli-

ance on food aid can have an adverse effect on internal production by curbing incentives or taking the pressure off governments to allocate sufficient resources for agricultural research and development.

REQUISITES FOR INCREASING FOOD PRODUCTION

There are a number of steps that can be taken, both in the United States and in developing countries, to increase the chances of success in meeting world food needs over the next twenty years.

Fortunately, in most of the potential food-deficit countries, the importance of increasing agricultural production is now recognized. Experience during the past three years has contributed to an important change in attitude on the part of government officials. It remains to be seen whether they will follow through by altering price policies which now inhibit production, and by allocating the resources needed to solve some of the technical problems.

The first requisite is to give those who till the soil additional incentives to increase food production. "Cheap food" policies which have been adopted at the insistence of civil servants or urban minorities are responsible in some instances for the relatively poor performance of the agricultural sector. Governments can encourage production by offering to purchase key food crops at more favorable prices or by subsidizing inputs such as fertilizer. Farmers will have an incentive to use additional fertilizer if it requires no more than five kilograms of grain (or the equivalent in root and tuber crops) to pay for one kilogram of nitrogen. Clearly, it is the ratio between crop and fertilizer prices that is critical from the standpoint of increasing production.

Reduction of post-harvest losses also would help to increase food availability, especially late in the marketing season before the new crop is harvested. Conventional storage structures used in industrial nations, such as those made of cement or steel, often do not prove satisfactory in tropical regions where temperatures and humidity are high. Fortunately, the need to develop storage methods suitable for use under tropical conditions is now recognized,

but more research is needed to devise improved methods using indigenous materials.

Yields can be increased in many areas simply by distributing irrigation water more efficiently and by improving drainage. It is also possible to exploit additional underground water reserves, especially in Eastern India and Bangladesh where monsoon rains are sufficient to insure adequate recharge. Growing a second or third crop in the dry season with supplemental irrigation has proved to be an enormously productive practice in many areas (although some of the potential gains from irrigation are now being foregone as a result of excessive application of water and the build-up of salts in countries such as Egypt). In other areas, substantial increases in production could be achieved by distributing water more efficiently. Faculty members in the Departments of Agricultural Engineering and of Rural Sociology at Cornell are now involved in joint research efforts designed to help developing countries create and maintain structures and institutions to utilize their water resources more effectively.

ENGINEERING RESEARCH IN AGRICULTURAL METHODS

Internationally supported centers of agricultural research, such as the International Rice Research Institute in the Philippines, the International Maize and Wheat Improvement Center in Mexico, and the International Institute of Tropical Agriculture in Nigeria have taken the leadership in developing improved varieties of food crops that are responsive to fertilizer and resistant to insects and disease. More attention is

now being given to the selection of varieties that will perform well under adverse conditions, not simply on the best soils or on irrigated land; this means selection for tolerance to moisture stress, low availability of phosphorus, and excess amounts of aluminum or iron in the soil. But research efforts by these centers will not solve all the problems. Much more needs to be done within developing countries to increase their research capacity so that they can create new varieties based on genetic material made available through the international centers. Research on both varieties and cropping practices has to be location-specific to cope with the enormous variability that exists in soils, climate, and pests.

Additional research also is needed to find ways of managing tropical soils so as to increase yields. Soils in the tropics tend to be low in organic matter and to have very poor water-retention capacity. They have the property of fixing large amounts of phosphorus, thus making it unavailable for crops. High soil temperatures combined with intermittent rain, even during the wet season,

*“The critical period
lies in the next
twenty years.”*

and sometimes an impermeable layer within a few inches of the surface limit the capacity of plants to develop an adequate root structure; thus plants are subject to periods of moisture stress. The Department of Agronomy at Cornell is now involved in research efforts designed to find out what can be done to overcome some of these limitations.

Agricultural scientists are beginning to learn more about the advantages of planting several species in the same field rather than a single crop, as is now commonly done in the United States. The combined yields of intermingled crops may exceed those of sole crops, especially where there are complementary relationships involved. More efficient use of soil moisture and plant nutrients, for example, may occur if two or more species with different growth patterns are intermingled. Damage by pests also may be reduced by growing crops together.

Other areas in which research can help to increase output include the development of minimum tillage techniques and better methods of controlling weeds and bird damage. Recent

experiments with minimum tillage techniques in Africa indicate that yields can be increased in some instances and erosion controlled by leaving crop residues on the surface and then planting directly in the stubble remaining from the old crop without turning over the soil with either plows or hoes. In addition to conserving moisture and lowering soil temperatures, such techniques reduce energy requirements for tillage; however, there is an offsetting economic and environmental cost involved, since increased use of herbicides may be required.

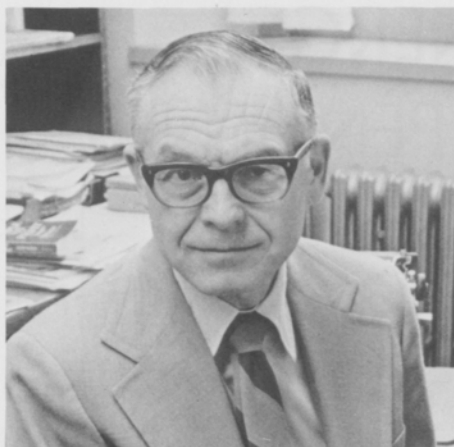
Better techniques for controlling weeds would pay high dividends in Africa. In many areas, crop production is held down by the inability of farmers to weed more land, rather than by a shortage of available cropland. If weeds could be controlled with less labor, farmers could plant a larger area to crops.

Losses attributable to birds also are very high, especially for crops such as rice, sorghum, and millet. As yet no one has devised a practical method of preventing serious damage, other than

by scaring birds with human effort. The labor required for “bird scaring” represents one of the largest items in the total cost of producing upland rice in West Africa.

LONG-TERM SOLUTIONS TO THE WORLD FOOD PROBLEM

Solving the world's food problem is difficult but not impossible. Many of the technical problems that now limit production in tropical areas can be solved, provided that additional scientists are trained and sufficient resources are devoted to both basic and applied research. But although increased support for research is necessary, this alone will not insure success. In addition, farmers must be given adequate incentives in the form of attractive prices for food crops and access to improved seeds, fertilizer, pesticides, and credit. Countries that are relatively well off can assist, not only by training scientists and engineers, but also by helping to finance international research centers, the construction of fertilizer plants, and in some cases, irrigation and drainage projects. Increased food aid still may



be required, but there are compelling political as well as economic reasons for giving first priority to increasing production of indigenous food crops within the developing countries.

In the long run, of course, the food problem in the developing world cannot be solved without slowing down the rate of population growth. The only alternative to this is massive international transfer of food—a strategy that probably would require a reduction in the consumption of meat and livestock from grain-fed animals in the higher-income countries. Birth rates are already beginning to drop in many developing countries, but it is totally unrealistic to expect the decline to occur fast enough to stabilize the population within the next two or three decades. The rate of increase in food requirements probably will peak between now and the year 2000, and then begin to decline as birth rates come down. The critical period lies in the next twenty years.

Long-run answers to the food problem will depend also on our ability to develop alternative sources of energy. Industrial nations can economize on

the use of energy for tillage and crop drying, but more energy will be required during the next two decades for fertilizer production. There is no way that the world's food needs during this interval can be met without applying more mineral fertilizer. Eventually, the capacity to fix atmospheric nitrogen may be transferred to plant species other than legumes. But even if this proves to be feasible, it is not likely to provide adequate nitrogen for the increase in crop yields that will be required over the next ten to twenty years. If the world's hungry are to be fed, sufficient energy must be made available to at least double and probably even triple fertilizer production.

Kenneth L. Robinson, professor of agricultural economics, is an economist with special interest in United States and foreign food and agricultural policies. In recent years he has been concerned with the economics of increasing food production in tropical Africa; during a leave from Cornell in 1973-74, he served as

visiting economist at the International Institute of Tropical Agriculture in Ibadan, Nigeria.

Robinson has been a member of the Cornell faculty since 1951. He first came to the University after completing undergraduate studies at Oregon State College in 1942, and earned the Cornell M.S. degree in agricultural economics in 1947. He also holds the Diploma in Agricultural Economics from Oxford University (1949) and the Ph.D. in economics from Harvard University (1952). He has served as a visiting lecturer at the University of California at Berkeley and as a Fulbright lecturer at the University of Sydney, Australia.

*His professional activities in the past several years have included service as a consultant to the National Science Foundation on research priorities in crop production and on economic effects of improved weather forecasting. He has also served on the U.S. Department of Agriculture Feed Grains Advisory Committee and as a member of the New York Council of Economic Advisers. His publications include a book, *Agricultural Product Prices*, written with William G. Tomek and published by the Cornell University Press in 1972.*

FOOD AND ENERGY: THEIR INTERDEPENDENCE

by Donald R. Price

Almost a quarter of the energy consumed in the United States is connected with agriculture, the nation's largest single industry. The cost of imported oil is nearly offset by the revenue from exported food, fiber, and wood. These two facts demonstrate the interdependence of two commodities essential to human existence—food and energy.

The provision of food and the supply of energy became widely recognized as potential world problems only in recent years. The energy problem was rapidly propelled to the forefront of attention in the United States by the fuel shortages of 1973, caused partly by the oil embargo. At about the same time, the international food problem began to intensify and for the first time in history, a world food conference was convened. The situation in which the United States finds itself today graphically illustrates the interrelationship of these two crucial problems: This nation is a very important source of food for the world's people, yet because modern agriculture has become heavily dependent on energy from petroleum, the food-production capacity of the United States is

dependent on the availability of fossil fuel. The ability of developing nations to produce food by fuel-dependent technology is also limited by the amount of oil and gas they can obtain or afford. A severe shortage of fossil fuels would force the development of agricultural practices different from those currently used.

Such changes in agricultural methods would require considerable time and intensive research efforts, but they could enormously reduce the agricultural dependence on energy supplies. Combinations of conservation techniques and alternative sources could allow many agricultural operations to become nearly energy self-sufficient.

FUEL FOR FOOD: A BASIC EXCHANGE IN TODAY'S WORLD

In the United States, energy consumption connected with agricultural industry now stands at about 22 percent. This comprises 16.5 percent directly related to the food chain and 5.5 percent used for all aspects of natural fiber and forestry production. The amount used for the food system is distributed as

Table I. ENERGY USE
IN THE U.S. FOOD SYSTEM

Energy Use	% of U.S. Total
Production (on-farm)	3.0
Processing	4.9
Distribution	1.5
Food preparation in the home	4.3
away from home	2.8
Total	16.5

Source: *Energy Use in the Food System* (1976). Federal Energy Administration report FEA/76/083/0.

shown in Table I. The data include both direct and indirect energy inputs; for example, the "on-farm" energy category includes that used indirectly for such purposes as the manufacture of fertilizers, pesticides, and machinery, as well as that used directly to power tractors, combines, irrigation pumps, milking machines, sawmills, conveyors, grain dryers, and heating and ventilating equipment.

Comparable data for New York State were compiled at Cornell in 1975 (and published as *Agricultural Engineering*

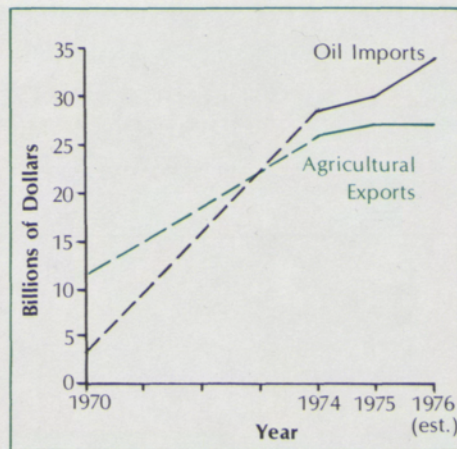


Figure 1. United States oil imports and agricultural exports since 1970. Agricultural products, especially grain, are the nation's single most important type of export to offset the balance-of-payments deficit.

Bulletins 405 and 406). This study identified the energy inputs to agriculture. For instance, in 1974 approximately 70 million gallons of diesel fuel and gasoline were consumed in tractors and other farm vehicles. And the fuel required to produce the approximately 242,000 tons of fertilizer used that year comprised slightly more than 5 trillion cubic feet of natural gas, 54.6 million kilowatt-hours of electricity, and 605,000 gallons of fuel oil. The reports also give details of energy use for crops, livestock operations, and greenhouses.

While the proportion of total United States energy used for "on farm" production—3.0 percent—is not overwhelming, there are some built-in peculiarities that can be troublesome. The fuel requirement for crop production is concentrated in short periods of time, once in the spring when crops are being established and again in the fall at harvest time. If shortages occur during these peak times, they can have serious consequences. If a lack of fuel delays a farmer as much as one week during the spring planting season, and if the delay is compounded by unfavor-

able weather conditions, the result could easily be crop failure. In the fall, a shortage of fuel at the critical time for harvest could cause large field losses of crops. After the crisis of 1973, many farmers increased their on-farm storage capacity to reduce the possibility of such a disaster.

The fuel-for-food requirement has intensified in the past few decades. Since 1950, agricultural production in the United States has increased by more than 50 percent, while labor requirements have decreased by more than 50 percent. This change was brought about partly by mechanization, which in turn resulted in a quadrupling of energy use. Farm labor has gradually been replaced by machines that require fuel or electricity. Some observers have advocated a return to the technology of 1950 or earlier in order to save energy, but the

result would be a drastic drop in production, with less land under cultivation, and decreased use of fertilizer, pesticides, irrigation, grain drying, and so forth.

FOOD FOR FUEL: THE OTHER HALF OF THE EQUATION

The second major interdependence of food and energy is related to the national balance of payments. Agricultural exports, largely grain, have been the single most valuable commodity group to offset dollars spent for foreign oil; Figure 1 shows the relationship between the costs of importing oil and the dollar returns from agricultural exports. Because of the increases in oil prices charged by the OPEC countries and the continuing rise in the amount of oil imported, it probably will not be possible in the near future for the United States to meet the cost of imported oil through the export of agricultural products. Nevertheless, the 20 to 30 billion dollars from agricultural exports will be a major asset in the balance-of-payments battle. Increasing yields and bringing additional land into cultivation could

FOOD AND THEIR INTERD

by Donald R. Price

help. So, of course, could energy conservation or increased domestic fuel production.

The political ramifications of both oil imports and food exports are complicated. The United States has already had a good taste of the political aspects of dependence on foreign oil. It is to be hoped that food and fuel will not become the guns and tanks of a new kind of war. To avoid this, world food and energy policies and cooperation are going to be essential. For all the nations of the world, the development of domestic energy sources and greater food production capability is extremely important.

THE ENERGY REQUIREMENTS OF FOOD PRODUCTION

Although the per capita consumption of food and the energy required to produce it are difficult to estimate, such calculations are the basis of any kind of prediction or planning. One such estimate for the United States is given in Table II. These data for the year 1972 show that the total requirement of energy for food production is the equiv-

Table II
FOOD CONSUMPTION AND ENERGY REQUIREMENTS FOR FOOD PRODUCTION IN THE U.S. IN THE YEAR 1972

Food Items	Food Consumption (lbs./person/year)	Energy Required (gal. of oil/person/year)
Animal products	660.6	37.6
beef	115.9	18.9
dairy	352.4	4.7
pork	66.4	4.7
fats and oils	14.9	3.5
poultry	51.5	1.6
eggs	38.7	1.3
veal and lamb	5.9	0.8
fish	14.9	2.1
Plant products	779.5	14.1
flour and cereal	138.6	2.2
sugar	120.8	1.4
fats and oils	41.6	3.7
fruits	130.7	1.9
potatoes	104.1	0.6
beans, peas, nuts	15.8	1.8
green and yellow vegetables	213.0	2.3
miscellaneous	14.9	0.2
Total	1,440.1	51.7

Source: Heichel and Frink (1975). *Journal of Soil and Water Conservation* 30:48-53.

alent of more than 50 gallons of oil per person annually. On the basis of a population figure for the United States in 1972 of 210 million, the total oil consumption for food production is calculated to be about 260 million barrels. By the year 2000, this total will be 400 million barrels, according to a projection that assumes a population of 300 million and some dietary changes (see Table III).

Several factors that cannot be accurately determined influence the estimates in Table III. These include the

possibility that there will be improvements in the efficiency of energy use for growing plants, and in the conversion of plant and grain feeds to meat and other animal products. Also, changes in dietary patterns cannot be predicted with certainty; changes in technology and consumer preferences or practices may have an effect. For example, if beef consumption were to decline instead of increase, this would reduce the energy requirements because the ratio of energy input to energy output is considerably higher for beef than for grains.

Table III

FOOD CONSUMPTION AND ENERGY REQUIREMENTS FOR FOOD PRODUCTION PROJECTED FOR THE U.S. IN THE YEAR 2000

Food Items	Food Consumption (lbs./person/year)	Energy Required (gal. of oil/person/year)
Animal products	579.3	42.5
beef	156.4	
dairy	239.6	
pork	67.3	
fats and oils	14.9	
poultry	53.5	
eggs	26.8	
veal and lamb	5.9	
fish	14.9	
Plant products	<u>779.5</u>	<u>13.9</u>
Total	1,358.8	56.4

Source: Heichel and Frink (1975) and Heady (1972). CARD Report 405, Iowa State University.

not impossible, to meet the demands for either food or energy.

CORNELL RESEARCH IN AGRICULTURE AND ENERGY

Researchers at Cornell are engaged in a number of projects related to the conservation of energy or the development and use of new sources of energy for food production. Many of these are centered in the Department of Agricultural Engineering.

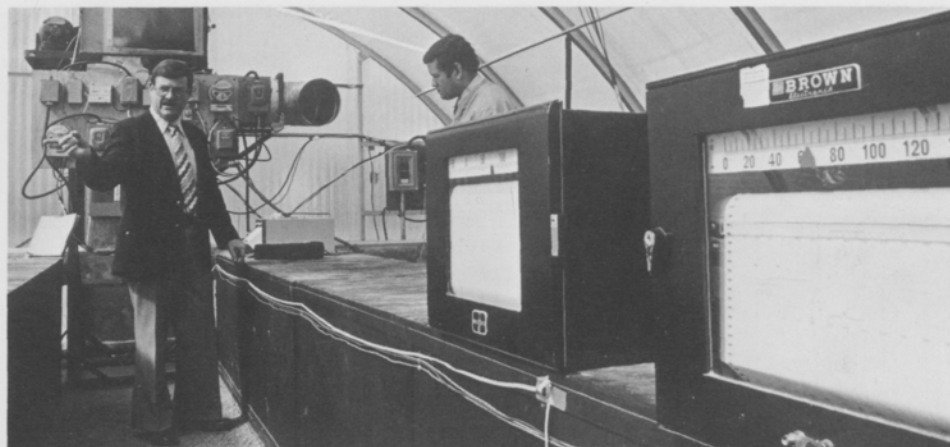
An example is the development of equipment that reduces the need for hot water and sanitizing chemicals on dairy farms. In New York State, dairying is the largest single agricultural industry—more than half of the state's agricultural income is derived from the sale of milk—and on a modern dairy farm, the electrical energy used to heat water for cleaning and sanitizing milking equipment and for cooling the milk amounts to more than half the total amount used on the farm. The equipment designed by the Cornell researchers reduces the water-heating requirements by more than 50 percent and at the same time reduces the demand for cleaning and

Similar extrapolations of population and energy-consumption figures to include the entire world yield some overwhelming totals. If the world population were indeed to reach 7 billion by the year 2000, as has been projected, and if the per capita food consumption everywhere were equivalent to the current United States consumption, and if the production technology now used in this country were to be used throughout the world, then the total energy consumption per year would be equivalent to 9.5 billion barrels of oil a year. Of course, it is not reasonable to expect that diets will be the same throughout the world or that production technology will be the same as that in the United States today (even though there has been movement in these directions).

Dietary differences could reduce the total energy requirement, but they would not in themselves be sufficient to eliminate the concern. Therefore, if the energy-supply problem is to be affected significantly, agricultural practices throughout the world will have to be substantially different from the current United States technology. Changes that would provide for significant use of alternative sources such as solar energy could have some effect—contingent, of course, on successful research and development.

But regardless of what plans are made, what technology is developed, or what energy resources are tapped, there remains the overriding world problem of overpopulation. If the projected population increases to 7 billion people by 2000 and 8 billion by 2050 actually occur, it will be extremely difficult, if

The use of solar energy for heating greenhouses is being studied by a Cornell research group. Right: Professor Price (on the left) and Thomas D. Hayes, research associate, check data recordings. Below: the experimental greenhouse.



sanitizing chemicals by about 75 percent. The design is in the process of being patented by the University. If it is adopted on dairy farms throughout the United States, the energy savings will be tremendous.

Other researchers, supported by a grant from the Energy Research and Development Administration (ERDA), are developing methods of converting animal manures and agricultural waste materials to methane gas. The feasibilities of various bioconversion technologies are now being tested in pilot demonstrations. ERDA, in cooperation with the Agricultural Research Service (ARS) also supports research on the use of wind turbines to provide hot water for milking centers. One of the methods under investigation is the use of a churning action in a fluid to transfer energy from the wind to water; a full-scale demonstration is planned for some time within the next two years. Some of these projects are discussed by William J. Jewell elsewhere in this issue of the *Quarterly*.

Studies are under way to develop systems for manure handling, storage,

“Agricultural exports, largely grain, have been the single most valuable commodity group to offset dollars spent for foreign oil.”

and land application that will optimize the value of the manure as a fertilizer for plant growth. Valuable nutrients, especially nitrogen, are lost under current handling and storage practices. If the manure were stored properly and applied as needed for plant growth, the resulting reduced need for purchased nitrogen would have a significant effect on energy demands for agriculture.

Basic biological processes are also being studied for ways in which plant production could be made more efficient. For example, one research group is seeking to induce genetic or biological changes that would enable plants such as corn to utilize nitrogen from the air. This capability occurs naturally in several legumes, including soybeans, and if it could be developed for corn, considerable savings in energy would result.

Historically, agriculture has been about the only industry to utilize solar energy to a significant extent. The major aim has been to facilitate the basic process of photosynthesis by which the sun's energy is converted to food energy. The row spacing of plants, for

instance, is determined mostly on the basis of the room needed for maximum absorption of sunshine by the plant leaves. At Cornell, one group of researchers is investigating possible techniques to improve the efficiency of the photosynthesis process. Others are studying the effective use of solar energy for heating greenhouses. A model structure erected on the campus features modular gravel beds that double as growing benches and as heat-storage units: excess heat recovered during the daytime is reclaimed during the night.

These projects, and many others at Cornell that relate to food production and energy, suggest the scope of opportunity for research in this area. The results are sure to have a major influence on the health and well-being of the world's people.

Donald R. Price, associate professor of agricultural engineering at Cornell, has centered his recent research and professional interests on the interaction of food

and energy, the subject of this article. Recently he served as chairman of an Engineering Foundation conference which drafted a national energy policy for the food system, a study that is being used in the current development of an overall federal energy policy.

Price holds three degrees in agricultural engineering: the B.S. and Ph.D. from Purdue University, and the M.S. from Cornell. He joined the Cornell faculty in 1962. At the present time he serves as chairman of the Task Force on Energy and Agriculture of the College of Agriculture and Life Sciences and as program leader of the Environmental Studies Program in the Department of Agricultural Engineering.

He is also program director of the New York Farm Electrification Council and a member of the board of directors of the National Food and Energy Council. He is active in the American Society of Agricultural Engineers and is a member of the honorary societies Sigma Xi, Alpha Epsilon, and Phi Kappa Phi.

His publications include nearly one hundred articles on electrification, mechanization, environmental subjects, energy use and conservation, and alternative energy sources.

NATURAL GAS FROM AGRICULTURAL WASTES

by William J. Jewell

This past cold winter, natural gas shortages which forced the closing of schools and industries throughout the North stimulated a growing interest in the idea of generating gas from waste organics such as manure. The possibility that such a valuable commodity as natural gas could be provided from a renewable source with the simultaneous solution of an existing waste-disposal problem has attracted much attention. At Cornell, the biological conversion of organics such as cow manure to methane and other byproducts has been under study since 1973, and ongoing work shows that it could become a reality in the near future.

POLLUTION PROBLEMS IN FOOD PRODUCTION

The popular image of rural America is one of pastoral scenes far removed from urban pollution. Actually, however, there is a growing potential for pollution of the rural environment as food-production rates increase. United States agriculture has expanded at an unprecedented rate in the past two decades—the poultry industry (see Figure 1) is an example—and although

large-scale agricultural methods are largely responsible for the beneficial increase in food-production capability, providing a great abundance of food at low costs, they have also intensified waste-management problems.

The quantity of agricultural residues is immense; the total waste produced by people as garbage and sewage is small in comparison (see Figure 2). A typical New York dairy farmer with about fifty cows spends up to 40 percent of his labor managing animal wastes that can be equivalent to the waste produced by five thousand people—and there are ten thousand dairies of this size or greater in the state. A poultry operation with one million birds can produce more waste than a human population of half a million.

The magnitude of agricultural residues emphasizes the need for effective management. When improperly managed, these residues may be washed off the land as a result of erosion. This runoff, unlike sewage, is difficult to observe and cannot be measured directly; agricultural residues containing runoff are part of the problem referred to as *nonpoint-source* pollution. Compari-

Figure 1

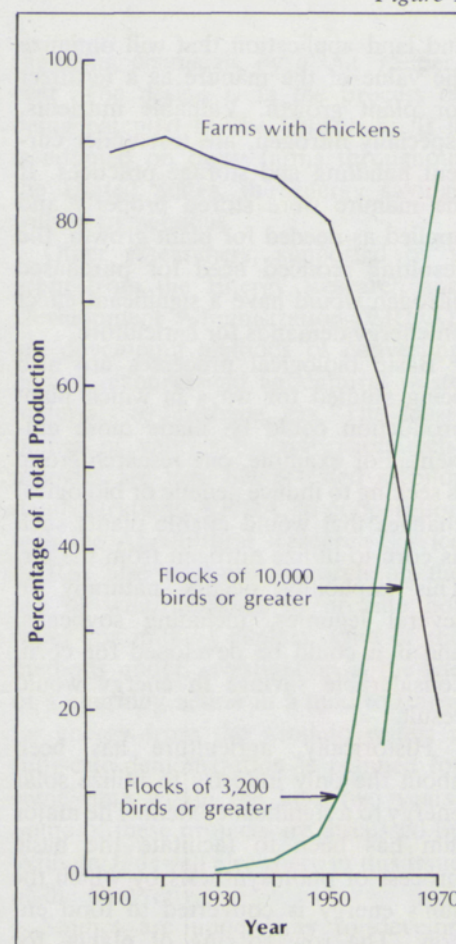
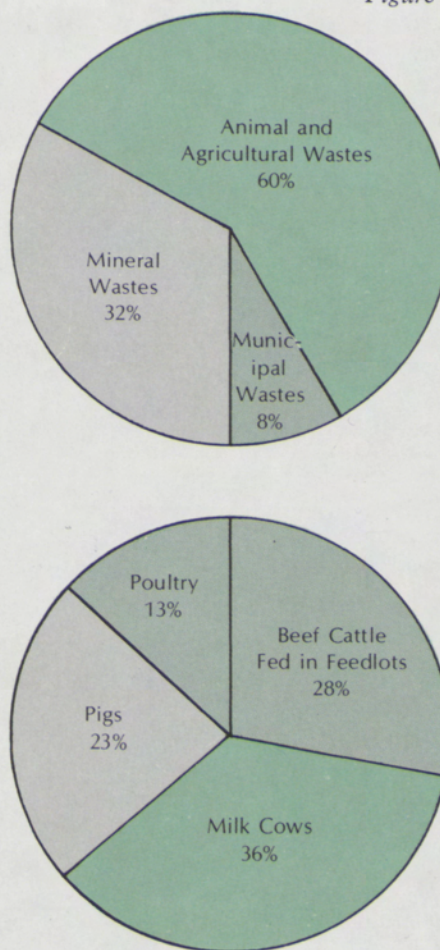


Figure 1. Chronological changes in the size of chicken-raising operations in the United States. The curves in color reflect how fast the industry is changing: for example, in 1962, 50 percent of all chicken-raising farms had flocks with more than 3,200 birds, but by 1968, 50 percent had flocks of more than 10,000 birds. The steady development of fewer and larger facilities has resulted in lower costs to consumers, but increasing waste-disposal problems.

Figure 2. Comparative amounts of solid wastes produced in the United States in 1969. The large percentage of animal and agricultural wastes (top circle) is subdivided into major groups (below).

son of this kind of pollution to point sources, such as domestic sewage, raises complex questions regarding cost-effective solutions for pollution control. A rule-of-thumb estimate is that in any watershed where the average population density is less than three people per acre, the nutrient pollution from runoff may exceed that from the raw sewage.

Figure 2



The issues involved in agricultural waste management include also the feasibility of converting wastes into usable products such as methane gas. At the present time, most agricultural residues are applied to the land in order to make beneficial use of their value as fertilizer. The possibility of converting the stored solar energy in farm wastes to methane prior to their land application is a promising area of investigation.

At Cornell, interest in the generation of energy is an aspect of an overall concern with agricultural waste management. A particularly active graduate program in agricultural waste management and rural environmental engineering has developed over the past twelve years. It has its roots in the Department of Agricultural Engineering, but it involves personnel in many divisions of the University, especially in the College of Engineering and the College of Agriculture and Life Sciences. Academic areas that interact with agricultural engineering in this program include agricultural economics, agronomy, ani-

NATURAL GAS FROM AGRICULTURE

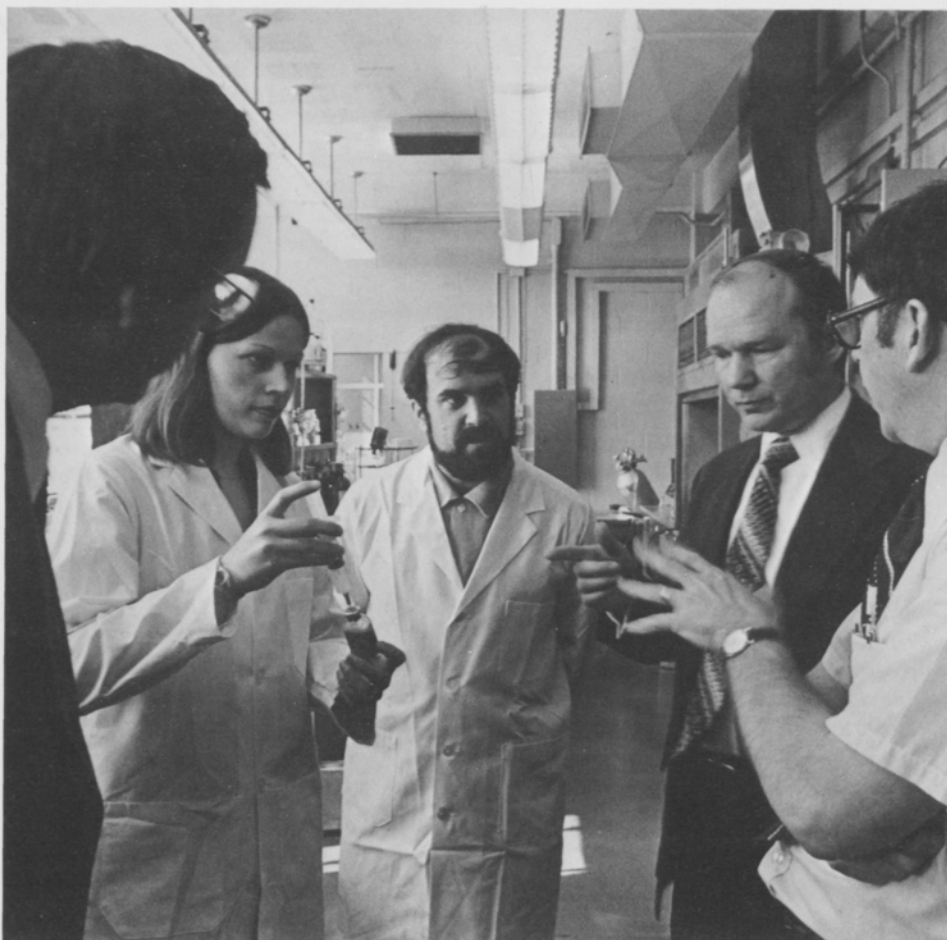
by William F. Jewell

mal science, poultry science, biological sciences, microbiology, chemical engineering, civil and environmental engineering, and rural sociology.

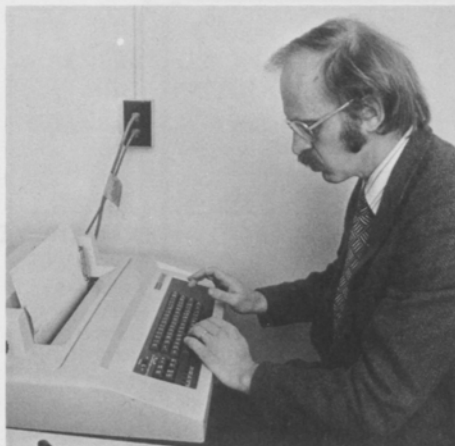
AGRICULTURAL RESIDUES FOR ENERGY: FACT OR FANTASY?

The vision of a manure pile being converted into a natural gas pump is an engaging one, but of course it bypasses the many engineering problems that must be confronted. Among practical questions are these: If the conversion were accomplished by anaerobic fermentation, would the resulting combination of carbon dioxide and methane be usable? Can significant quantities of methane be generated? Is the required technology available? Could it provide fuel to satisfy existing and future demands for food-production processes, and if so, would it be economically feasible? Would on-site use be the best utilization of farm-produced gas? Or would it be practical to make use of gas produced from agricultural wastes for nonagricultural needs?

These questions and others were examined by a multidisciplinary group at Cornell which studied the feasibility of



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Members of the Department of Agricultural Engineering form the nucleus of the University's research program in agricultural waste management and rural environmental engineering.

1. The anaerobic digestion of manure is discussed by (left to right) Professor Raymond C. Loehr, director of the Environmental Studies Program; Patricia Dauplaise (holding a model anaerobic digester), research technician; Michael Switzenbaum, graduate student; Professor Jewell; and Professor David C. Luddington.

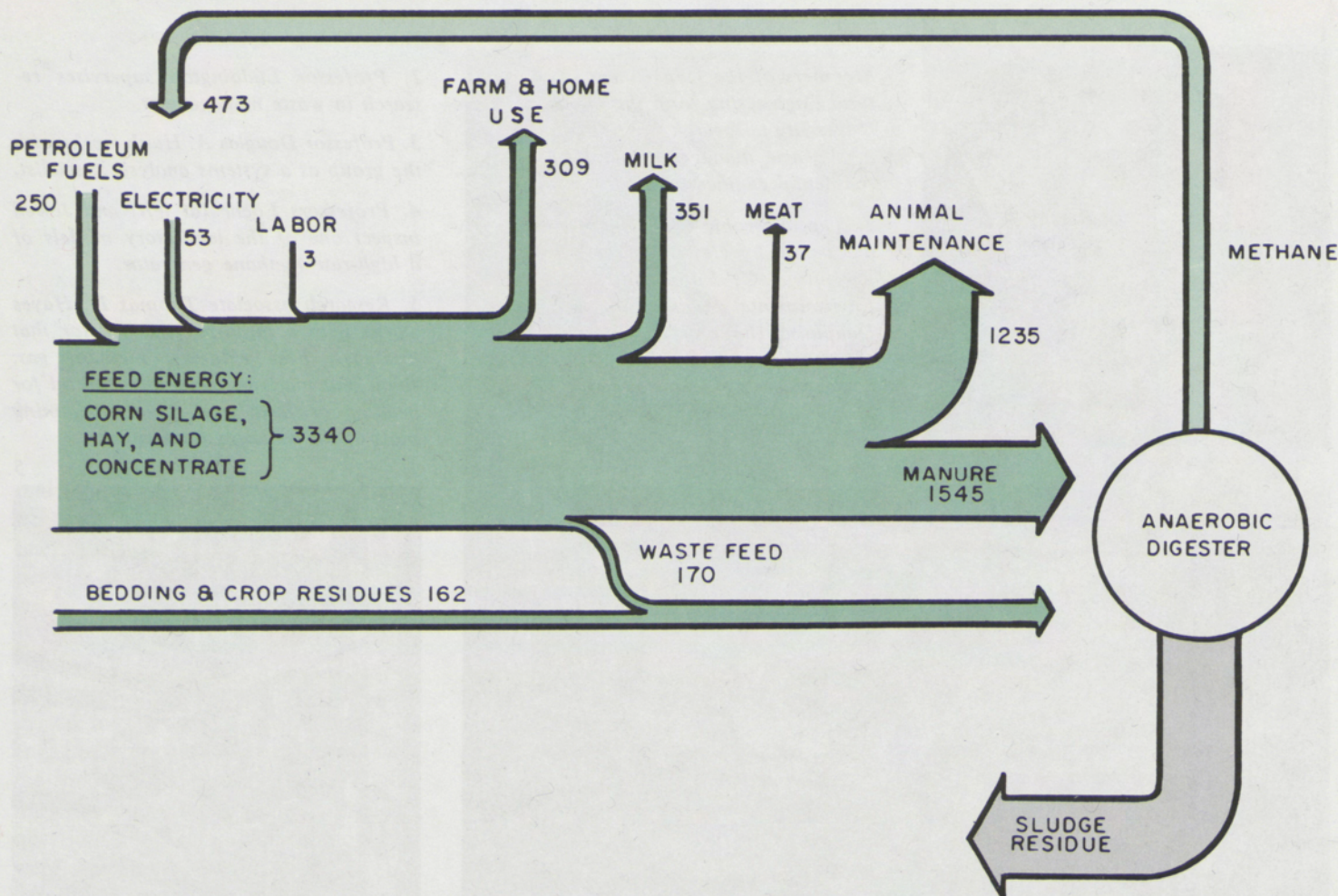
2. Professor Luddington supervises research in waste management.

3. Professor Douglas A. Haith works with the group as a systems analysis specialist.

4. Professors Loehr (at left) and Jewell inspect one of the laboratory models of a high-rate methane generator.

5. Research associate Thomas D. Hayes works with a multi-purpose reactor that produces three effluents: methane gas; solid float material, potentially useful for bedding or feed; and liquid containing most of the nutrients for fertilizers.





producing energy from agricultural wastes.* Early in their study, the re-

*The final report of the Cornell study group, probably the most comprehensive treatment of the subject now available, is *Bioconversion of Agricultural Wastes for Pollution Control and Energy Conservation* by W. J. Jewell, H. R. Davis, W. W. Gunkel, D. J. Lathwell, J. H. Martin, Jr., T. R. McCarty, G. R. Morris, D. R. Price, and D. W. Williams. It may be obtained from the Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161.

searchers estimated that on a national basis, the total amount of energy available from animal wastes and crop residues would constitute between 1 and 10 percent of the total energy usage. "Energy farming" of large land areas or the oceans could increase the amount of energy that could be generated. At a more practical level, the crop residue from ten to twenty acres could provide all the heat required for a home in northern New York, although even this small-scale technology is nearly totally undeveloped.

Figure 3. Diagram of energy flow on a hypothetical 100-cow dairy farm equipped with an anaerobic digester for methane generation. The numbers represent millions of kilocalories.

The Cornell group considered various possible ways of using agricultural residues to generate energy. For example, processes based on high-temperature and high-pressure pyrolysis are available. The most promising method, however, appeared to be a microbial process of anaerobic ferment-

Table I
ENERGY USE IN MILK AND
BEEF PRODUCTION*

Operation	Annual Energy Usage (kcal $\times 10^{-6}$)	
	Total	Per Animal
40-cow dairy	164	4.1
100-cow dairy	306	3.1
1,000-head beef feedlot	670	0.7

*In the U.S. in 1975. Includes energy used directly in the form of electricity, gasoline, diesel fuel, heating oil, and labor.

Below: These tanks composed the main methane generator constructed for a 100-cow dairy in Hornberg, West Germany, in 1952. Energy from this system would now cost more than twenty times the corresponding price of purchased energy.



tation to produce a mixture of carbon dioxide and methane gas, while leaving all the plant nutrients to be recycled in the stabilized humus material. This is the approach used in a project supported by the Energy Research and Development Administration (ERDA).

As part of the study, a comprehensive analysis was made of energy needs in the production of milk and beef (see Table I). A comparison (see Figure 3) of the fuel needs and the energy potentially available from fermentation of the organic wastes showed that the required

energy could be entirely supplied by the methane generated from the manure, bedding, and milking wastes. Other analyses have also shown that energy potentially available from methane generation on farms exceeds the existing usage. The concept of a relatively energy-independent food-producing facility emerges as a real possibility.

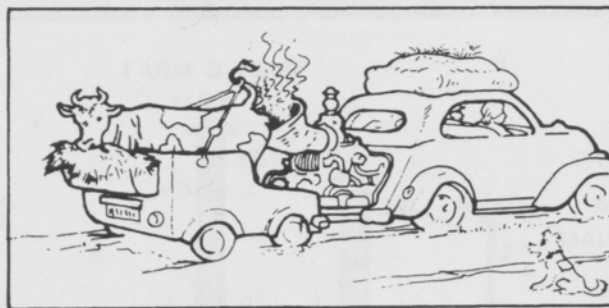
ENERGY FROM ORGANICS AS AN HISTORIC IDEA

The concept of generating natural gas from organics is not new. As early as

1936, work in Illinois had progressed through pilot experiments to an advanced understanding of the process of energy production from agricultural residues. It was reported* that a ton of cornstalks would furnish enough gas for four hundred people for one day, allowing twenty-five cubic feet per capita per day, and that with 30 percent of the land planted to corn, a circular area eight miles in radius would produce enough cornstalks to supply a city of eighty thousand inhabitants with gas. The residue would be suitable for paper-making, the report indicated. The cost of producing the gas was estimated to be about the same as the cost of natural gas at that time.

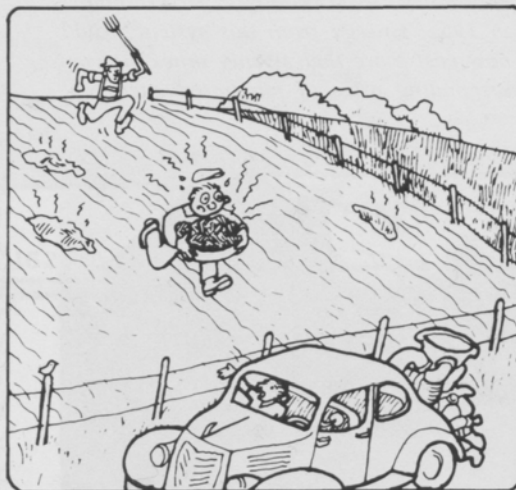
In the mid-1940s, several thousand farms in France were using simple methane generators. The popular press in Germany picked up the idea (see the examples of cartoons that appeared

*This classic report, *Anaerobic Fermentation* by A. M. Buswell and W. D. Hatfield, was published in 1936 as State Water Survey Bulletin 32 (Urbana, Illinois: University of Illinois).

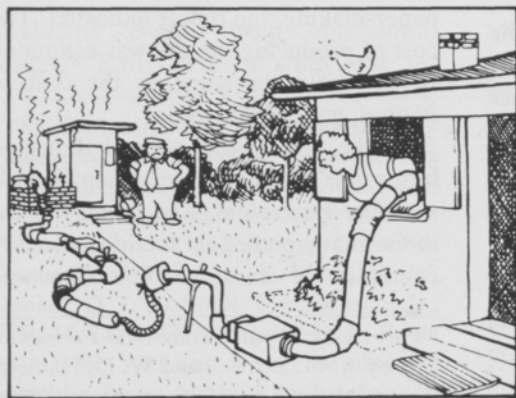


"Is it time yet, Bessie?"

These cartoons accompanied a newspaper story, published in Germany in 1944, which reported that a farmer from Limoges, France, had built an apparatus which generated gas from cow manure and which he used to run his machinery and for fuel in the kitchen and laundry. His system consisted of two 10-cubic-meter fermentation tanks which could hold a three-month supply of manure. The newspaper was published by the National Socialist German Workers Party.



"Run, Otto, here he comes!"



"There is enough for only one pancake—we have five people to feed!"



"Be happy, Lucie, by chance I was able to scrounge up a few miles of gas and we can drive to Potsdam tomorrow and visit Grandma."

around this time), and during the latter part of the decade, eighteen highly complex installations were built in that country. These systems provided gas for multiple purposes; a compressed form, for example, was used for tractor fuel. The problem with these systems was that the energy they produced was not economically competitive with the low-cost energy then on the market. Today, however, thousands of smaller and simpler units are reported to be either in use or under construction in India, Korea, China, and other developing countries.

The overall impression gained in reviewing the history of methane-generating schemes is that up to a few years ago, very little progress had been made in understanding and optimizing the technology as it applied to agricultural wastes.

FERMENTATION PROCESS DESIGN AND ECONOMICS

In order to evaluate both the technical and the economic feasibility of potential systems, the Cornell group modeled several for specific agricultural operations and estimated their capital and operating costs.

Three different types of cow-manure anaerobic fermentors—for conventional, batch-load, and plug-flow digestion—were built. The conventional system was essentially the same as the kind that has been used for many years in sewage sludge treatment; the batch-load unit was a practical system similar to one presently being promoted by a well-known German engineering consultant firm; and the plug-flow system was the simplest the group could develop. The design criteria for these three

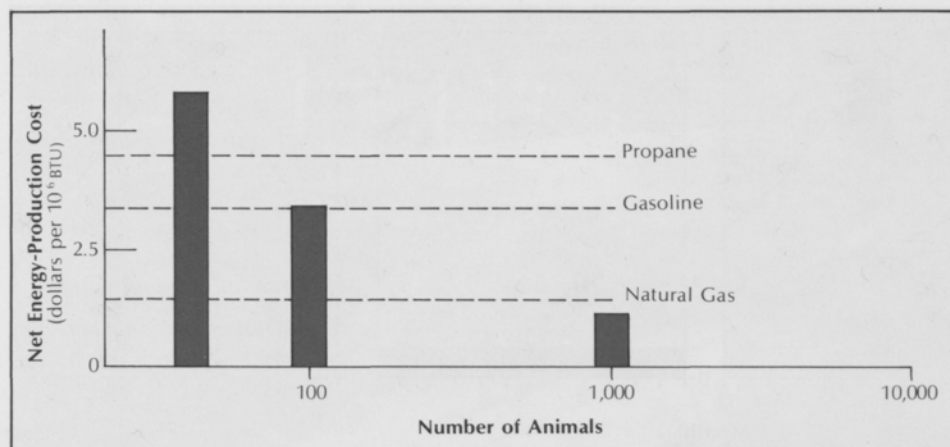


Figure 4. Estimated net cost of methane generated from agricultural wastes, as compared with commercially available fuels. The colored bars pertain to methane generated by the lowest-cost anaerobic fermentation system for 40-cow and 100-cow dairy farms and for a 1,000-head beef feedlot. The figures for propane, gasoline, and natural gas (at the federally controlled interstate levels) are for the year 1975.

types of fermentor are summarized in Table II.

These three systems were evaluated in long-term laboratory tests, including measurements of gas production. Costs for the least expensive system, the plug-flow design, are summarized in Table III for the three animal-production operations studied. The estimated costs of energy in the form of generated methane as compared with the costs of alternative, commercially available forms of energy are shown in Figure 4.

Although the data presented in the figure are encouraging, there are several remaining problems. For example, these costs do not include gas storage or cleaning or conversion of the gas to other usable forms of energy. If only half of the energy can be easily used at the agricultural facility, what happens to the remaining portion? The cost of conventional gas-storage equipment appears to be too high to be feasible on a small scale, and therefore the current prospect is that any gas that cannot be readily used must be wasted.

The possibility of selling excess gas to a pipeline company was included,

Table II
DESIGN CRITERIA FOR THREE TYPES
OF COW-MANURE ANAEROBIC FERMENTORS

	Digester Design		
	Conventional	Batch Load	Plug Flow
Hydraulic retention (days)	10	32.5	30
Temperature (°C)	32.5	20*	32.5
Influent solids (% by weight)	10	10	10
Solids reduction (% of dry weight)	32 (50)†	38 (55)†	30 (45)†
Gas production (liters/gm solids)	0.27 (0.42)†	0.32 (0.46)†	0.25 (0.38)†
Gas composition (CH ₄ /CO ₂)	65/35	65/35	60/40

*Two digesters operating on ten-day feeding plus ten-day batching schedules.

†Numbers in parentheses refer to wastes from beef-feedlot operations.

Table III
ESTIMATED COSTS OF METHANE-GENERATING SYSTEMS

	Farming Operation		
	40-cow dairy	100-cow dairy	1,000-head beef feedlot
Total capital costs*	\$10,000	\$14,000	\$27,000
Annual operating costs*	2,460	3,300	6,300

*Include costs for pretreatment units, fermentors, and gas-handling equipment; storage of treated residue and the cleaning or storage of gas are not included. All figures were calculated for the lowest-cost option, the plug-flow design.

Figure 5

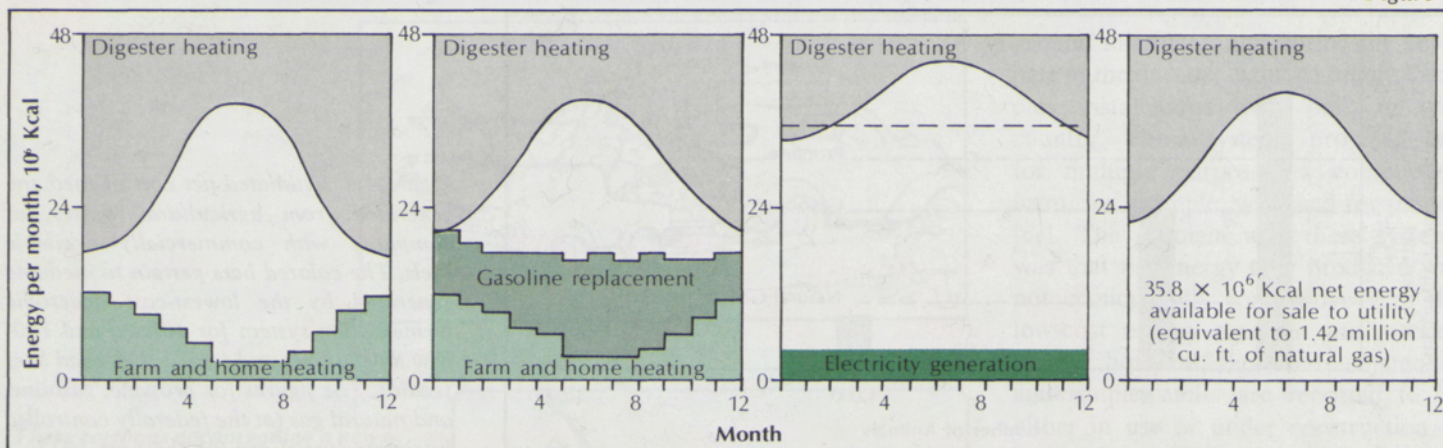
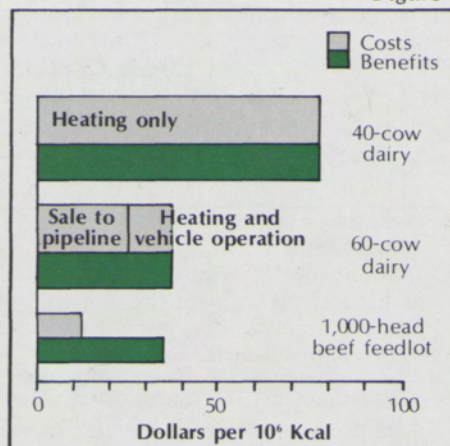


Figure 6



however, in an analysis made to determine the least-cost plan for biogas utilization. An example of the analysis data is shown in Figure 5, which pertains to a 100-cow dairy. The methane that could be generated would provide not only for home space heating, but also for water heating, milking-parlor space heating, clothes drying, and home cooking for one household. There would even be enough to serve as a replacement for gasoline used on the farm. During the summer months, at least, there would be a considerable surplus.

In an overall assessment of this technology, several factors other than energy production should be considered: potential benefits include also labor reduction, odor control, and nutrient recovery. Some sample comparisons of estimated benefits and costs are shown in Figure 6.

One significant conclusion drawn from the Cornell study is that even though few improvements have been made in agricultural residue fermentation technology over the past four decades, the method appears to be feasible for energy generation, pollution control,

and nutrient conservation in many agricultural operations. Furthermore, it is reasonable to assume that improvements in fermentation technology can make the process even more attractive. The ongoing Cornell study is attempting to estimate the improvement that might be made with innovative applications and development of fundamental information.

Gas from agricultural residues represents a clean, renewable energy-production system that is the closest of any now proposed to being available at

Figure 5. Monthly energy production versus energy demand for anaerobic fermentators. These examples of analyses made at Cornell pertain to a batch-load fermenter and gas-handling system for a 100-cow dairy, with the generated methane used for the indicated purposes. The open spaces represent excess quantities of methane; unless this excess were sold to a utility company (as in the diagram at far right), it is assumed to be unused.

Figure 6. Comparisons of costs and potential benefits of anaerobic fermentation systems. These examples are for conventional technology applied to three different animal food-production operations. The cost figures represent totals for energy generation and utilization. The benefits include labor reduction, odor control, and nutrient recovery, in addition to the energy obtained.

competitive costs. ERDA estimates that by the year 2020, about one quarter of our total energy needs could be derived from renewable sources, and that biomass could provide a significant fraction of this type of energy.

Perhaps the highest priority at this time is to determine whether better and



Animal-waste digesters can provide a source of fuel and simultaneously solve waste-disposal problems.

1. The only full-scale functioning animal-waste digester unit in the United States of which Professor Jewell is aware is this one located at a 350-head beef feedlot in Michigan.

2. Feedlots like this one in Colorado could make large-scale use of digesters to handle the huge amounts of animal wastes concentrated in relatively small areas.

3. A pilot-scale digester at Cornell's Animal Science Teaching and Research Center at Harford, New York, is large enough to handle the waste from three to five cows. This is a simplified anaerobic fermentor, called an unmixed horizontal displacement reactor, that is being developed for small farms. A feed tank located to the right of the reactor pumps the manure, which then flows by gravity under cover of a rubberized membrane. On the farm, a covered trench would be used. Laboratory personnel in the picture are Donald F. Sherman (left), research technician, and Robert J. Cummings, research support specialist.

4. Experimental work with a four-stage anaerobic digester model is carried out by Kenneth Fanfoni, research support specialist.



*“...the crop residue from
ten to twenty acres could
provide all the heat
required for a house in
northern New York”*

less costly means of methane generation can be developed. This is the main focus of the current ERDA-sponsored study at Cornell. The Cornell project is one of twenty or thirty in this general area of research that ERDA is sponsoring in university and corporate laboratories around the country. These projects range from small-scale and pilot-plant studies to large-scale test operations, and include thermophilic digestive processes, thermal processing methods, and biophotolysis with algae. The wastes being worked on include animal manures, municipal garbage, and wood wastes, and the products sought include ethanol, nutrients, and oil, in addition to methane.

The national energy policy now under development will surely encompass at least three components: conservation, increased use of coal, and the development of renewable, clean energy sources. Anaerobic fermentation of agricultural wastes and other organics is a particularly attractive alternative for renewable, clean energy because it can supply a significant amount and simultaneously provide pollution control and allow valuable plant nutrients to be recycled. Manure and other agricultural wastes appear to be that rare phenomenon: an energy source with beneficial rather than detrimental side effects.

William J. Jewell, associate professor of agricultural engineering at Cornell, has major research interests—reflected in this article—in agricultural waste manage-

ment, rural environmental engineering, land disposal of wastes, and biological and chemical mechanisms involved in pollution control. His activities in these areas also include industrial consultation, which has extended over a period of sixteen years, in a wide variety of pollution problems. His efforts to bring attention to the problems and possibilities of agricultural waste management include the organization of the first national conferences on rural environmental engineering (in 1973) and energy considerations in waste management (in 1974).

Jewell holds the B.S. degree in civil engineering from the University of Maine, the M.E. in sanitary engineering from Manhattan College, and the Ph.D. in environmental engineering from Stanford University. After completion of the doctorate in 1968, he spent sixteen months as a postdoctoral research fellow at the University of London and the Water Pollution Research Laboratory in Stevenage, England, under sponsorship of the U.S. Water Quality Administration. He joined the Cornell faculty in 1973, after teaching at the Universities of Texas and Vermont. His honors include a National Science Foundation Engineering Research Initiation Award.

He has published widely in professional journals, and currently serves as technical review editor for the Journal of Environmental Engineering of the American Society of Civil Engineers, the Journal of Environmental Science and Technology, and the Water Pollution Control Federation Journal. He is active in a number of professional societies; at the present time he is serving as an elected member of the board of directors of the Association of Environmental Engineering Professors, as chairman of the American Water Works Association research committee on control of nitrates in the environment, and as chairman of the national research committee of the Water Pollution Control Federation.

CHICKEN MANURE TO CHICKEN FEED

A Recycling of Agricultural Nutrients

by Michael L. Shuler

Our ancient enemies, malnutrition and starvation, still haunt us in spite of tremendous advances in world agriculture over the past three decades. Our vast productivity gains could be wiped out by an extended period of unfavorable weather. Our world food problem could become a world food crisis.

Not only the quantity but the kind of food is critical: One of the essential factors in preventing malnutrition is an adequate supply of protein. But protein production is limited by the availability of fixed nitrogen—nitrogen in the form of compounds such as ammonia and urea—and for much of the world's plant protein, notably grains, this means a dependence on industrially produced fertilizer. It has also come to mean a dependence on fossil fuels, which are required for the manufacture of fixed-nitrogen fertilizer. Shortages of fossil fuels, or high prices for them, can mean shortages of food, especially nutritionally important protein.

Here is where chicken manure comes in. This agricultural waste is potentially a valuable source of protein. Instead of disposing of manure, polluting the en-

vironment in the process, the resourceful agriculturalist could recycle it back to feed by converting the fixed-nitrogen compounds to single-cell protein. Conversion processes such as this could provide a partial solution to the inter-related problems of insufficient food protein and environmental damage. In addition, they would offer farmers the advantages of a feed-production method that is largely independent of weather and of fluctuations in grain prices.

A waste-to-protein conversion scheme for poultry manure is the subject of cooperative research at Cornell by faculty, students, and staff members of the College of Engineering and the College of Agriculture and Life Sciences. The supervising faculty members are Richard E. Austic, animal nutritionist in the Department of Poultry Science; Harry W. Seeley, Jr., of the Laboratory of Microbiology in the Department of Food Science; and myself in the School of Chemical Engineering. As the principal investigator, I would like to discuss this project in terms of both its specific utility and its broader implications.

NITROGEN-FIXED FERTILIZER: THE NEED AND THE PROBLEMS

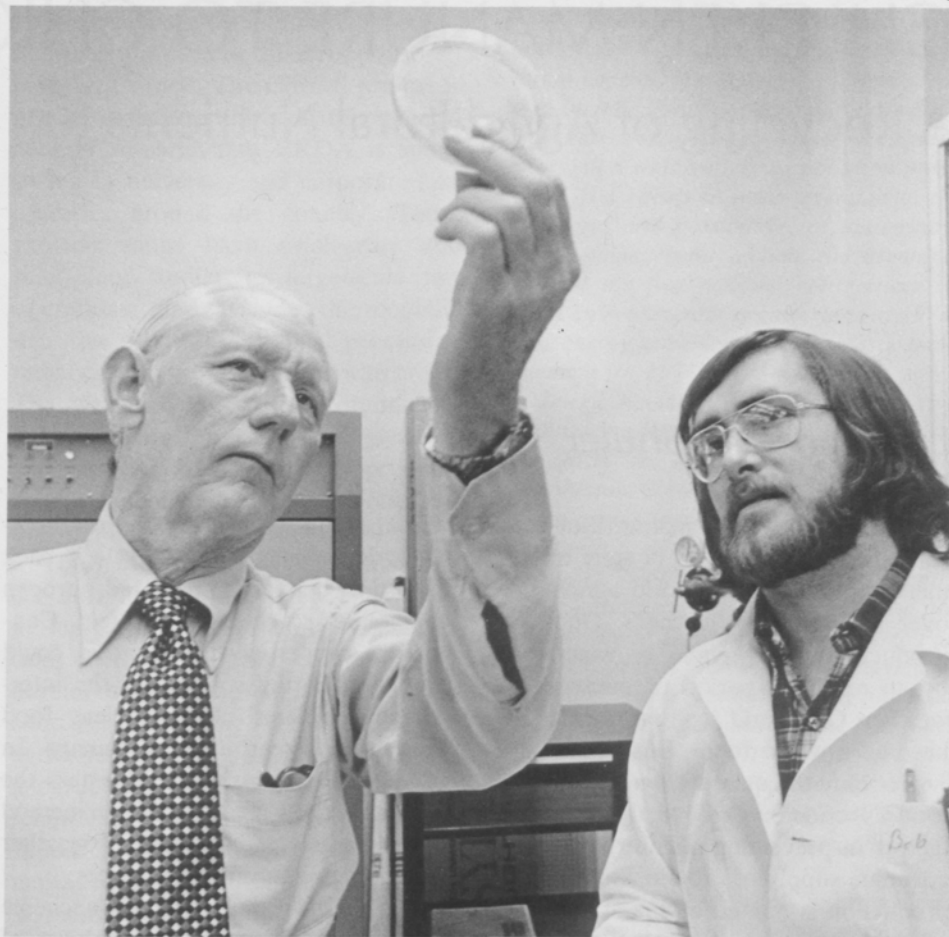
The story begins with the need for fixed nitrogen for growing crops. Although we are bathed in an atmosphere containing about 80 percent nitrogen gas, none of it is accessible to plants until it is converted into ammonium salts. The conversion can be accomplished biologically by a few microorganisms, or it can be done by a high-temperature, high-pressure industrial process. The biological process is economically important only for the growth of legumes such as soybeans; grains such as corn and wheat depend upon the supply of fixed nitrogen that comes almost exclusively from industrial nitrogen fixation. As energy for the manufacture becomes more scarce and costly, industrially fixed nitrogen also increases in price.

Ironically, much of the fixed nitrogen applied to a field is lost through processes such as denitrification, soil erosion, and runoff. The loss amounts to about 60 percent of the nitrogen applied to corn fields, for example. Indeed,

much of the nitrogen released into the environment comes from nutrient losses in plant protein production or from manure. There is also danger of contamination, for fixed nitrogen is a potentially hazardous material. It can lead to algal blooms and consequent environmental degradation of aquatic systems. And it can be detrimental to human and animal health. High concentrations of fixed nitrogen in water supplies can lead to methemoglobinemia in animals and human infants; severe cases can be fatal. There is also a danger that the fixed nitrogen will be converted into nitrosamines, which may be carcinogenic.

A PROMISING SOLUTION FOR THE POULTRY MANURE DISPOSAL PROBLEM

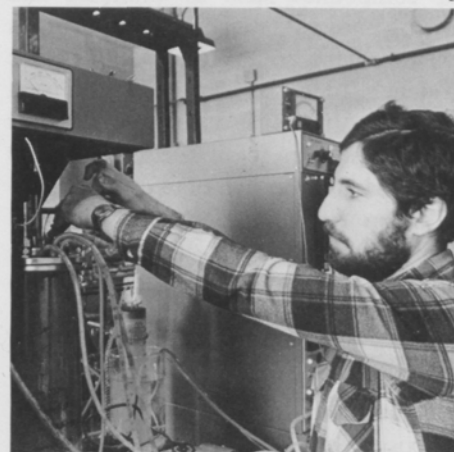
The egg-production industry is an attractive system for application of the waste-to-protein conversion principle because chicken-manure disposal is a common and serious problem and because the ultimate product, egg protein, is prized for its usefulness and high nutritional quality.



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3





1. Cooperating in the chicken-manure conversion project are Professor Harry W. Seeley, Jr., of the Department of Food Science (left), and graduate student Robert D. Vashon. They are inspecting a culture of a microbe being studied for possible use in the waste-to-protein conversion process.

2. Eugene Roberts, graduate student working with Professor Shuler, adjusts a mixer for a controlled experiment.

3. Drawing a sample from the second stage reactor is graduate student Fikert Kargi.

4. Inspecting data from an amino acid analyzer are (left to right) Professor Richard E. Austic of the Department of Poultry Science; Michelle Reif, laboratory technician; Ann Henry, graduate student; and Maribea Marranca, technician.

5. Ann Henry weighs chicks in preparation for a feeding trial with an experimental product.



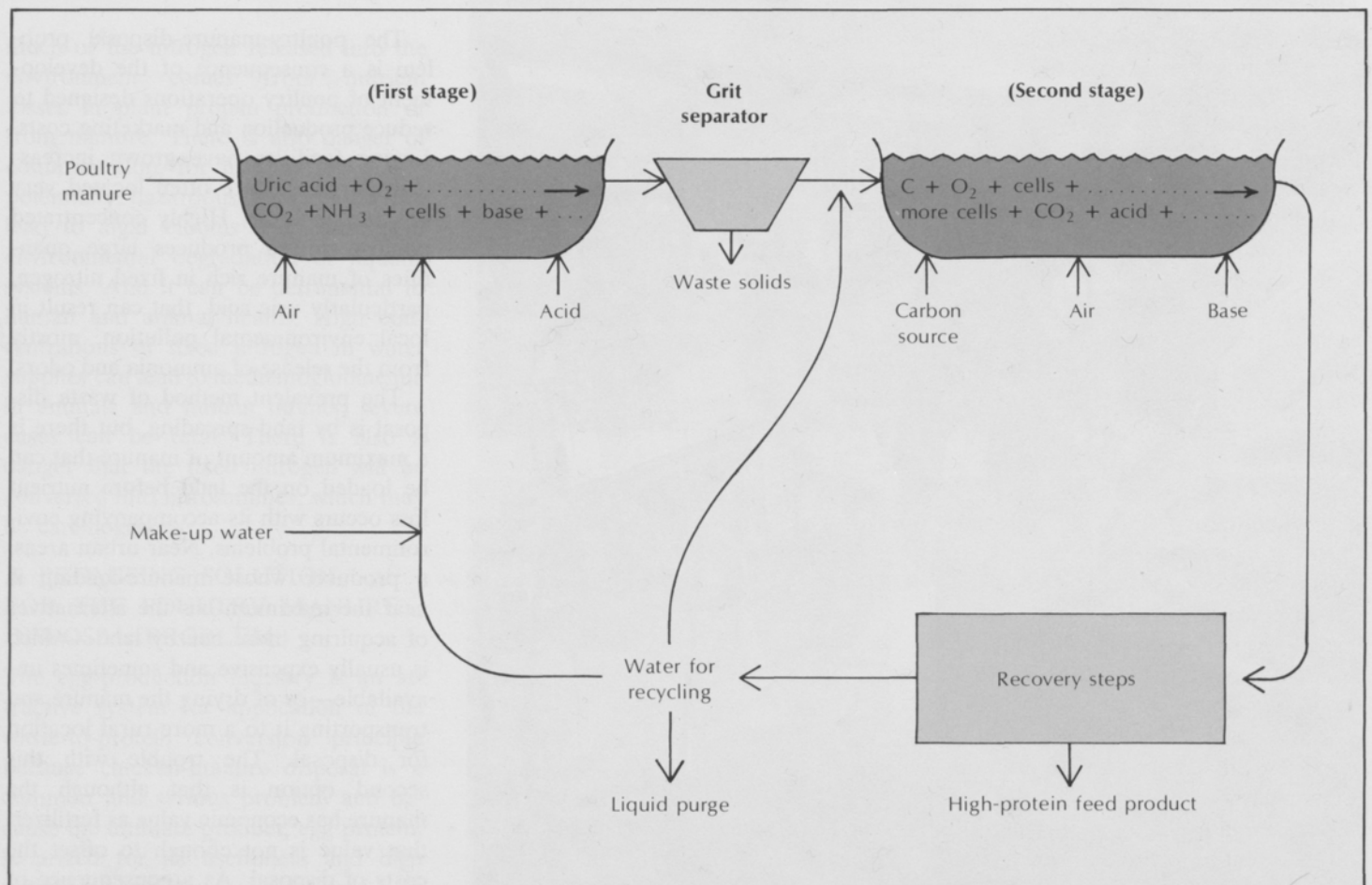
The poultry-manure-disposal problem is a consequence of the development of poultry operations designed to reduce production and marketing costs. Laying facilities have grown increasingly large and are often located very near urban areas. Highly concentrated poultry culture produces large quantities of manure rich in fixed nitrogen, particularly uric acid, that can result in local environmental pollution, mostly from the release of ammonia and odors.

The prevalent method of waste disposal is by land spreading, but there is a maximum amount of manure that can be loaded on the land before nutrient loss occurs with its accompanying environmental problems. Near urban areas, a producer whose manure-loading is near the maximum has the alternatives of acquiring more nearby land—which is usually expensive and sometimes unavailable—or of drying the manure and transporting it to a more rural location for disposal. The trouble with this second option is that although the manure has economic value as fertilizer, that value is not enough to offset the costs of disposal. As a consequence of

Figure 1. A possible process scheme for the controlled aerobic microbial conversion of poultry manure into single-cell protein, as developed by the Cornell research team. In the experimental studies, naturally occurring organisms, largely of the genus *Pseudomonas*, accomplished the crucial degradation of uric acid in the first stage; glucose added during the pH-controlled second phase enhanced the efficiency of the process. The optimal conditions for stage 1 were pH 6.5 and 25°C; complete conversion of uric acid could be obtained with holding times as low as 2.5 hours. In stage 2, under various

conditions, ammonia conversions up to 95 percent were obtained, but for adequate ammonia conversion and high carbon utilization, the optimal conditions were found to be pH 6.5, 30°C, and a holding time of 1.5 to 3 hours. The product recovered was found to be high in lysine and adequate in methionine and contained a good balance of the other amino acids required by the chicken.

In ongoing research, possibilities such as the use of other organisms and additives are being investigated. Criteria are process efficiency, economics, and nutritional quality of product.



this poultry-manure problem, there is a compelling economic incentive for the development of new methods of waste utilization.

A CONTROLLED AEROBIC FERMENTATION SCHEME

Last May Cornell received from NSF-RANN a two-year grant to study the economic, microbial, and nutritional feasibility of a controlled microbial process for the conversion of poultry manure into a single-cell protein product that could be fed back to the hens. Many other schemes for the use of poultry manure or a product from manure as a feedstuff have been suggested, but generally they have failed because of the low nutritional value of the product or the cost of production. The scheme proposed by our Cornell group is different in that it involves a *controlled* microbial *conversion* of the manure into a nutritious, high-protein feedstuff.

Poultry manure contains, on a dry-weight basis, approximately 6 percent nitrogen in the form of uric acid (about 70 percent), protein (10 percent), ammonia (10 percent), and other organic compounds; it also contains about 27 percent ash, 13 percent fiber, and 40 percent non-nitrogenous, nonfibrous organics. On the basis of this manure composition, the composition of a typical aerobically grown microorganism, and some preliminary observations, our research group developed the process shown in Figure 1.

The important first stage of the process is the breakdown of uric acid into ammonium ion as a result of the action of microorganisms. It is this reaction that is essential to the complete recovery and conversion of the fixed nitrogen

in the manure. A significant observation is that the natural uric-acid-degrading organisms are inhibited by readily available carbon compounds such as glucose. Accordingly, the needed addition of carbon must be delayed until after the uric acid reaction has been completed. We have found that only about 5 percent of the organisms present in the manure participate in the uric acid degradation; other organisms probably consume much of the ammonia and the non-nitrogenous, non-fibrous organic matter. The overall result of the first stage is a substantial increase in biomass.

In our initial experiments, we utilized the natural flora, which produces large quantities of basic compounds. Without pH control, the pH of the system would rise to values of around 9 or 10; at these levels, the ammonium ion is converted into ammonia gas, which is volatile and easily stripped from the reactor. It was obvious that if all the fixed nitrogen were to be conserved, either the ammonia would have to be recovered from the exit gas stream, or the pH in the reactor would have to be controlled. In our initial scheme, we have chosen to control the pH at a value of 7 or less by the addition of acid.

In the second stage, the main reaction is the conversion of fixed nitrogen and carbon from the first stage into biomass which is largely protein. Since the effluent from the first stage is rich in fixed nitrogen but poor in carbon, a carbon source—we have been using glucose—is added to balance the concentration of nutrients. The natural flora growing on sugar produces a great deal of acid, and since a lowered pH decreases the biomass growth rate, pro-

visions must be made for pH control by base addition.

The cell-rich effluent must then be sent to a recovery system where the solids can be removed from the liquid. A feasible method would be to centrifuge the second-stage effluent and dry the solids. The liquid would be recycled to effect a more complete conversion of the fixed nitrogen and carbon into cellular protein. The liquid purge is necessary also to control the concentration of any compounds that might build up to toxic levels.

An additional necessary step is the removal of large, heavy grit such as sand, oyster shell fragments, and grain hulls. Such material would decrease the protein content of the final product and would be mechanically undesirable. The best location of a grit separator might vary with different process modifications; in the diagram (Figure 1), it is shown after the first stage. The residue from the grit separator should be low in BOD (biochemical oxygen demand) and nitrogen, and relatively odorless and easy to dispose of by land spreading.

SOME INITIAL FINDINGS AND PLANNED RESEARCH

With the scheme we have outlined, we anticipate that 90 percent of the fixed nitrogen in poultry manure could be recovered to yield a product containing about 40 to 50 percent protein. Especially important is the quality of the product: it contains a good proportion of the amino acids essential to the diet of the chicken, including two—lysine and methione—that are present in low amounts in many commercial feed-stuffs. Our product contained a high 8.6 percent lysine and an adequate 3.2 percent methione.

The potential contribution of the process is indicated by the figures assembled in Table I, which applies to a 45,000-hen operation. A preliminary economic evaluation of the process scheme indicates that it is potentially economical for egg producers with 50,000 or more hens. More than half of this country's hens are maintained in operations of this size or larger.

Further development will be based on analysis of specific experimental findings. For example, we found the maximum temperature for stage 1 to be a low 30°C, and this, combined with the inhibition of the uric-acid-degrading pathways by easily metabolized carbon sources, places a limitation on the first-stage process. Professor Seeley is therefore directing work on the development of an organism able to degrade uric acid in the presence of sugars and at a higher temperature. If such an organism can be developed to replace the natural *Pseudomonas* strains, the two-stage process could be reduced to a single stage.

In the second stage, the natural flora

Table I
**PROSPECTS FOR PROTEIN
YIELD FROM POULTRY MANURE**

The figures refer to a 45,000-hen operation that includes the Cornell bioconversion process.

	Pounds per day
Fuel consumption	10,000
Wet manure produced (75% water)	11,400
Feed produced (10% water)	1,500-1,700
Protein recovered	600-700

was tested for growth on glucose over a range of pH and temperature. However, an important problem may have been encountered: The data suggest the possible existence of inhibitors of the ammonia conversion. At least one of these inhibitory agents may be produced by the cells as a byproduct of their growth. The presence of inhibitors could greatly restrict the yield of solids, lead to excessive processing costs because of the larger reactors, aerators, centrifuges, etc., that would be required, and make the use of a liquid-recycle stream difficult. These possibilities are being evaluated at the present time. If the natural flora is found to be inadequate, we plan to test several other process alternatives. The most probable approach would be to develop a "semi-pure" culture in the second stage. For example, methanol, a very inexpensive source of carbon, could be fed. Most organisms cannot utilize methanol, and so if the tank were seeded with a large quantity of a methanol-using organism, it would become dominant and control the reaction characteristics and the nutritional qualities of the product. An-

*"Instead of disposing of
manure, polluting the
environment in the
process, the resourceful
agriculturalist could
recycle it back to feed."*

other possibility would be to keep the pH in the second stage at a low level where only a few organisms could easily grow; such organisms might be lactobacilli or yeasts. In addition to testing the "semi-pure" culture approach, we plan to investigate carbon sources other than glucose (which is too expensive). Molasses will certainly be tested, along with any carbonaceous waste stream, such as whey, that might be economically attractive.

Since toxic compounds and pathogenic organisms could build up during a liquid recycle, we will monitor the concentrations of metals such as arsenic and copper and of common pathogens, such as *Salmonella sp.*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*. A simulated liquid recycle will be obtained by slurrying the manure with supernatant from the centrifugation process.

Throughout the course of the project, we intend to evaluate process alternatives in terms of their potential economic effect. Economic analyses will be made by some of the students in the Master of Engineering (Chemical) degree program as their design projects.

Each potential product must be tested also for nutritional quality and ease of recovery. Professor Austic will direct the nutritional studies. For rapid screening, we will analyze for amino acid content, total protein, and phosphorus. The more promising products will be subjected to feeding trials to determine the metabolizable energy, the nutritional quality of the protein, and the availability of phosphorus. The best product will be tested for its effects on egg production and quality.

This project is a good example of the



only through a multidisciplinary approach. The economic, microbiological, nutritional, and product engineering aspects of the process are strongly interrelated and cannot be evaluated independently. The required diversity in expertise is illustrated by the composition of the NSF-RANN overview committee for the project: George T. Tsao of the chemical engineering faculty of Purdue University; Leo S. Jensen of the poultry science faculty at the University of Georgia; Stanley B. Smith, feed specialist at Agway, Inc.; Cam C. Calvert of the Agricultural Environmental Quality Institute, United States Department of Agriculture; Leslie W. Driggs of the New York State Department of Agriculture and Markets; W. Dexter Bellamy, microbiologist at the General Electric Company; and Norman Hecht, poultryman of Hecht's Hatchery, Inc.

The world's food, energy, and environmental problems are very much intertwined. Their solution will require the efforts of engineers working not independently, but as members of multidisciplinary teams.

Michael L. Shuler, assistant professor of chemical engineering at Cornell, writes that the concept for the poultry-feed project described in his article was "hatched" by Bob Finn and Dick Austic during bus rides to work. (An article by Professor Finn is included in this issue; Professor Austic is a co-investigator for the project.)

Shuler has been at the University since the spring term of 1974, following completion of his doctoral work in chemical engineering at the University of Minnesota at Minneapolis. He studied at the University of Notre Dame for the B.S. degree, granted in 1969. Supporting graduate studies in microbiology, biochemistry, and mathematics helped prepare him for his current research in biochemical engineering. At Cornell he holds a joint appointment with the School of Chemical Engineering and the Institute of Food Sciences (at Geneva, New York), and he is also a member of the Graduate Field of Food Science and Technology.

His professional experience includes summer work with the American Oil Company in Whiting, Indiana, on the production of single-cell protein from petroleum, and with a process engineering group at the Army Ammunition Plant in Joliet, Illinois. He is a member of the American Institute of Chemical Engineers and the honorary society Tau Beta Pi.

FERMENTATION ALCOHOL

A New Look at an Old Process

by Robert K. Finn

The most economical way to convert renewable resources—crops and crop residues—to liquid fuel is probably to produce ethanol by fermentation. Today this ancient process is being looked at with new interest by nations that have long depended on petroleum as a major source not only of fuel, but of industrial alcohol for other purposes.

Because of cheap petroleum, the production of ethanol by synthesis from ethylene has increased in both United States and Western Europe ever since the 1930s; today more than 90 percent of the two billion pounds of industrial alcohol used annually by the United States comes from this source. On a worldwide basis, however, three-fourths of the nonbeverage alcohol is still made by fermentation. In Asia, Africa, South America, and Eastern Europe, it is more economical to make alcohol from molasses or various starchy plant residues than to use petroleum imported with hard currency. Even Japan has a sizeable fermentation industry. A question that concerns industrialists, planners, and researchers in the United States is what the prospects are for in-

creased use of fermentation processes in this country.

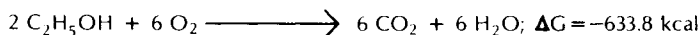
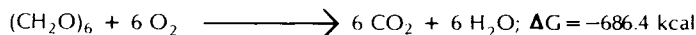
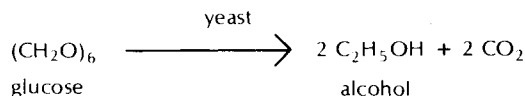
THE ANCIENT AND MODERN ART OF MAKING ALCOHOL

The art of fermenting sugar with yeast to produce beverage alcohol was probably practiced before the time of recorded history. Even the more sophisticated process of distillation to produce concentrated alcohol—the ethanol of commerce—goes back to the time of Napoleon. In 1811, in response to Napoleon's offer of a million francs for the development of practical processes for refining sugar, Jean Baptiste Cellier patented a method of refining beet sugar by extraction with alcohol, and subsequently he improved the process of alcohol recovery by introducing distillation. Cellier's patent of 1813 describes the essential features of a modern beer still: It shows the first use of a vertical column with bubble-cap trays operating on the countercurrent principle, and in addition to a partial condenser (invented by an earlier distiller) it had provisions for preheating the feed by condensing the overhead

vapors. This invention of Cellier won him a gold medal in 1816. A hundred years later, the technology was applied to petroleum refining and so formed much of the early basis of chemical engineering as a separate discipline.

ENERGY CONSERVATION AND PROCESS EFFICIENCY

The basic reaction in the fermentation process is the conversion of simple sugar such as glucose to ethanol in the presence of yeast. If the starting material is cellulose or starch, it must first be hydrolyzed to simple sugars. The alcohol is formed in about 95 percent of the theoretical yield, and even though half the initial weight and a third of the carbon is lost, most of the energy is conserved. More than 90 percent of the chemical energy contained in the glucose molecule is still in the alcohol molecule. Furthermore, about half of the "lost" energy is conserved by the yeast cells and used for synthesis of their own tissues; and since yeast protein for animal feed is a recoverable byproduct, the overall process is very efficient.



Above: The basic fermentation reaction, understood since prehistoric times; and a comparison of the energetics of combustion. The reaction is very efficient, since almost 95 percent of the theoretical yield of alcohol can be obtained, and because surplus yeast protein can be used for animal feed. The figures for energy change show that most of the chemical energy in the sugar molecule is retained in the alcohol molecule.

PROSPECTS FOR ETHANOL AS A LIQUID FUEL

Ethyl alcohol is actually superior to gasoline as a motor fuel. A gallon of ethanol, despite its relatively low thermal value, will produce as much power as a gallon of hydrocarbon if the engine is properly designed with high compression ratio. An especially valuable characteristic of ethanol as fuel is its smooth, low-temperature combustion without appreciable pollution.

For the United States, with ample supplies of coal and lignite, synthetic methanol will be more attractive as a liquid fuel than fermentation alcohol for some time to come. But other countries

without such fossil reserves are already beginning to consider the idea of "energy farms" for the production of ethanol. The most ambitious of such undertakings is under way in Brazil, which now imports 80 percent of its oil at an annual cost of three billion dollars. Brazil has committed almost a half billion dollars to the development of a program for producing alcohol from sugar cane and from manioc or cassava, a starchy root that can grow in the poorer soils in tropical countries and which is known in the United States in the form of tapioca.

A program as extensive as this one in Brazil has important social and political aspects, as well as economic impact. Not only are food carbohydrates expensive to burn as fuel, but also one can question the ethics of doing so in a hungry world. On the other hand, the alcohol-production program has an advantage in that in comparison with other ways of capturing solar energy, agricultural methods require much less capital and much more labor. For the developing countries, this combination is highly desirable, as pointed out in a recent re-

port on the Brazilian effort in *Science* (February 11, 1977).

COST OF RAW MATERIALS: THE KEY TO FEASIBILITY

Unless wastes are used or appreciable byproduct credit can be taken, more than half the cost of the alcohol produced by fermentation is in the carbohydrate at the start. Before World War II, when considerable alcohol was still made by fermentation in the United States, it was estimated that the cost of molasses amounted to three-fourths of the total cost of production in a large plant. Table I shows that of the primary renewable resources, molasses remains the cheapest. Direct comparison of corn and molasses cannot be based directly on such a tabulation, however; it is expensive to cook and hydrolyze the corn, but on the other hand, feed grains from corn are a more valuable byproduct than molasses slops. An old rule of thumb still holds: Use of corn can be justified only if its price per bushel is not more than seven times the price of a gallon of molasses plus eighteen or twenty cents. Moldy corn or other

Table I
COSTS OF CONVENTIONAL CARBOHYDRATES, SPRING 1975

	Wholesale Cost (cents/lb)	Carbohydrate (percent)	Cost of Carbohydrate (cents/lb)
Refined sugar	33.0	100	33.0
Hydrated dextrose	21.6	91	23.7
Corn syrup	14.4	81	18.0
Rice	10.3	74	13.9
Wheat	5.6	67	8.4
Corn	5.2	68	7.7
Molasses	2.7	55	4.8
Ethanol	14.9	95	15.7

Source: C. E. Dunlap (paper for Institute of Food Technologists, June 1975).

Table II
COSTS OF CELLULOSE, SPRING 1975

	Cost (dollars/ton)	Cellulose (percent)	Cost of Cellulose (cents/lb)
Unbleached sulfate pulp	310-315	95-98	16
Grass hay	40-50	20-35	6-12
Groundwood pulp	165-175	80-85	10
Sugarcane bagasse	15-17	50-55	1.6
Waste newsprint	14	75-80	0.9
Waste corrugated	10	75-80	0.65
Wheat or rice straw	Collection	45-50	
Corn cobs, stalks	Collection	35-50	
Municipal refuse	Negative	50-55	

Source: C. E. Dunlap (paper for Institute of Food Technologists, June 1975).

products unfit for food or feed can be effectively utilized in small scattered fermentation plants. A good example is the recent opening of a fermentation alcohol plant in Juneau, Wisconsin, that uses waste milk whey from cheese manufacture.

Because of reluctance to use food carbohydrates for fuel, considerable attention is being given to cellulose, a feed and fiber carbohydrate. Some cellulosic wastes are viable candidates for ethanol production, as indicated in Table II. One must take into account, however, the much greater difficulty and expense of hydrolyzing cellulose instead of starch to a fermentable syrup; lignin is almost always present in crude cellulose supplies, and this must first be broken down or removed in order to facilitate enzymatic hydrolysis. A further consideration is that once the cellulose has been treated sufficiently to enable it to be saccharified, there is again the question of whether to convert it to fuel or feed it to a ruminant animal. Finally, the costs of collection simply make it impractical to do much on a large scale with most agricultural residues. Concentrated sources are not

plentiful; conversion of all the municipal waste in the country into fuel alcohol by fermentation would produce a quantity of fuel equivalent to only 5 percent of the nation's current gasoline consumption.

STATE OF THE ART OF FERMENTATION TO ALCOHOL

The usual batchwise fermentation of molasses is conducted in tanks of several hundred thousand gallons capacity over a period of forty to fifty hours at an optimum temperature of

30°C. The heat of fermentation is appreciable (260 BTU per pound of sugar fermented), and since this is generated most rapidly during the first fifteen to twenty hours, adequate cooling can be a problem in the tropics where water temperatures are high. The molasses must be diluted with water from its normal strength of 55 percent sugar to perhaps 16 percent sugar; otherwise, the alcohol formed would bring fermentation to a halt. As every winemaker knows, fermentation is progressively slowed down as alcohol ac-

cumulates. A 16-percent sugar solution will yield 8 percent alcohol, but if concentrations were much higher than this, the process would be greatly prolonged. To provide inoculum for the fermentors, yeast is grown aerobically in dilute molasses to a high cell density in separate tanks. In some places, particularly in Russia, continuous or semicontinuous operation is used so as to obtain higher productivity.

Distillation is performed in two stages. The fermented molasses, called wash, is sent to a beer still. The overhead, containing 40 volume percent alcohol, is further distilled to yield a spirit that is 190 proof or 95 volume percent alcohol. This is an azeotrope, or constant-boiling mixture, which behaves almost as if it were a chemical compound. Its volatility is higher than that of pure alcohol. To "break the azeotrope" and produce absolute (100 percent) alcohol requires additional distillation in the presence of a third component such as benzene. Slops from the bottom of the beer still are dried for an animal feed supplement or sometimes used as fertilizer.

Even though it may be efficient in principle, fermentation has built-in process costs that are almost as immutable as the biochemistry. Distilling the wash requires some fifty pounds of steam for each gallon of commercial alcohol produced. Steam costs can amount to a third of the total cost of conversion, and despite schemes of vapor recompression and the like, little process improvement seems possible. Not much advantage can be gained by distilling solutions more concentrated than 8 percent ethanol, and below 4 or 5 percent, steam consumption becomes excessive, as indicated by the shape of



Fermentation for alcohol production has a long history.

Left: This historic photograph shows an open fermentor tub once used at the Old Taylor Distillery in Frankfort, Kentucky. The bubbles are from escaping carbon dioxide. (Photograph courtesy the National Distillers & Chemical Corporation.)

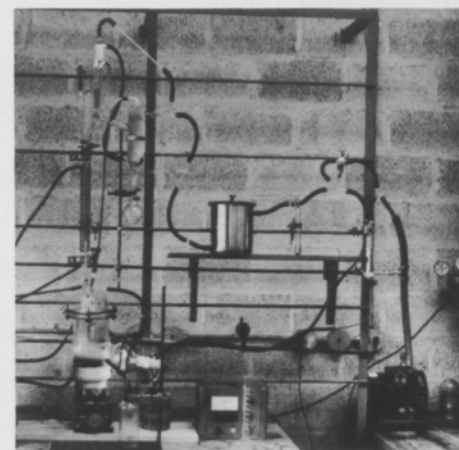
Below: A potential process for industrial alcohol is under development at Cornell. This apparatus was used in Professor Finn's work on the Vacuform process.

the vapor-liquid equilibrium curve. This fact places a penalty on dilute syrups prepared from starch or cellulose wastes.

ARE FURTHER PROCESS IMPROVEMENTS POSSIBLE?

Since the yeast is able to convert sugar to ethanol and carbon dioxide at 95 percent of the theoretical yield, a fact noted by Pasteur, one cannot expect any dramatic breakthrough by way of mutant strains (as has indeed been possible in antibiotics manufacture, for example). Several interesting developments that affect the rates of fermentation and hence the size of the equipment needed are worth noting, however.

One of these is the use of high concentrations of yeast to bring about very rapid fermentation. In work directed by Dr. Keith Steinkraus at the Cornell University Agricultural Experiment Station in Geneva, New York, it was shown that even a 25-percent sugar solution could be fermented to 12 percent alcohol in only three hours by a heavy yeast cream. Death of the cells is rapid, but by lowering the temperature



and enriching the mixture with vitamins, it is possible to achieve some cell multiplication. Of course, one way of holding a high yeast population is to conduct the fermentation in a packed tower of some sort, so that pellicles remain attached to solid surfaces. Such a falling-film process has been studied in a pilot plant for waste sulfite liquor by the Crown Zellerbach Paper Company and is also under investigation at Oak Ridge National Laboratories.

In the School of Chemical Engineering at Cornell, we have been exploring

*“...it appears likely that
many new plants for
fermentation alcohol will
be built in this country
over the next decade.”*

another approach to speeding up the fermentation: continuous removal of the inhibitory ethyl alcohol as it is formed. The fermentation is carried out under reduced pressure with simultaneous distillation. So as not to kill the yeast, it is necessary to maintain a pressure of 30–35 mm mercury at the optimal temperature of about 30°C. The principle of using vacuum to remove alcohol is not new, having been patented in 1948, but the claims were not verified by experimental data. Our first attempts at vacuum fermentation were unsuccessful, but the cause was traced to the extremely anaerobic environment of the yeast and we found that by supplementing the sugar solutions with sterols and fatty acids or by occasionally admitting air, the process could be operated successfully. We have conducted continuous fermentation for many days and envisage a full-scale “Vacuform” process as shown in Figure 1.

The proposed process offers several advantages. Direct addition of full-strength molasses is possible. Not only would the fermentors be smaller, but there would be less water to evaporate from the beer-still bottoms. By recycling a portion of the still-viable yeast, either directly or as a centrifuged cell cream, the fermentation rate could be further enhanced; moreover, if the recycled inoculum were aerated, no additional nutrients would be needed. Tests at Cornell and also at Charles Wilke’s laboratory at the University of California at Berkeley show that a concentration of sugar three times higher than the normal 16 percent can be fermented in only one-third the time, even without continuous cell recycle. Still higher pro-

ductivities were obtained by Professor Wilke when he recycled the cells.

In the Vacuform process, the heat of fermentation is used directly for distilling off alcohol, rather than being removed with cooling water as it is in the conventional process. But although this saving in energy represents about 7 percent of the latent heat required for distilling off the alcohol, the advantage is offset by a much greater energy requirement of the process: Because of the low pressure, a larger volume of noncondensable carbon dioxide must be pumped up to atmospheric pressure. This problem might be lessened by reducing the size of the fermentors, but then elaborate additional equipment would be needed to condense the alcohol at the specific low temperature and pressure. One obvious improvement would be to find thermotolerant yeasts, such as have been developed in both Russia and mainland China, that can ferment at 40° to 50°C. Use of such yeasts would permit higher pressures in the fermenter and would therefore reduce by half the energy needed to maintain the vacuum. Such a yeast is specified in the modified Cornell process design described below.

USE OF AN AZEOTROPE TO REMOVE ALCOHOL

A modification of vacuum fermentation that appears to be more promising economically is currently being studied in our laboratory. This “Azeoform” process is represented in Figure 2. The chief innovation is the addition of hexane, a paraffin hydrocarbon, to the fermenting mash to form a ternary low-boiling azeotrope that can be distilled off at a more moderate vacuum. We

Figure 1

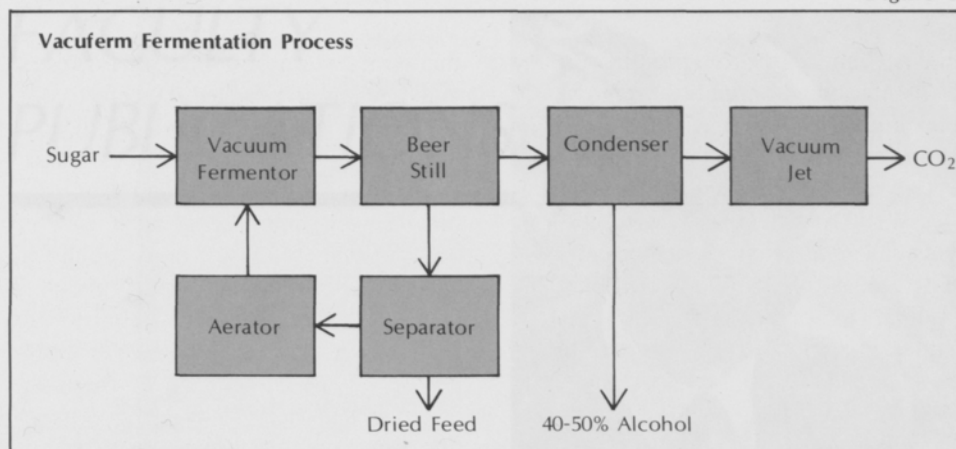
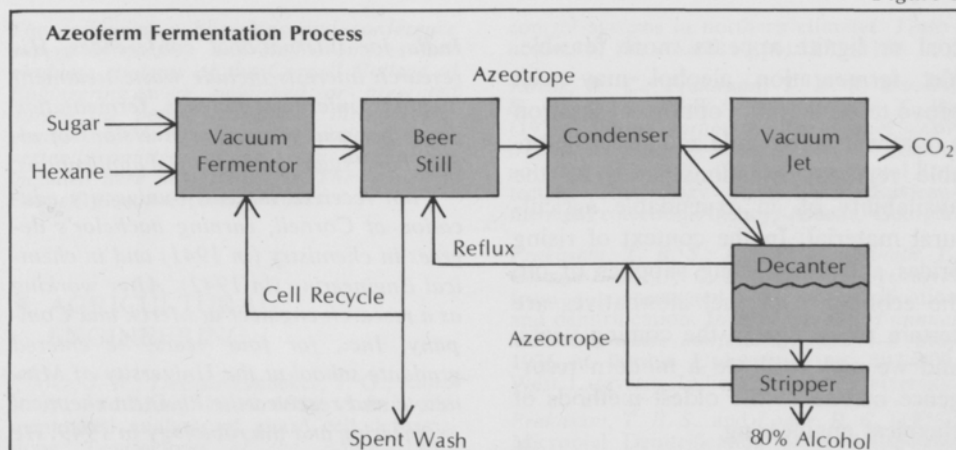


Figure 2



Figures 1 and 2. Simplified flow charts for Cornell-designed fermentation processes. Both systems are designed to use undiluted molasses, the cheapest source of sugar, as the starting material, although they could be adapted to other carbohydrate materials. With either process, the principal product, ethanol, could be further rectified as needed.

The Vacuferm process (Figure 1) calls for a temperature of about 30°C and a reduced pressure equivalent to 30-35 mm mercury. The holding time is about 12 hours. Carbon dioxide is removed by a steam jet ejector.

In a modified system, the Azeoferm process (Figure 2), hexane is introduced into the fermentor, which is operated at 40°C under vacuum conditions equivalent to 300 mm mercury for a holding time of 10-12 hours. A ternary azeotrope containing, by weight, 3 percent water, 12 percent ethanol, and 85 percent hexane is continuously distilled off and condensed with chilled water to give two liquid layers. The upper layer, containing more than 95 percent hexane, is returned to the still as reflux. The lower layer, amounting to an eighth of the total condensate, is redistilled at atmospheric pressure in a secondary column where hexane is stripped off as an azeotrope of substantially the same composition as that from the beer still.

have previously shown that in the absence of air, hexane does not inhibit the growth or metabolism of yeast.

We are just now beginning laboratory work on this process, but we have already made a rough economic comparison with classical batch fermentation. We chose preliminary designs for each process that would produce twenty-six million pounds of ethanol per year; the costs of final rectification steps were not included in the comparison, nor were other costs common to both processes. The analysis shows that costs

for steam and cooling water are about the same for both processes, but that equipment costs are considerably less for the Azeoferm system. The comparative figures for equipment are \$600,000 for the conventional system (two-thirds of this is for fermentors and heat exchangers) and only \$125,000 for Azeoferm (which requires a special condenser to handle the immiscible liquid mixture, but only one relatively small fermentor). Of course, many costs cannot be properly evaluated without operation of a pilot plant, but our esti-



mates are that the overall manufacturing cost for ethanol would be 15 to 20 percent lower with the Azeoform process than with the conventional batch system, assuming that the plant must be constructed.

U.S. PROSPECTS FOR FERMENTATION ALCOHOL

This preliminary conclusion brings us back to the question of the feasibility of fermentation processes for the United States.

Because of the increasing price for ethylene from petroleum, it appears likely that many new plants for fermentation alcohol will be built in this country over the next decade, to continue the supply of ethanol for its present industrial uses. The economic attractiveness of fermentation processes will be enhanced by the introduction of improved methods, such as Cornell's Azeoform process, which is expected to show its greatest savings over conventional systems in the area of capital investment.

Significant use of fermentation alcohol for liquid fuel seems less likely in this country; methanol obtained from

coal or lignite appears more feasible. Yet fermentation alcohol may well prove to be a viable option, at least on a relatively small scale and under favorable regional situations, such as the availability of an expendable agricultural material. In the context of rising prices and diminishing supplies of oil, the economics of fuel alternatives are certain to change in the coming years, and we may well see a modern resurgence of one of the oldest methods of chemical engineering.

Robert K. Finn, professor of chemical engineering, has been promoting the possibilities of microbial engineering techniques for some years, both in his research and through consultation and participation in international conferences. Last year, for example, he spent a sabbatic leave as a Guggenheim Fellow at the Institute of Microbiology in Zürich. He also attended the fifth International Fermentation Symposium in Berlin, continuing an association he began as a delegate to the first symposium held in Rome in 1960. He spent an earlier sabbatic leave in Stuttgart as a Fulbright Research Professor, and in the past few years has visited Japan and

India for international conferences. His research interests include waste treatment methods, microbial kinetics, fermentation processes, and enzymic conversions of alcohol and sugar for industrial applications.

Finn received his early university education at Cornell, earning bachelor's degrees in chemistry (in 1941) and in chemical Engineering (in 1942). After working as a research engineer at Merck and Company, Inc., for four years, he entered graduate school at the University of Minnesota and received the Ph.D. in chemical engineering and microbiology in 1949. He joined the Cornell faculty in 1955 after six years at the University of Illinois at Urbana, where he established a program in bioengineering.

Throughout his academic career, he has been active also as a consultant; organizations he has worked with include the Commercial Solvents Corporation, the Viobin Company, Versar, Inc., the Syracuse University Research Corporation, the Mobil Research and Development Corporation, and the International Minerals and Chemical Corporation.

He is a fellow of the American Association for the Advancement of Science, and a member of a number of professional and honorary societies.

FACULTY PUBLICATIONS

The following publications and conference papers by faculty and staff members and graduate students of the Cornell College of Engineering were published or presented during the period September through December 1976. Earlier publications inadvertently omitted from previous listings are included here in parentheses. The names of Cornell personnel are in *italics*.

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_____. 1976. Teat End Tissue Responses to Dynamic Changes in Vacuum Level. Paper read at 29th Annual Northeastern Mastitis Conference, 30 September-1 October 1976, in Chaffey's Locks, Ontario, Canada.

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Engineering: Cornell Quarterly

Published by the College of Engineering,
Cornell University
Edmund T. Cranch, Dean

Editor: Gladys McConkey

Circulation Manager: Beth Rugg

Graphic Art Work: Francis Russell

Lithographers: General Offset Printing Co.,
Springfield, Massachusetts

Typography: Eastern Typesetting,
Hartford, Connecticut 06103

Photographic credits for this issue are as follows.

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