FROM THE ARCHIVES

Workshop on Energy and Agriculture in Developing Countries (1981)

Pages
116

Size
8.5 x 10

ISBN
0309330408

Board on Science and Technology for International Development; Commission on International Relations; National Research Council

Workshop on Energy and Agriculture in Developing Countries

Airlie, Virginia

June 29-July 1, 1981

Board on Science and Technology for International Development
Commission on International Relations
National Research Council
United States of America

National Academy Press
Washington, D.C. 1981

81-0188
c. 1

These proceedings have been prepared by the Board on Science and Technology for International Development, Commission on International Relations, National Research Council, for the U.S. Agency for International Development, Washington, D.C., under Grant No. DAN-5538-G-SS-1023-00, Amendment No. 3.

INTRODUCTION AND SUMMARY OF RECOMMENDATIONS AND CONCLUSIONS

Faced with the rising price of fossil fuels and the need to increase food supplies, developing countries and development assistance agencies are closely examining the relationships between energy use and agriculture.

In response to a request from the Agency for International Development (AID), the Board on Science and Technology for International Development (BOSTID) convened a workshop, June 29-July 1, 1981, near Washington, D.C., to examine these relationships. Chaired by Emery N. Castle, president, Resources for the Future, the workshop considered not only energy used in agricultural production but also the energy used to transport, process, and store agricultural products and to prepare food for consumption.

The purposes of this workshop were to review existing issues and to advise AID of promising program opportunities to help solve energy-related problems in agriculture in developing countries. These issues include such questions as:

- How is energy used in agricultural production and postharvest operations in developing countries?

Note: This introduction includes statements made at the workshop by Emery N. Castle, chairman; Douglas Caton and Emmy Simmons, Agency for International Development; and Bill Stout, Texas A&M University, opening speaker at the meeting.

- o Where are energy-related costs the highest and which operations are most amenable to technological change?
- o In what ways have energy-related problems of agriculture, such as shortages of firewood, affected the environment adversely, and what remedies are available?

In designing programs to address these and other questions, AID must seek simultaneously to improve employment opportunities and food production in a developing country.

ENERGY AND AGRICULTURE IN PERSPECTIVE

When reading the report of this workshop, it is important to bear in mind the following. First, any adjustments that agricultural sectors in developing countries can make to minimize the problems and take advantage of developments in world energy markets depend on the broader context within which the agricultural sector of a specific country must operate.

Second, it must be remembered that more efficient energy use in the agricultural sector is one means of achieving economic growth with equity and security--not an end in itself--as are efforts to improve the balance of payments and attain self-sufficiency in energy and food. Thus it is important to select adjustments that yield the highest rates of return to the economy as a whole, using as far as possible prices and cost factors that reflect real opportunity costs. It is not, therefore, appropriate to select programs that save the most energy in physical terms, without considering the social, economic, and environmental costs involved.

Third, in most low-income nations development depends on increasing agricultural productivity. Experience worldwide has shown that such growth is positively correlated with intensified energy use. While every effort should be made to improve energy efficiency, it would be counterproductive with today's technology to starve the agricultural sector of energy supplies required for its future development.

Fourth, evidence suggests that people involved in agricultural production and related support services find it easier to adjust to higher prices or even limited but certain supplies of fuel than to adjust to unexpected changes in supplies. Policymakers can take steps to buffer the domestic economy against these uncertainties--for example, holding larger stocks of petroleum, food grains, or foreign exchange; setting up standby emergency allocation schemes; and giving more weight to energy and food self-sufficiency in project selection. However, because such steps may be expensive and must be taken cautiously, higher priority should be given to improving current markets and distribution systems to ensure that existing supplies are shared equitably and efficiently among regions and sectors of the country.

Finally, the largest proportion of energy consumed per capita in the rural sector is in the preparation of food, as indicated in Table 1. Although this fuel use has not normally been considered within the agricultural sector, the consequences for agriculture of the inevitable expansion of fuelwood and charcoal use are so profound--since deforestation is destroying the ecosystem in which future agricultural production must occur--that they must be addressed as a matter of priority in the energy-agricultural nexus. The provision of fuel on a sustained, renewable basis is essential to future agricultural production, as well as to the well-being of the producers and their poor urban counterparts.

TABLE 1 Breakdown of fossil and renewable energy use in the food system of rural populations of developing countries.

	Fossil energy		Renewable energy		Total	
	(kcal)	(Percent)	(kcal)	(Percent)	(kcal)	(Percent)
Production	130,000	6.50	490,000	24.5	620,000	31.00
Processing	15,000	0.75	20,000	1.0	35,000	1.75
Storage	5,000	.25	20,000	1.0	25,000	1.25
Transport	30,000	1.50	20,000	1.0	50,000	2.50
Preparation	20,000	1.00	1,250,000	62.5	1,270,000	63.50
TOTAL	200,000	10.00	1,800,000	90.0	2,000,000	100.00

Source: Pimentel, D. and Pimentel, M. 1979. Food, Energy and Society. Halstead Press, New York, New York, p. 125. (percentages added)

ORGANIZATION OF THE WORKSHOP

Workshop participants included a panel of specialists selected by BOSTID and a large number of AID personnel familiar with the practical and cultural aspects of energy-related problems in developing countries. Participants divided themselves into two working groups concerned with the elements of agricultural production and with transportation, processing, and other postharvest operations. After an introductory plenary session, the working groups met separately to discuss specific topics and draft reports on what they considered major problem areas. These reports were presented in a final plenary session and are included in this volume.

The wide variety of conditions found in developing countries posed a considerable challenge in the preparation of this report. Some countries are dependent on imported forms of commercial energy, usually liquid petroleum fuels, while other countries are somewhat more endowed in this respect. Some countries have found an area of comparative advantage, are engaged in international trade, and are well on their way to greater economic development, while others are still preoccupied with the problems of a subsistence economy and are searching for ways to provide basic necessities for a rapidly growing population. Thus in preparing this report, it was necessary on the one hand to strive for fundamentals that apply in most circumstances. Such an effort placed a premium on the ability to see both energy and agriculture in a global context, not specific to a particular country or region. On the other hand, when considering energy and agricultural issues, it is important to keep in mind the diversity of countries and regions and the variability in situations. Therefore, some of the recommendations in this report do not apply to all Third World countries or situations.

Throughout this report, an attempt has been made to specify potential AID activities that are suggested by problems involving energy and agriculture. In some instances, the answers are not readily available and developing them will require time, effort, and significant investment. In other cases, results can probably be obtained rather quickly by the education of key groups or by other means.

Finally, it is important to understand that this report does not claim to provide a comprehensive treatment of energy use in economic development or in agriculture. Rather, it serves as a step toward providing greater recognition of the relationship between making optimal use of energy in agriculture and meeting goals for social and economic development.

SUMMARY OF RECOMMENDATIONS AND CONCLUSIONS

Each working group report contains specific conclusions and recommendations that merit attention. In summary, they are:

General

- Increasing energy prices have stimulated worldwide interest in new technologies and strategies that would make food systems more efficient and use renewable energy alternatives. However, technologies and strategies must be appropriate for local conditions, must maintain or increase food supplies, and must be economically viable.

- Given the diversity among regions, variability in conditions, uncertainty in resource bases, and future development of technologies, developing countries must formulate energy-use policies that are flexible enough to withstand modification as conditions change.

- Given the high cost and scarce supplies of energy in developing countries, the following general strategies may be applicable and should be considered in national food strategies:

  - Growing low-volume, high-value export crops and importing food, taking into consideration normal fluctuations in markets

  - Increasing production (acreage) of low energy-input crops

  - Decreasing intensive feeding of grain to livestock, which are inefficient converters of grain

  - Where appropriate, emphasizing crop production of high-protein, high oil-content crops for food and fuel

  - Increasing production, if possible, for food and fuel where people are concentrated (i.e., growing more food in and around urban areas), shifting crop production to the most favorable areas, and exchanging production between regions or between countries

  - Growing only those crops best adapted to particular regions within countries.

- Since the greatest amount of energy consumed in the rural sector is used to cook food, and because of the important effects of deforestation on agriculture, cooking must be considered along with energy use in agriculture as a whole.

Mechanization of Agricultural Production

- If more food is to be produced in developing countries, more energy-intensive mechanization is required. Human and animal power may not be sufficient to produce additional food rapidly enough to feed growing populations. Power requirements for deep-rooted crops and the need for timely field operations often leave no choice but to mechanize. Moreover, use of mechanical power can often reclaim cropland formerly used to produce feed for draft animals and can make possible agricultural production on marginal land that would otherwise be unusable. However, problems can accompany mechanization: inadequate management, fuel shortages, safety hazards, and relocation or redundancy of labor, particularly women.

Fertilizer and Biological Nitrogen Fixation (BNF)

- Natural sources of nitrogen, when properly managed and conserved by crop rotations and recycling crop residues and manures, have proven adequate for a modest level of cereal yields in the past in many developed countries. However, they are not adequate for the intensive agriculture (high yields and multiple crops) that is needed to feed the present and future world population. The present challenge is to find methods to supplement natural nitrogen fixation processes with chemically fixed, inorganic, nitrogen fertilizer without interfering with them.

- The most urgent fertilizer-related objective is more efficient use of fertilizers at the farm level, particularly nitrogen fertilizers which are by far the most energy intensive, the most expensive, and the most popular. Means of increasing efficiency in the use of fertilizer include more balanced use of fertilizer, better timing and placement, and correction of known deficiencies of secondary nutrients and micronutrients in the soil. Long-term attention needs to be given to more precise determination of nutrient requirements of crops and to improved forms of fertilizers that are easier to use efficiently. Greater use of compound fertilizers may facilitate more balanced use.

- Continued research is warranted to identify farm management practices that make full use of biological nitrogen fixation and waste organic materials.

- There is need to generate further information on the roles and implications of various economic incentive programs, including fertilizer subsidies. This should be done in the context of fertilizer-related national goals, including (1) improving the efficiency of fertilizer use, (2) achieving balanced fertilization, and (3) saving nonrenewable energy.

- Better timing and placement in the use of fertilizers require providing information to farmers and timely delivery of fertilizers to the farm. Continued research is needed to define plant nutrient needs and the most effective timing and placement of fertilizers.

- Biological nitrogen fixation could help to ameliorate energy supply problems and to offset the costs of imported food fiber, fuel, and fertilizers in developing countries by allowing, for example, the more widespread adoption of fast-growing, nitrogen-fixing trees and shrubs for feed, fuel, and construction purposes. Currently, such species are not widely used in many developing countries, nor is their potential for large-scale production understood because, until recently, commercial nitrogen fertilizers were less expensive, their management was more easily understood, their manufacture using cheap energy was uniform around the world, and price and profit margins were easily calculable by producer and consumer. By comparison, countries trying to establish a policy for import substitution using BNF techniques are faced with a series of unknowns that must be addressed. A coherent program for exploitation of BNF might include the following elements:

    - Highly versatile information systems for data collection and evaluation to establish what is known about the use of BNF

    - Definition of the environmental stress characteristics of the agricultural production areas for which improvement is desired

    - Systems for speeding exploration, sampling, and subsequent test introduction of promising genetic material

    - Information dissemination systems so that new knowledge can be used efficiently by rural producers.

To carry out such a program, developing countries will require a cadre of scientific and technical personnel capable of adaptation testing and dissemination of results.

Pest Control

- Integrated pest management (IPM) programs appear to offer a reasonable solution over time to pest-related problems in developing countries. Because such programs require trained personnel, training programs in pest management should be initiated in cooperating countries and integrated within existing extension programs wherever possible.

- Training manuals must be developed or modified to reflect the problems and needs of specific areas.

- Areawide pest suppression or total pest population management should be considered where farmers will benefit from reduced energy requirements, increased levels of crop protection, reduced environmental stress, and simplified pest control.

- Accurate and rapid identification of the pest organism and associated species is essential to any IPM program. Worldwide, taxonomic services on most arthropods and many other pests are needed. The establishment of regional diagnostic centers that would serve groups of developing countries should be supported.

Water for Crop Production

- The first step in reducing energy requirements in irrigation is to seek by any means to conserve and reduce requirements for irrigation water. Only after steps to save water have been completed should steps to use alternative energy sources be taken.

- All alternative sources of energy for irrigation, as opposed to purchased commercial energy, should be explored. The alternative energy supply must be dependable and available during the critical flowering and fruiting stages of crop growth. Alternative energy sources must not be subject to excessive operational problems, and must be within the economic reach of the farmers.

- Improvement and repair of earthen watercourses can reduce water losses by 40 percent or more.

- On-farm irrigation practices can be improved by checking the efficiency of irrigation pumps and using the best crops for irrigation. The actual water requirements of crops should be determined so that the amount and timing of each irrigation are proper for crop needs.

- Surface water supplies should be used when available.

- Developing countries should place new emphasis on management, extension, and training, and on the adaptation and transfer of appropriate technology from developed countries.

- Research, other than that associated with adapting existing technologies to conditions in developing countries, should receive lower priority than efforts to improve management and water conservation.

- Research and development should be directed to alternative systems for managing drylands through agroforestry and ecological improvement to relieve the need for energy- and water-intensive irrigated crop production.

Transportation

- In some countries the full impact of rising energy costs has not been passed on to the cost of transportation fuel. In addition, the cost of energy is frequently a relatively small part of the total transportation bill, not enough to induce consumers to take strong conservation measures. Governments should therefore review their energy pricing policies and related programs to ensure that consumers are receiving strong incentives to use energy efficiently.

- Typically transportation is heavily regulated either by explicit government transportation policies or agricultural and other policies affecting transportation, which usually evolved during an era of low-cost energy supplies. With the increasing need to manage energy resources, these policies should be reexamined to identify particular energy inefficiencies and modified as necessary to balance use of energy against development objectives. In this light, national pricing policies for agricultural commodities should be reevaluated when they create uneconomic production patterns, uneconomic markets, and increased transportation costs.

- Efforts to conserve energy in agriculture-related transportation should focus on:

-- Training and assistance directed toward improving local management skills and techniques, particularly in urban traffic management, in rationalizing the operation of the transportation system, and in load matching between outbound and inbound shipments to increase load factors and thus energy efficiency.

-- Research activities: applied research should be encouraged and technical information and results should be transferred to developing countries, particularly in the areas of alternative fuels, fuel extenders, and appropriate technologies for local transportation.

-- Technical training: lack of skilled mechanics and other technicians limits the potential for technological improvements in efficiency and may in fact reduce efficiency because sophisticated equipment that is improperly maintained or operated may use more energy than the "less efficient" equipment it replaces.

The overriding goal in all these areas is transportation systems that move the maximum amount of agricultural produce to markets and consumers as quickly, cheaply, and efficiently as possible. The energy component of such a system must be kept firmly in mind, but saving energy should not be considered a higher priority than this overriding goal.

Postharvest Food Systems

o Reduced postharvest losses could mean conservation of energy expended previously in the food production process. This is particularly important where energy-intensive fertilizer and other inputs have been used.

o Increased processing of foods can lead to energy conservation by increasing shelf life, reducing bulk or weight to be transported, reducing the amount of home cooking required, or making available more by-products for further processing and use.

o The impact of new food technologies on consumers and particularly on the special needs of rural women must be noted.

o In view of the relative lack of attention to postharvest food losses in many countries, promotion of food conservation through information and economic incentives is needed.

Postharvest Food Systems: Energy Supply Objectives

- o Assessment of the various energy inputs into food processing indicates that solar energy-based technologies are the most suitable for increased near-term exploitation in developing countries. Consequently, a major emphasis should be placed on using solar energy in its various direct and indirect forms.

- o The efficiency of traditional fuel use must be improved. More traditional energy sources must be used to provide processed foods in urban areas. New technologies can help in the long term, but conservation is necessary immediately. In addition, a number of alternative processes would reduce energy inputs:

  -- Substitution of solar energy for mechanical drying and cooking

  -- Substitution of indigenous fermentations for canning

  -- Substitution of evaporative cooling and heat sinks (cool water, earth, shade, elevation) for mechanical refrigeration (a growing demand as Western styles are adopted, e.g., soft drinks, beer)

  -- Increased cooking efficiency--soaking solutions, minimum cooking, precooking, insulated holding, use of pressure cookers, better stoves.

- o Present food shortages, the limited resources available for conducting surveys, and the need to push forward with existing energy technologies for increased food production and processing efficiency dictate that energy surveys be given limited financial and managerial support compared with interventions that will have near- or long-term effects. However, limited continuous surveys to monitor energy use, output, and efficiency before and after intervention will be invaluable for assessing cross-sectoral effects and relative success of energy-related interventions in the food supply system. The creation of national food conservation policy bodies to identify critical areas of food loss and to recommend corrective measures is amply justified. These bodies should also be able to assess opportunities for energy conservation within a nation's agricultural production and postharvest systems.

- o The overall goal in developing countries is not to reduce the total energy expended in processing food, but, on the contrary, to increase the amount of processed foods where postharvest food losses reflect waste of both energy and food. To do this will require more energy. The most desirable energy system for a particular locality, the efficiency of each system, and the economic and cultural impacts of using alternative energy systems for food processing and consumption vary widely. Training is therefore crucial for making wise choices among alternative energy systems and deserves strong support.

o Many small, low-cost devices have been developed and are repeatedly cited in diverse reports and handbooks as having promise for use in the postharvest food system. However, information is rarely available on the extent to which such devices have been adopted, modified, or rejected, and constraints and reasons for failure are rarely reported. For relatively little expense, it would be extremely useful to examine by case study the successes and failures of efforts to promote appropriate technologies. The case study should include a technical and social analysis and examination of the processes or approaches used to develop and promote appropriate technologies. Various approaches to such a study, including the appropriate technology "supermarket" and the model village approach, have been documented. These approaches could be evaluated to produce guidelines for future efforts tailored to user needs.

Energy and the Food Consumption System

o In a developing country fire is often used for many purposes: cooking, keeping insects away, preserving food, security, social interaction, lighting, and heating. Therefore, energy efficiency alone by may not determine what is socially desirable and acceptable.

o Higher fuel costs and convenience affect urban consumption patterns and cooking methods. Urban residents are increasingly using ready-to-eat cereal products and other convenience foods that are precooked by commercial vendors. These products shift cooking from the individual household and allow for economies of scale. At the same time, the demand for wheat products goes up, entailing foreign exchange costs. Such changes require:

-- Better documentation of the trend toward vended foods reported for cities in Africa, India, and Sri Lanka, and its relationship to energy costs

-- Experimental work on foods made from wheat substitutes that can be prepared with the same convenience and greater economy for the consumer: cassava cake, maize, millet cake, etc.

o The recent abundance of low-cost fuels has obscured the extent to which some areas have diets based on an earlier era when fuel was scarce. A book that reviews cookery styles should be prepared. Foods are consistent with cultural patterns and that require a minimum of energy in cooking should be developed.

o Analysis of the impact of rising oil prices and a growing scarcity of traditional fuels indicates that generation of biomass (particularly for charcoal) is critical to satisfying energy needs for cooking in urban areas and, thereby, relieving pressure on rural areas. To take advantage of biomass production, efforts should be undertaken to:

-- Select, collect, store, and distribute adequate supplies of much more diverse selected genetic material

-- Reconsider policy options concerning land use, ownership, and rights with a view to supporting revegetation and renewable fuelwood production

-- Develop a more effective mechanism for giving farmers access to genetic and technical resources

-- Strengthen forest services by training multipurpose foresters and supporting the integration of forest services into agroforestry production systems.

Reforestation

o Reforestation for fuelwood purposes or the production of biofuels is a top priority in the development of alternatives to fossil fuels and should receive major emphasis in AID's assistance to developing countries.

o AID should create a cadre of forestry specialists and, with its help, devote attention to the following goals:

-- Identify areas that are most in need of reforestation, determine what fuel crops are most appropriate for such areas (possibly a combination fuel- and food-producing trees), and explore means of motivating host countries--in both the public and the private sectors--to plant such crops.

-- Launch a training program for foresters in developing countries.

-- Set up demonstration programs in several cooperating countries.

-- Provide financial assistance for large and small reforestation projects in selected areas until they become self-sustaining.

-- Develop and support fuelwood projects that will provide sustained energy sources for food processing and preparation and a better quality of life.

REPORT OF WORKING GROUP I:

ENERGY IN AGRICULTURAL PRODUCTION

INTRODUCTION

Energy for world agriculture is a necessity, not a luxury. People in developing countries commonly eat about three times as much food energy as they can produce through manual effort, assuming a daily food intake of 2,000 kilocalories (kcal) and a manual power output of 75 watts (1/10 horsepower) for a 10-hour workday.

Agriculture is an energy conversion process--the conversion of solar energy to food energy. Agricultural productivity is greatly increased by judicious use of fossil energy in the form of, for example, fertilizer, fuel, and pesticides. However, because world supplies of fossil fuels are waning and their prices are rising, alternate sources of renewable energy and more energy-efficient agricultural systems are needed to maintain food supplies and the quality of life.

Increasing energy prices have stimulated worldwide interest in new technologies and strategies that would make food systems more efficient and use renewable energy alternatives. However, technologies and strategies must be appropriate for local conditions, must maintain or increase food supplies, and must be economically viable.

Typical operations in agricultural production are outlined in Figure 1. All agricultural operations require energy in one form or another--human labor, animal power, fertilizer, fuels, electricity, etc. Fertilizer (especially nitrogen) and pesticides are heavily

AGRICULTURAL PRODUCTION

Preparing the land

- o Tillage
- o Contour and drainage grading and maintenance

Planting

- o Seed genetics
- o Seed production
- o Germ plasm diversity

Irrigating the land

- o Well drilling
- o Water pumping and drainage
- o Land levelling
- o Canals, dams, and other structures

Applying nutrients

- o Commercial N, P, K, Ca, Mg, S
- o Nitrogen fixation
- o Growth promoters
- o Soil amendments
- o Organic materials

Controlling pests

- o Insect
  - chemical
  - nonchemical
- o Weed
  - tillage and other nonchemical
  - herbicide
- o Predators
  - rodents
  - birds

Controlling disease

- o Pesticides
- o Nonchemical

Harvesting*

FIGURE 1 Operations in agricultural production requiring energy. *Though not strictly part of the production process, harvesting is included here for convenience.

dependent on fossil fuel feedstocks. Mechanical work is necessary for all farming operations including tillage and water pumping. In developing countries, there is limited room for conserving commercial energy in production operations because so little is used (see Table 2). However, productivity and, therefore, quality of life can often be improved by using more energy--for example, in fertilization and in postharvest operations.

TABLE 2 Opportunities for conserving energy in agricultural production.

Preparing the land	-- Reduced or zero tillage (assuming no increased chemical usage) -- Chisel vs. moldboard vs. disk plowing
Irrigating the land	-- More efficient pumps -- More efficient water use on farms -- Reducing water losses in water courses and canals -- Salinity control
Applying nutrients	-- Efficient application of fertilizers -- More energy-efficient formulations of fertilizers, including organic fertilizers from human and animal wastes -- Energy-efficient manufacture of fertilizers -- Proper testing of soil -- Biological nitrogen fixation
Controlling pests and disease	-- Biological methods -- Integrated system -- Ultra low volume sprayers -- Resistant varieties of seeds/plants -- Intercropping
*Harvesting	-- Increased efficiency of equipment use including reducing loss

*Though not strictly part of the production process, harvesting is included here for convenience.

Energy inputs in agriculture can be increased by allocating more fossil fuels or by developing renewable alternatives for use on farms. Technologies for using renewable alternatives on a small scale (solar energy, wind energy, hydroelectric power, biomass fuels, etc.) are constantly being improved. However, site-specific, life-cycle economic analyses of such technologies must be conducted to determine their economic feasibility. Although this may seem an overwhelming task considering the diversity of applications, modern hand-held, programmable calculators available for a few hundred dollars make this task more manageable.

If the agricultural production sectors of developing countries receive the appropriate economic signals, and the knowledge, skills, and access to credit needed to take advantage of these signals are available, many of the adjustments necessary for more efficient use of energy in agriculture will not require special government programs. For example, farmers will change cropping techniques in ways that reduce energy costs if it is clearly profitable for them to do so and if the required inputs are available on a regular basis. However, only limited improvements in many technical relationships--for example, the efficiency of a pump or better plant growth resulting from various fertilizer applications--can be expected as a consequence of improvements in the functioning of economic markets. In many areas, additional research will be needed to make significant progress in the long run, and it will not occur in the agricultural sector of most developing countries without direct intervention by the government. Thus the following recommendations emphasize the need to give higher priority to research in specific areas.

Given the high cost and scarce supplies of energy in developing countries, the following general strategies may be applicable and should be considered in national food strategies:

- Growing low-volume, high-value export crops and importing food taking into consideration normal fluctuations in markets

- Increasing production (acreage) of low energy-input crops

- Decreasing intensive feeding of grain to livestock, which are inefficient converters of grain

- Where appropriate, emphasizing crop production of high-protein, high oil-content crops--for food and fuel

- Increasing production, if possible, for food and fuel where people are concentrated--i.e., growing more food in and around urban areas

- Shifting crop production to most favorable areas and exchanging production between regions or between countries

- Growing only those crops best adapted to particular regions within countries.

GERM PLASM

Available seed or other planting material for each crop constitutes the germ plasm on which production of that crop is based. Plant breeding programs, which increase the number of crop varieties with desirable characteristics, depend on the worldwide pool of genetic material, including wild varieties, for the diversity that is necessary to support plant breeding.

Efficient agricultural productivity ultimately depends on the genetic characteristics of the crop and on the selection of the most suitable strain or variety of crop for local conditions existing in the region.

International and national agricultural research centers under the auspices of the Consultative Group on International Agricultural Research (CGIAR) have carried out plant breeding programs for the major food crops and have developed the so-called "miracle" rice varieties and the strains of wheat and root crops and legumes that have supported the "green revolution" in many countries. The extensive variety trials organized for ranges of crops on both a national and regional basis provide valuable information about the response of crop varieties to different soil types and cultural practices.

To date, most germ plasm research has been directed toward increasing crop yields per unit area per day and maximizing economic return to the producer. Some research has concerned other crop attributes--e.g., short and strong stems to support heavier seedheads without lodging; protein quality; resistance to disease, insects, and damage in storage--which have implications for other uses. Very little research has been directed specifically to energy considerations, although in forest genetics the selection of fast-growing, higher quality tree species may implicitly also support higher energy productivity of biomass; most forestry research has been geared to quality of lumber, uniformity of stands, and disease resistance rather than energy content.

The selection of the best germ plasm for energy characteristics in crop breeding is a complex topic that has many ramifications. It remains largely speculative and in the domain of basic research rather than technology likely to be available soon for application in developing countries. For this reason, the topic was not included as a separate subject of discussion at this workshop. However, for completeness, we provide here some examples of the need to assess the potential of a number of aspects of germ plasm selection directly related to energy use in agriculture in developing countries:

- Multipurpose crops might provide higher proportions of residues to be used for energy even at the expense of reduced food content. (The risk of losing topsoil and nutrients should be carefully weighed against potential energy benefits.)

- Fuel quality of crop residues would be greatly enhanced by lowering the silica content in rice husks, straw, and peanut hulls, if this could be achieved without affecting productivity, lodging, or pest resistance.

- Other opportunities may result from higher energy costs and would make selection for energy factors feasible, such as response to lower levels of fertilizer use (i.e., the converse of efforts to increase biological fixation), improved water efficiency, and greater pest resistance, which might eliminate the need for a particularly expensive pesticide. Although market forces presumably will encourage these potential economies, developing countries are frequently the last to derive the benefit from new technologies unless governments and technical assistance agencies provide support.

MECHANIZATION OF AGRICULTURAL PRODUCTION

Developing countries should analyze their specific situation in terms of labor availability or shortage and other factors before making decisions regarding the type of mechanization needed. Consideration of large-scale mechanization may not be appropriate in a number of developing countries.

As discussed at this workshop, mechanization includes the use of tractors and machines for land preparation, planting, cultivation, and harvesting. The purposes of mechanization are:

- To increase the productivity of the farm family or to multiply its ability to do work

- To improve the quality of work or to make it less arduous

- To do jobs that cannot be done manually or to overcome time constraints of critical operations. For example, land clearing is difficult to accomplish without specialized equipment such as root rakes, root plows, and heavy-duty offset disk plows.

Mechanization usually improves yields through better land preparation, more precise placement of seed and fertilizer, and more efficient harvesting. Mechanization also encourages the production of difficult crops, such as soybeans. Worldwide soybean production probably would not have reached its current level without development of the combine (combined harvester-thresher).

In labor-short countries, mechanization could reduce the periodic fluctuation in demand for labor. For example, when production and harvesting of a seasonal crop are mechanized completely, peak labor requirements are smoothed out and seasonal labor does not need to be hired specifically for transplanting and harvesting.

Mechanization and Liquid Fuels

Mechanization depends on the use of liquid fuels, chiefly diesel fuel which is widely used in tractors, trucks, and other farm engines. The substitution of biomass-based fuels for petroleum fuels has received considerable attention worldwide. Although ethanol is the most commonly proposed alternative for gasoline, thus far only Brazil has implemented an extensive national policy to extend gasoline fuel with ethanol. Gasoline engines need few modifications to burn mixtures of up to 20 percent ethanol in gasoline, and Brazil is producing automobile engines that can burn 100 percent ethanol. Diesel fuel is more difficult to use with ethanol.

Field tests have shown oils from oil palm, safflower, sunflower, soybeans, peanuts, coconut, corn, cotton, and rape seed to be successful diesel fuel alternatives. These oils have combustion characteristics similar to diesel fuel but with slightly lower Btu output. Extensive tests in Brazil, South Africa, Australia, and the United States show that degummed sunflower, peanut, and soybean oil mixed with diesel fuel can be successfully used in diesel engines having indirect injection systems. The problems of incomplete combustion of such oils used in direct injection engines has yet to be resolved. However, transesterification with methanol to form the methyl esters has been employed successfully in recent tests. The maximum permissible percentage of vegetable oil must be determined by regions, based on the cost-benefit ratio.

In many developing countries, gas from excess biomass, methanol, and ethanol extenders for spark ignition engines, and vegetable oils (or their methyl esters) for diesel engines, are promising alternatives to increasingly uncertain supplies of high-cost petroleum fuels. The higher prices and lower Btu content of these alternatives can be offset by balance-of-payments benefits and assured domestic agricultural production of food, fiber, and fuel. To countries rich in land and water resources but poor in petroleum, the knowledge that they can improve their balance of payments and stimulate their agriculture, while producing alternative fuels domestically, can be very valuable.

Mechanization Under Three Sets of Conditions

In a system where there is incentive to produce more food and capital is available either internally or externally, a farmer's cropping system will be defined by one of the following sets of conditions:

I. Abundant labor with restricted land and water resources

II. Abundant labor with sufficient land and water resources

III. Shortage of labor with sufficient land and water resources

Management, education, and training (operation and maintenance of machines on site) are important for mechanization in all three of these situations, as are solutions to local application problems. Local manufacturing of farm implements depends on a country's technological capability and availability of materials. Pressures for local manufacturing are high in I and lower in II and III.

Technology transfer in agricultural mechanization varies significantly among the three situations. Situation I is labor intensive with slow, deliberate mechanization and a minimum of capital investment in machinery. This system makes impractical the efficient growth of some deep-rooted crops that require deep tillage, such as cotton, sugarcane, and soybeans, and minimizes the potential for multicropping.

Situation II involves an intermediate level of mechanization with a blending of animal and small-tractor power. It is a practical system where both human and natural resources are adequate and animal power can serve as power, transport, and food. This system provides time to train and develop operators.

Situation III encourages rapid mechanization with high-level technology and maximum use of large, efficient tractors and implements. This system requires more capital but is more energy efficient (more work done per liter of fuel). It provides faster production of more food, greater potential for export, permits two to three plantings per year for certain crops, such as soybeans, and the potential for early improvement in the standard of living. The high degree of mechanization provides the opportunity for land leveling and contouring to conserve water and soil.

If more food is to be produced in many situations in developing countries, more energy-intensive mechanization is desirable. Human and animal power may not be sufficient to produce additional food rapidly enough to feed growing populations. Power requirements for deep-rooted crops and the need for timeliness of field operations often leave no choice but to mechanize. Moreover, use of mechanical power can reclaim cropland formerly used to produce feed for draft animals and can make possible agricultural production on marginal land that would otherwise be unusable.

If farms are too small for efficient or economic mechanization, the following alternatives should be considered:

- More effective use of draft animals and mechanical linkages
- Forming farm machinery cooperatives
- Encouraging farm contractors to sell services to small farmers
- Encouraging pooling or exchange of machines and tractors
- Providing a state machinery pool (the least desirable alternative).

Problems of Mechanization

Problems that may accompany mechanization include inadequate management, fuel shortages, safety hazards, and relocation of labor.

Inadequate Management. If mechanization is not properly managed, the effect will be failure or delay. Formal and extension education of farm managers is essential. For example, estimating the proper size of tractors can be done by using rules of thumb or determined more precisely by calculations using weather data and information on soil types, crops, geographic area, etc. Implements can be matched to tractors by using published data available through the American Society of Agricultural Engineers (ASAE 1981a).

Shortage of Fuel. A community can minimize hardships during periods of fuel shortage by (1) keeping a seasonal supply of fuel; (2) producing some of their own fuel, such as vegetable oils or alcohol; or (3) keeping some animal power available. However, (1) and (2) may be too costly.

Safety Hazards. The use of farm machinery increases the risk of serious accidents. Regulations or laws alone have generally not been effective in reducing the number of farm accidents. However, the number of machinery-related accidents can be reduced by providing machine operators with extension education or training and by advocating proper design of farm tractors and machines. Developing countries should insist that machines being imported or manufactured locally be equipped with safety devices, such as power take-off shields, fenders, and guards. The ASAE standard "Safety for Farm Machinery" (ASAE 1981b) provides an excellent guide.

Labor Relocation. As farm laborers acquire skills as machinery operators, mechanics, and welders, their relocation may temporarily disrupt agriculture. However, such relocation would provide skilled workers for manufacturing and service jobs in other sectors of a nation's economy.

Fuel Conservation. When the fuel supply is limited, first priority should be given to using it for tillage, which should be reviewed to determine possible fuel savings. For example, for certain climatic conditions and soils the use of minimum tillage and chisel plowing is cost effective. However, management becomes somewhat more complex when minimum tillage is used.

It is much more productive for human labor to be used to operate tractors and other power sources rather than to be used directly for power. A 10-horsepower tractor can do 100 times more work in a day (when pulling a plow, for example) than an average man, although less energy efficiently. As labor costs increase--efficiencies of production must increase with them--mechanization will become increasingly necessary.

FERTILIZER AND BIOLOGICAL NITROGEN FIXATION*

If any one of the 16 essential plant nutrients is lacking, a plant cannot complete its life cycle--from seed germination to flowering to viable seed production once again. Of these 16 elements, three (carbon, hydrogen, and oxygen) are obtained from air and water. The six so-called macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur) must be supplied by commercial fertilizers, soil amendments, or recycled organic materials when soil supplies are inadequate. The first three have traditionally been the main concern of the fertilizer industry and are known as primary nutrients, but increasing frequency of deficiencies of the other three has forced attention to be given to supplying one or more of them in fertilizers. The other seven essential elements (boron, chlorine, copper, iron, manganese, molybdenum, and zinc) are called "micronutrients" because plants require them in small quantities, less than 1 kg/ha. Supplies of these are usually adequate but increasing incidence of deficiencies of some of them, such as zinc, have been noted in some developing countries.

Nitrogen is largely regarded as the most important fertilizer nutrient because its supply more often limits crop yields, although phosphorus is the limiting factor in many tropical soils. However, nitrogen fertilizer is used in much larger quantities in developing countries, and its manufacture is by far the most energy intensive. Although elemental nitrogen is abundant in the earth's atmosphere, plants cannot use it until it is "fixed" in chemical compounds.

Nitrogen fixation requires energy, whether by natural or man-made processes. Nature's fixation of nitrogen is dramatically seen in high-energy discharges of lightning which cause the nitrogen and oxygen of the air to combine to form nitrogen oxides that react with water and eventually form nitrates in rain water or soil. Fixed nitrogen brought down by rainfall may average 5 kg/ha and originates partly from meteorological sources and partly from decaying vegetable matter. Nitrogen is also fixed in nature by biological processes through microorganisms in the soil. This process also requires energy which is supplied indirectly by the sun for the synethesis of the organic matter that nourishes microorganisms. Biological fixation of nitrogen is most efficient in soils that are well supplied with mineral nutrients,

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*This section is based in part on "Energy and Fertilizer: Policy Issues, Options, and Economic Implications," by M.S. Mudahar and and T.P. Hignett, International Fertilizer Development Center, Muscle Shoals, Alabama, 1981. The paper was commissioned by the Agency for International Development.

particularly phosphorus and calcium. However, application of chemical nitrogen fertilizer tends to inhibit biological fixation to an extent that depends on timing and placement.

These natural sources of nitrogen, when properly managed and conserved by crop rotations and recycling crop residues and manures, have proven adequate for a modest level of cereal yields in the past in many developed countries. However, they are not adequate for the intensive agriculture (high yields and multiple crops) that is needed to feed the present and future world population. The present challenge is to find methods to supplement natural nitrogen fixation processes with chemically fixed, inorganic nitrogen fertilizer without interfering with them.

Inorganic Fertilizer

Man's first effort to fix nitrogen imitated nature's lightning flashes; high-energy electric arch generators associated with hydroelectric generators fixed the nitrogen of the air to form nitrates. However, the process was wasteful of energy and was soon abandoned. Where cheap, abundant hydroelectric power is available, electrolytic production of hydrogen to make ammonia by the Haber-Bosch process is preferable. With a given amount of electricity, four times as much nitrogen could be fixed as compared with the arc process, and higher analysis nitrogen fertilizers could be made. Synthesis of ammonia from nitrogen and hydrogen requires very little energy, but the production of hydrogen is energy intensive.

Low-cost hydroelectric power is available only in a few countries, and this premium form of energy is often so valuable for industrial purposes that other sources of energy and feedstock are now used to produce nitrogen fertilizer. Only 1 percent of the world's nitrogen fertilizer is made with electricity as a major input. Natural gas is the most efficient source of both energy and chemical feedstock and supplies over 70 percent of the world's nitrogen fertilizer. Natural gas-based plants are the most energy efficient and the least capital intensive of all known methods for production of synthetic nitrogen fertilizer. Also, natural gas is usually a less expensive form of energy than petroleum-derived fuels or electricity.

While the value of chemically-fixed nitrogen is well established and cannot be underestimated, it has been increasingly difficult for some nations that depend on high-priced, petroleum-derived feedstock to supply nitrogen fertilizers. Their cost has increased more rapidly than the value of agricultural products, especially in those countries where foodgrain prices are controlled at a low level. In other countries, increased fertilizer costs have been matched by increased prices of agricultural products. For those countries that depend on imports, both food and fertilizer prices have risen sharply in the last decade.

Fortunately, natural gas deposits are widely, although unevenly, distributed and known reserves are increasing as discoveries exceed use. Several countries are building or planning new nitrogen plants based on recently discovered natural gas deposits. Those countries that do not have natural gas face difficult problems. Naphtha has become much too expensive for nitrogen fertilizer production. Heavy fuel oil is a possibility but costs are likely to be higher than for imported nitrogen. Use of coal as fuel and feedstock to make nitrogen fertilizer is technically feasible, but highly capital intensive and, with present technology, the process has a low level of reliability.

Eventually the nitrogen fixation process may use renewable resources. It is technically feasible to use methane derived from biogas or alcohol generated from biomass. Direct gasification of biomass is another possibility. Various other schemes based directly or indirectly on solar power are under study but none seem both technically and economically promising at present. For the remainder of this century we shall have to rely mainly on nitrogen fertilizers made from natural gas. Countries that do not have natural gas face alternatives of importing ammonia or finished nitrogen fertilizers or subsidizing domestic production of nitrogen fertilizer using more expensive feedstocks or processes. Higher prices may be partially offset by more sparing or more efficient use of fertilizer nitrogen, conservation by recycling, more reliance on natural fixation processes, and more reliance on the less energy-intensive fertilizers and soil amendments.

In the developing countries as a whole, only 2.7 percent of their total commercial energy use is in the form of fertilizer. In the case of imported fertilizers, most of the energy is expended outside of the importing country. The form of energy may well be natural gas that would otherwise be wasted by flaring. Energy use in agriculture, including fertilizer, in developing countries averages only 4 percent of their total commercial energy use. In view of the importance of the agricultural sector in most countries, a higher priority might well be assigned to its energy allocation.

During 1978-79, the world fertilizer industry used 1.5 percent of the total world energy consumption, of which 81 percent was used for manufacturing operations and 19 percent for packaging and distribution. The share of fertilizer energy by nutrients was nitrogen, 82 percent; phosphate, 11 percent; and potash, 7 percent.

Fertilizer Use. The most urgent fertilizer-related objective should be the more efficient use of fertilizers at the farm level. This applies particularly to nitrogen fertilizers, which are by far the most energy intensive and most popular. Means for increasing efficiency in the use of fertilizer include more balanced use of fertilizer, better timing and placement, and correction of known deficiencies of secondary nutrients and micronutrients in the soil. Long-term attention needs to be given to improved forms of fertilizers that are easier to use efficiently and more precise determination of nutrient requirements of crops. Greater use of compound fertilizers may facilitate more balanced use.

Continued research is warranted to identify farm management practices that will make full use of biological nitrogen fixation and of waste organic materials.

Fertilizer Manufacture. Operation of ammonia-urea plants at a low percentage of capacity is wasteful of energy. For example, operation of an ammonia plant at 60 percent capacity (frequent shutdowns) may use 25 percent more energy per ton of product than continuous operation at full capacity.

Technological improvements can decrease energy use in the production of urea by 32 percent, based on the average U.S. use of energy in urea production in 1979. Some of these improvements can be added to present plants.

Urea is the most energy-intensive nitrogen fertilizer and also the most difficult to use efficiently. Existing urea plants may be converted to make granular urea, which is easier to use and has better physical properties than prilled urea. However, more consideration should be given to ammonium sulfate and phosphate sulfate. The value of the sulfur in these products should be considered.

More energy-efficient processes for the manufacture of phosphate fertilizer are available and should be used. Examples are hemihydrate processes and processes that do not require drying or grinding of phosphate rock.

More phosphate rock should be used for direct application where conditions are suitable, that is, where soils are acidic and good-quality (reactive) phosphate rock is available and less expensive than soluble phosphate. Rock phosphate is especially useful to build up the fertility of low-phosphorus, low-calcium soils. Small supplemental additions of soluble phosphate may be needed for maximum yields.

Among soluble phosphates, ammonium phosphate is the most energy-efficient source of both phosphate and nitrogen, particularly at the farm level.

Fertilizer Transportation. Relatively little energy savings in transportation and packaging can be expected in the short term. In fact, better packaging (smaller and stronger bags) and package handling procedures and more prompt delivery are needed even at the expense of greater energy use. Longer-term saving can be achieved through greater use of rail and water transport.

Fertilizer Policy. In response to scarce supplies and higher prices of energy, there is need to generate further information on the role, options, and implications of various economic incentive programs, including fertilizer subsidies. This should be done in the context of fertilizer-related national goals, including (1) improving the efficiency of fertilizer use, (2) achieving balanced fertilization, and (3) saving nonrenewable energy.

Such information must serve as a basis for developing guidelines for possible interventions or incentive programs under different agricultural, climatic, and socioeconomic conditions. Generating this information will involve a series of case studies in several developing countries.

However, these recommendations cannot be carried out successfully without the active support of governments. In most countries, the government must take the lead in promoting energy-efficient use of fertilizers whether by intervention, education, regulation, research, or by some combination of these actions. The most immediate gains are expected from recommendations concerning appropriate fertilizer use. Better timing and placement in the use of fertilizers require providing information to farmers and timely delivery of fertilizers to the farm. Continued research is needed to define plant nutrient needs and the most effective timing and placement of fertilizers.

Biological Nitrogen Fixation (BNF)

Two types of symbiotic nitrogen fixation are known; bacteria in association with leguminous plants are mutually dependent for production of energy and fixation of nitrogen that both symbionts need for survival. A similar relationship exists between blue-green algae and azolla, a small water fern that grows in flooded fields. Plant residues from legumes and azolla supply organic matter and nitrogen for other crops. Nitrogen is also fixed and made available to nonleguminous plants through the action of associative or free-living microorganisms. This area of nitrogen fixation is still poorly understood and requires research. The extent to which associative microorganisms supply nitrogen to crops through intermediaries such as fungi is also in great need of investigation. For example, it is not known how such microorganisms can be introduced into cropping systems, nor it is known how their effectiveness can be maintained.

There is no single cropping, forestry, or livestock system that could not potentially benefit from the appropriate use of organic sources of nitrogen. Although the benefits will be tempered by considerations of comparative costs and the intensity of production desired, the use of biologically fixed nitrogen deserves consideration when agricultural development strategies are being developed.

Biological nitrogen fixation has great potential for expanded application in developing countries that are energy-poor and have need to offset costs of imported food, fiber, fuel, and fertilizers. It has been reported that a handful of inoculant containing nitrogen-fixing bacteria can substitute for 300 pounds of chemical nitrogenous fertilizer. If so, the cost, including the use of energy, for production, transportation, and application of the inoculant is negligible when compared with the costs of chemical nitrogenous fertilizer required to produce the same yields.

Biologically fixed nitrogen could make more efficient use of energy in the following areas:

- o Food crops--annual legume production; mixed traditional legume and other food crop production systems; fallow-crop systems including crop rotations; legume fallow crops in sedentary and slash-and-burn crop production systems; aquatic cropping systems including the production of animal feed and fish protein.

- o Permanent cash crops--legume shade and windbreaks that may also be used for firewood and green manure ground covers for coffee, cacao, tea, and similar crops; associative sources of biologically fixed nitrogen perhaps combined with mycorrhizae for crops such as sugarcane, citronella, and cotton.

- o Livestock--forages and feeds making use of pasture legumes in mixed grazing systems as fodder for draft animals and as feeds for poultry and swine.

- o Forestry utilization through the introduction or reintroduction of fast-growing trees and shrubs for feed, fuel, and construction purposes. Recent studies show that leguminous species are not exclusively the preferable types, but that nonlegumes such as casuarina apparently benefit through associative microflora other than bacteria of the genus Rhizobium.

The list of possible applications of biological nitrogen fixation to reduce dependence upon costly energy sources in developing countries has barely begun. BNF alternatives to inorganic nitrogenous fertilizer are particularly attractive because, in contrast to other means of meeting needs for food and energy, BNF technologies are relatively inexpensive, transferable, low volume, and apparently risk free. However, they are not popularly used nor is their potential understood on a large-scale production basis for the simple reason that until recently, energy-intensive commercial nitrogen fertilizers were less expensive, their management was more easily understood, their manufacture using cheap energy was uniform around the world, and price and profit margins were easily calculable by producer and consumer. By comparison, countries trying to establish a policy for import substitution using BNF techniques are faced with a series of unknowns that must be addressed. Experience suggests that these issues will be more difficult to resolve than those involved in the introduction of chemical fertilizers. The difficulty lies in the worldwide immediacy of need and of potential demand once an alternative appears to have been identified. A coherent plan for exploitation of BNF might include the following elements:

- Highly versatile information systems for data collection and evaluation to establish what is known about the use of BNF. These should include observations on crop nitrogen requirements made since the mid-1800s by every colonial power in the tropics and subtropics. For example, the experience of the Japanese, Italians, Portuguese, Germans, Belgians, Spanish, and Chinese should not be overlooked when surveying what has been found by the French, Dutch, British, and Americans.

- Definition of the surface and subsurface environmental stress characteristics of the agricultural production areas where improvement is desired, and in which:

  - Successful biological production methods and materials are used for man's benefit. These production techniques should be quantified.

  - Diverse biological materials provide some of man's needs. Species that may be only marginally utilized at present should be included: Amaranthus; salt-tolerant Leucaenas, Sesbanias, Neptunias; and aluminum-tolerant analogues to these species.

- Systems for speeding the exploration, sampling, and subsequent introduction and testing of promising genetic material.

- Strengthening information dissemination systems so that new knowledge can be used efficiently by rural producers.

Properly focused and managed, rapid evolution toward specific national applications in developing countries should occur. This implies that these developing countries will require a cadre of scientific and technical personnel for adaptation testing and dissemination of results. Additional needs will be identified, but they will not be costly, especially when compared with the rising expense of chemically-fixed nitrogenous fertilizers.

Plant Growth Promoters

Certain chemical compounds that are thought to stimulate the growth mechanism of plants hold promise as a new, low-cost way to increase agricultural crop yields. These so-called growth promoters are similar to the plant growth regulators that have been used for inducing root growth, regulating crop maturation, and other purposes not directly related to crop yields. Plant growth promoters do not supply plant nutrients and, therefore, are not a substitute for fertilizers. However, they may contribute to the more efficient assimilation of plant nutrients derived from fertilizers and soils.

Brassinolide is a growth-promoting substance isolated from plant pollen in studies more than 10 years ago at the Beltsville Agricultural Research Center of the U.S. Department of Agriculture. Because the expense of isolating brassinolide precluded its use on field crops, two synthetic analogues called brassinosteroids were developed at Beltsville in 1980. Under experimental conditions, these substances have been shown to increase yields of certain vegetable crops by 6-30 percent at application rates equivalent to about 500 milligrams per hectare. It is estimated that brassinosteroids would cost $2-$5 per hectare to produce commercially; patents are being sought.

Triacontanol is a naturally occurring growth promoter discovered at Michigan State University in the mid-1970s. Early trials were highly inconsistent because of the many factors that affect a plant's response to triacontanol. These factors include the method of formulation and the acidity and metal-ion concentration of the product as it is prepared for application. In 1981, the makers of a patented triacontanol formulation reported 20-90 percent increases in yields of soybeans, corn, tomatoes, and other vegetables following application at rates equivalent to 25 milligrams per hectare. Work is under way to develop triacontanol formulations specifically for plant species such as soybeans and field corn, which respond to the growth promoter less readily than some other species. The patented triacontanol product is nearing marketability in the United States and other countries. Its projected sales price is about $25 per hectare.

Much remains to be known about how growth promoters work. Specifically, how do they interact with plant hormones such as auxin to produce rapid growth? Are synthetic plant steroids safe for human consumption? Can growth promoters be adapted successfully for use with a wide range of plant species? Although the effectiveness of plant growth promoters has been established in experiments primarily with vegetable crops, further study is needed with cereal grains and other commercial field crops. Also, additional study will be required to establish procedures for the use of growth promoters by farmers under field conditions.

PEST CONTROL

Control of weeds, insects, and plant diseases is a basic requirement of food production throughout the world. Pest control in developing countries is critical because of inadequate funds, energy, and pesticides. A data base for assessment of crop losses worldwide has not been developed. However, Smith and Pimentel (1978) state that "Worldwide basic crop losses to all pests including insects, diseases, and weeds are estimated to be nearly 48 percent. This includes 35 percent preharvest and 20 percent postharvest losses."

Protection of crops requires a considerable expenditure of energy, especially in the case of controlling of weeds by plowing and cultivating the soil. However, the crop itself represents a source of energy captured from the sun by photosynthesis (Hayes 1980). Consequently, the judicious use of pest control methods can result in a net savings of energy by reducing crop losses as well as providing protection for the farmer's total investment.

Most developing countries are in the tropics and subtropics, where pest control problems are enormously more complex than in temperate zones, and the range and severity of pests are greater. Pests also tend to be more persistent because of the absence of winter cold. In some areas, year-round and multiple cropping provides continuous host plants to sustain pests.

Crop protection may involve one or more of the following pest control techniques:

Resistant varieties. Through selection and breeding, special physical or biochemical characteristics, physiological requirements, etc., are bred into or out of a plant, permitting the plant to escape pest damage partially or completely (Maxwell and Jennings 1980).

Attractants and repellents. Compounds produced by plants or the pest itself often can be used to the detriment of the pest species.

Physical, mechanical, and cultural control. Ditches, barriers, plowing, timing of planting, timely tillage, crop rotation, and crop competition have been used by farmers for centuries to reduce losses due to pests.

Natural enemies. The use of natural enemies has received greater emphasis in the last decade. New approaches with insect and plant diseases, exotic organisms, massive and augmentative releases, and manipulation of natural enemies have opened new vistas for pest control (Ridgway and Vinson 1976; Huffaker 1971).

Sterility and growth regulators. The use of chemosterilants and radiation-induced sterilization for insect control are relatively new control strategies. By reducing the fertility of one or both sexes of the pest, its life cycle is disrupted and subsequent pest populations are reduced or eliminated (Kilgore and Doutt 1967). The application of growth hormones and similar substances has resulted in insect control by disrupting the normal developmental cycle of the pest (Knipling 1979).

Standard chemical crop protectants. The use of insecticides, fungicides, and herbicides (all pesticides) has been and will continue to be a component of most crop protection programs. The proper use of chemicals in combination with other control strategies will be necessary for the immediate pest control that is essential for food and fiber production. The judicious use of chemical pesticides in combination with other control methods leading to integrated pest management (IPM) programs will pave the way for permanent long-term control, which is the ideal situation (Knipling 1979). Integrated pest management is not a chemical-versus-nonchemical concept.

An extension of the IPM concept to encompass specific cultural farming practices can lead to an overall economic crop management system. A specific need for this integrated approach may be evident following a pest-inflicted crop failure; extension workers in the field may demonstrate that IPM offers a better path to pest control.

Integrated pest management programs must be developed on a local or regional basis incorporating available methods and drawing upon the skills of local qualified personnel. IPM programs have been used successfully on cotton in Central and South America and Egypt and on rice in India, Thailand, and Malaysia (Mathys 1981).

The economic advantage of IPM was distinctly demonstrated in cotton production in Peru by using control practices that favored natural enemies. Within 2 years, the output of the cotton crop had doubled or tripled. Similar programs were instituted for potato and olive production in Peru. The advantages of IPM in cotton production were demonstrated in Colombia, Nicaragua, El Salvador, and Guatemala. An extensive program is under way in China on a variety of crops, including cotton, rice, pines, and a number of vegetables (Mathys 1981). Small and large farms growing annual and perennial crops were successful in applying the integrated pest control strategy.

To be successful, an IPM program requires well-trained personnel working with receptive growers. A training program must be designed for a country or region to address present and future pest control problems.

By its nature, IPM is multidisciplinary; it must involve entomologists, plant pathologists, weed scientists, agronomists, horticulturists, plant breeders, climatologists, systems scientists, toxicologists, computer programmers, and economists working together in a sympathetic administrative environment. It must also include biological and environmental monitoring capabilities.

To support these programs, information and expertise can be drawn from the public and the private sectors in the United States, from similar organizations within the host developing country, and from other international organizations, such as the International Institute of Tropical Agriculture, Ibadan, Nigeria, and the International Crops Research Institute for the Semi-arid Tropics, Hyderabad, India.

Ideally, the trained technician must be able to assess and respond to pest control problems at the village level. Because pest problems are often unique to a region or area, specific training documents or manuals must be developed or modified to meet the needs of the particular program. In addition, training programs must develop new cadres of extension workers or field scouts to monitor insect, disease, and weed populations to determine particular pest problems and to assess the effectiveness of the control techniques. This is a critical requirement in the training program because the success of any overall crop management system and its subsequent continuing support will depend upon demonstrated effectiveness of the techniques.

Integrated pest management is a concept. It cannot reduce pest losses, save the environment, or reduce health hazards until it is demonstrated and put into practice. In the past, the best results have been obtained when farmers have united over relatively large areas to control a specific pest or a number of pests on particular crops (Mathys 1981). However, inadequate knowledge of pest biology and behavior, insufficient recognition of the potential benefits of total population management, and the failure of agricultural scientists to agree on the need for integrated control programs may impede the development of the IPM concept (Jackson 1979).

Pesticides have played and will continue to play a role in pest control. They have made a significant contribution to high yields of U.S. agriculture. Furthermore, pesticides are currently part of all producer-supported integrated pest management systems. However, if integrated pest management systems can be expanded and properly coordinated, crop losses can be reduced by as much as 50 percent and certain uses of pesticides can be reduced by as much as 75 percent.

Recommendations

1. The application of integrated pest management programs appears to offer a reasonable solution over time to the ever-present and increasing pest-related problems in developing countries. Because such a program requires trained personnel, it is recommended that training programs in pest management be initiated in cooperating countries and be integrated within the extension programs that presently exist in many developing countries. Otherwise, students could be trained in neighboring countries.

2. Training manuals must be developed or modified to reflect the problems and needs of specific areas.

3. Areawide pest suppression or total pest population management should be considered where farmers will benefit from reduced energy requirements, increased levels of crop protection, reduced environmental stress, and simplified pest control.

4. Accurate and rapid identification of the pest organism and associated species is essential to any IPM program (Lattin 1980). There is a worldwide need for taxonomic services on most arthropods and many other pests. It is recommended that support be given for the establishment of regional diagnostic centers that would service groups of developing countries.

WATER FOR CROP PRODUCTION*

Because water, in combination with adequate plant nutrients and a proper climate, is essential for crop growth, good water management on farms is essential. As a first step, rainfall should be managed so that it is stored in the soil for future use and not permitted to run off. Therefore, the management of rainfall using practices such as water conservation terraces requires little energy, has a high payoff, and should be given high priority. Sometimes rainfall is too great, creating wet marshy areas unsuitable for crops. In this case drainage is required for maximum production.

In arid areas, rainfall is usually inadequate for proper crop growth, at least in some seasons and irrigation is necessary. In many locations, irrigation could enable multiple cropping by providing water when seasonal rainfall is inadequate. However, irrigation often requires a large amount of energy, which necessitates careful analysis in times of increasing energy costs. Of particular importance is the energy requirement for pumping deep groundwater. Improvement in dryland farming through species selection for drought tolerance, and ecological improvement through integration of perennial trees and shrubs in agroforestry systems, may be more cost-effective; long-term alternatives and should be considered carefully. However, if very high crop yields in arid areas are to be achieved, irrigation is essential.

Energy for Irrigation

Energy for Installing Irrigation. A one-time energy investment is required for all permanent irrigation equipment and structures. Included is the energy used in the manufacture of materials in dams, canals, wells, pumps, motors, etc., necessary for farm irrigation systems, and the energy used to perform the necessary construction, ditching, land leveling, and similar activities. These one-time energy requirements are distributed over the projected life of the system, and together with the annual energy cost of maintenance, constitute an annual energy investment required to provide the water supply and

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*This section is based in part on "Energy in Irrigation in Developing Countries: An Analysis of Energy Factors to be Included in a National Food Policy," by E.T. Smerdon and E.A. Hiler. This paper was prepared for the Agency for International Development, Project No. 930-0091, December 1980.

install a farm irrigation system. However, this investment does not include the energy required for pumping the water and operating the irrigation system.

In general, in developing countries it takes less than half as much energy to provide a surface water supply from reservoirs or a river as it does to provide a groundwater supply (178,000 kcal/ha/yr versus 410,000 kcal/ha/yr). Unfortunately, sometimes surface water is not available and groundwater must be used.

The total annual fixed energy input for farm irrigation systems varies from approximately 110,000 kcal/ha/yr for surface irrigation systems to about 290,000 kcal/ha/yr for sprinkler systems and 1,000,000 kcal/ha/yr for trickle systems. Since both sprinkler and trickle systems are pressurized and require pumping even when surface water supplies are used, they tend to require more energy than the surface irrigation systems. However, surface irrigation is often less efficient in applying water, particularly if the system is improperly designed and poorly managed. Consequently, well-designed systems with good land leveling and proper management are essential.

Pumping Energy. Pumping requires large amounts of energy. In fact, when pumping is from deep groundwater zones (depths of 30 meters or more), the energy cost of pumping alone will often prohibit irrigation except in special circumstances. For example, if crops in an arid region annually require 1 hectare-meter (10,000 cubic meters) of water per hectare and the water must be lifted 20 meters (m), then 2,000 megajoules (480,000 kcal) of energy are required per hectare per year to lift that quantity of water to the surface. If the water is lifted with an irrigation pump that has an efficiency of 50 percent (typical of field pumps) and a diesel engine with an efficiency of 25 percent, then 16,000 megajoules (3.8×10^6 kcal), which is equivalent to 108 gallons of diesel fuel, is required per hectare to pump this 10,000 m^3 of water. Any water wasted in a leaky irrigation canal system or a poorly designed and managed farm irrigation system will further increase the energy required to pump the water for crops.

The relation of the depth from which water is pumped (water lift) and the type of irrigation system to the total annual energy requirement for irrigation can be expressed graphically. The energy required to lift the water is separate from the energy required to pressurize the sprinkler and trickle systems. The curves in Figure 2 relate water lift and total energy use in irrigation for five irrigation systems designed to provide an annual net irrigation of 1 meter per year (corresponding to a consumptive use of 1 meter provided solely by irrigation). These curves are based on calculations that include the energy costs of providing the water supply and distribution system and the farm irrigation system. They also take into account the efficiencies of the different types of farm irrigation systems.

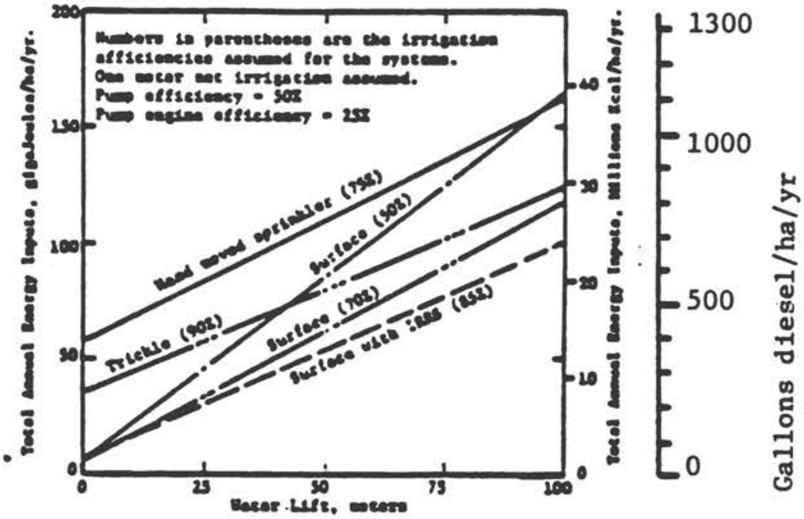

FIGURE 2 Total annual energy requirement for irrigation.

For convenience, the diesel fuel energy equivalence of the energy values in Figure 2 is shown in gallons of diesel fuel per hectare per year. This permits a quick estimate of the cost of pumping irrigation water based on the cost of diesel fuel in any particular country.

The importance of the efficiency of the farm irrigation system is illustrated by analyzing the surface systems illustrated in Figure 2. The total energy required is greater for the systems with lower efficiency. A general expression is developed showing the energy savings in operating irrigation systems possible from improvements in individual components of an irrigation system. Potential energy savings (PES), in percent, is given by

$$PES = 100 \left[1 - (D_a/D_b)(H_a/H_b)(E_b/E_a)_1(E_bE_a)_2 \cdots (E_bE_a)_n \right]$$

where D is the depth of net irrigation required by the crop, H is the total head (pumping lift) required of the irrigation pump, and E is the efficiency of the various components of the irrigation system. These include the pump efficiency, the efficiency of the watercourse in conveying water, and the efficiency of the irrigation application system on the farm. The subscript b indicates conditions before improvements, and the subscript a indicates conditions after improvements. Subscript numbers outside the parentheses denote the individual components in which the efficiency if improved and any number n of components may be included.

For example, assume that the net irrigation application is reduced to 700 millimeters (mm) from 800 so that the ratio of the amount of irrigation water required after improvements, D_a, to the amount required before improvements, D_b, is given by $D_a/D_b = 0.875$. Assume also that the total head is reduced from 50 m to 30 m, giving $H_a/H_b = 0.60$; the efficiency of the pump is increased to 0.67 from 0.55, giving $(E_b/E_a)_1 = 0.821$; the watercourse conveyance efficiency is increased to 0.70 from 0.50, giving $(E_b/E_a)_2 = 0.714$; and the efficiency of water application in the fields is increased to 0.80 from 0.65, giving $(E_b/E_a)_3 = 0.812$.

The combined effect of the various improvements in the irrigation system results in the following potential energy savings: $PES = 100 [(1 - (0.875) (0.60) (0.821) (0.714) (0.812)] = 100 (1 - 0.25) =$ 75 percent. That is, 75 percent of the original energy used to operate the irrigation system could be saved by this combination of improvements in irrigation practices. Stated another way, only one fourth as much energy as before would be required to provide the same amount of irrigation. Although all these improvements can seldom be made in a single system, the equation can be used to assess the magnitude of the energy savings resulting from each improvement, individually or collectively.

How might these savings occur in developing countries? It is possible through the use of improved crop varieties to reduce the water required by crops, D. The total head H required may be reduced by providing low-pressure irrigation systems where high-pressure systems existed before. Irrigation pumps in the field often have low efficiencies and can be repaired or replaced to markedly improve their efficiency. Watercourses can be renovated, thereby increasing the efficiency of water delivery. Finally, fields can be leveled and better on-farm irrigation practices installed to decrease the water losses that result from poor on-farm irrigation practices. Some of these improvements resulting in energy savings are usually feasible in developing countries.

Salinity. Salinity problems are often associated with irrigation in arid areas. When high salt-content water is used for irrigation, salts will accumulate in the soil and inhibit crop growth. Conditions leading to salt problems depend on many factors and require careful analysis by irrigation specialists. In some cases, the salts accumulate slowly after years of irrigation and the extent of the problem is not recognized until agricultural production is seriously reduced. Soil reclamation, costly both in terms of energy and monetary outlays, is then required. This problem can often be avoided by providing drainage when the irrigation system is installed and by proper irrigation management. The energy cost of installing drainage systems is relatively small on an annual basis and should not greatly exceed the cost of land leveling and providing the surface irrigation system, perhaps 200,000 kcal/ha/yr. Although the monetary costs of providing adequate drainage are often sizeable, it is not prudent to ignore the potential problem.

Alternative Energy Sources

All alternative sources of energy for irrigation, as opposed to purchased commercial energy, should be explored. The alternative energy supply must be dependable and available during the flowering and fruiting stage of crop growth because an adequate supply of water at that time is critical to crop production. Any alternative energy source must not be subject to excessive operational problems, and it must be within the economic reach of the irrigation farmers. The energy source with the greatest potential for use in irrigation in the near term (the next 15 years) is wind where velocities average at least 19 kilometers per hour. Biomass energy has the second greatest potential for use in irrigation if the required sources of biomass are available. The ways in which biomass may be used to produce energy are ranked as follows: direct combustion, gasification, methane, oil-producing plants, and ethanol. Direct use of solar energy ranks behind wind and biomass energy because of its high cost and of the technological advances that must yet occur before solar energy technology will approach economic feasibility and operational dependability.

Recommendations

The following are the most important steps that should be taken to reduce energy requirements in irrigation. The first step is to seek by any means to conserve and reduce requirements for irrigation water. Conservation of water in irrigation saves energy. Only when steps to save water have been completed should steps to use alternative energy sources be taken. Using alternative sources may shift energy use from traditional commercial sources, but with the possible exception of wind energy, these alternatives are likely to be quite expensive.

The recommendations for practices that may be adopted by individuals or by groups of farms are (roughly in order of priority):

- Improve the watercourse to reduce losses. Improvement and repair of earthen watercourses can reduce losses by 40 percent or more, according to studies in Pakistan. These improvements often can be made with local labor and equipment. Lack of money to line canals or install pipe should not prevent repair and renovation of earthen watercourses.

- Improve on-farm irrigation practices. Surface irrigation is the least expensive irrigation system to build and requires the least energy to operate. Generally, surface irrigation should be used when topography and soil characteristics permit. Precision land leveling should be provided. An irrigation application efficiency of 70 percent or more is possible in most cases in the small fields in developing countries with good management.

- The efficiency of irrigation pumps should be checked because it is often 50 percent or less. Low pump efficiencies should be detected and pumps with very low efficiency repaired or replaced.

- Ensure the best crops for irrigation are used and the actual water requirements of the crops are known so that the amount and timing of each irrigation are proper for the crop needs.

- Use surface water supplies when they are available. The energy required to provide surface supplies is generally less than half that required for tubewells, and this does not include the continuing requirement for energy to pump groundwater to the surface.

The following are general recommendations for governments and cannot be implemented by individual farmers:

- Developing countries should place new emphasis on management, extension, and training and on the adaptation and transfer of appropriate technology from developed countries, taking into account the different conditions under which the technology will be used.

- Research, other than that associated with adapting existing technologies to conditions in developing countries, should receive lower priority than efforts to improve management and water conservation.

- Basic developmental efforts on alternative energy technologies should continue, but not as a priority item for the Agency for

International Development's promotion of increased food production. Such support should come from other sources. Most feasible alternative energy technologies will have uses in many sectors of the economy, the food sector being only one of these.

- Research and development should be directed to alternative systems for managing drylands through agroforestry systems and ecological improvement to relieve the need for energy- and water-intensive irrigated crop production.

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REPORT OF WORKING GROUP II:

ENERGY IN THE POSTHARVEST SYSTEM

INTRODUCTION

As in agricultural production, the use of energy is critical to the efficiency and modernization of the postharvest system (see Figure 3). Since the major portion of food crops produced in developing countries remains in the rural sector and largely outside the cash economy, comparatively little fossil fuel is used in the harvesting, drying, processing, and transportation of these basic staples, with notable exceptions, such as rice milling in Southeast Asia. The greatest amount of energy consumed in the rural sector is used to cook food, and, because of the important effects of deforestation on agriculture, cooking--the final and most critical step in the food chain--must be considered along with energy use in agriculture as a whole. The production of fuelwood on marginal lands, roadsides, hedgerows, and other areas around fields and settlements, in addition to more traditional forest conservation efforts on watersheds, is becoming increasingly important to the support of sustained agricultural productivity. There is increasing pressure on rural wood supplies to produce cooking fuel, particularly charcoal, as a replacement for electricity, kerosene, and bottled gas in urban areas.

As in agricultural production, energy use in the postharvest system must increase to improve the quality and quantity of food and food products and to increase their value to the consumer. It may be possible, however, to increase the efficiency of energy use and to use different sources of energy more efficiently to carry out postharvest operations. This section of the workshop was therefore organized to consider the principal stages through which agricultural products pass from the point of harvest to consumption, with a view to identifying

POSTHARVEST SYSTEM

<u>Primary processing and storage</u>

- o drying
- o threshing

Products — Markets — Consumers

<u>Secondary Processing</u>

Cereals and pulses	Perishables	Commercial crops
- milling/hulling - parboiling - grinding - oil expelling and crushing	o Potatoes, cassava, and other tubers - drying/grinding - fermenting - refrigeration o Fruit, vegetables, fish, and meat - refrigeration - salting, drying, and smoking - pickling - canning and bottling	o Tobacco - drying o Coffee - drying and roasting o Sugar cane - crushing - refining

Markets

Consumers

FIGURE 3 Energy use in postharvest operations.

opportunities for increasing efficiency of energy use and potential alternative energy sources that could replace imported fossil fuels or depleted forest resources.

Among the points considered for discussion were the following:

- Reduction of postharvest losses could result in the utilization of energy that has already been expended in the production of the food; this is obviously of particular importance where energy-intensive fertilizer and other inputs have been used in its production.

- Increased processing of foods can lead to energy conservation through increasing shelf life, reducing bulk or weight to be transported, reducing the amount of home cooking required, or making more by-products available for further processing and use.

- There is particular need to note the impact of new food technologies on consumers and particularly on the special needs of rural women.

- In view of the relative neglect of the problem of postharvest food losses in many countries, there is need for greater national attention to the promotion of food conservation through information and economic incentives.

TRANSPORTATION

The demand for transportation increases as urban populations grow and agricultural production increases. The transportation sector in developing countries currently uses 50 percent or more of the liquid fuel supplies, most (80 percent) of this amount is allocated to transportation by roads, and it is estimated that 60 percent or more is used in trucks, of which about 50 percent is for hauling food and other agricultural commodities or agricultural inputs. In sum, between 12 and 15 percent of liquid fuel supplies in developing countries are consumed in agriculture-related transportation, although these percentages vary according to the degree of industrialization and the geography of particular countries. In addition, large amounts of animal and human energy are used in transportation at the local village level.

Significant substitution for liquid fuels in the transportation sector is unlikely in the near future. Therefore, the overriding question is: What is the least costly system of assembling and moving agricultural products from geographically dispersed production units to consumers located in other rural areas or urban centers and in transporting foodstuffs and agricultural inputs back to rural areas?

For the following examination of the conservation of liquid fuel, the agricultural transportation system is divided into three segments.

- Local transportation: the movement of agricultural products from the farm to the local market, usually a distance of less than 25 km. It is estimated that this segment of the system accounts for a relatively small part (2 percent) of total consumption of liquid fuels, since most of the transportation will be by traditional methods, such as bullock carts, handcarts, and bicycles.

- Intercity transportation: the movement of goods from the local market to the gates of the town or city where it will be consumed. This is long-distance transportation (200-300 km) by trucks of various sizes, trains, or waterways. This segment of the agricultural transportation system accounts for the largest share, perhaps 10 percent, of total consumption of liquid fuels.

- Urban transportation: the distribution of agricultural products within the city or town. The distances are relatively short, 25 kilometers on average. Although transportation may be accomplished by commercial as well as traditional means, the heavier use of commercial transportation in the intra-urban segment than in the local segment and the prevalence of congested traffic imply that the share of liquid fuels consumption is about 4 percent--higher than the share consumed by the local sector but much lower than that of the intercity transportation sector.

For each of these sectors, three types of conservation possibilities are examined:

- Minimizing or optimizing the demand for transportation of agricultural products

- Shifting to more energy-efficient forms of transportation

- Improving the efficiency of road transportation.

Conservation Possibilities

Optimizing Transportation Services. Liquid fuel supplies could be conserved through the following steps:

- Local assembly. Product bulking at local market centers and temporary storage facilities are necessary to accumulate sufficient quantities for shipment to more distant markets in larger and more efficient vehicles.

- Processing. Processing of products in the assembly areas is a means of reducing the physical bulk and thus the net tonnage of products before longer-distance shipment to urban centers. It can also be important in the conversion of perishable products (e.g., milk, fruits, and vegetables) into more durable commodities that require high-cost, specialized transport and handling services. Feasibility studies can determine the optimum number, size, and location of processing facilities to minimize assembly and shipping costs.

- Urban distribution. The wholesaling function requires market terminal facilities and institutional arrangements for breaking down shipments to a suitable size for movement to retail outlets. Here, too, optimization in the location and layout of the wholesale market and terminal facility can reduce transportation and energy costs.

- Distribution of agricultural inputs and foodstuffs to rural areas. The backflow of these commodities can be made less costly by coordinating shipments with the outbound movement of agricultural products to urban centers. Information systems that link trucking with potential shippers are essential for effective use of trucking equipment.

The seasonality of agricultural production and of farm demand for commercial inputs, such as fertilizers, complicates the coordination of transportation services. Temporary storage in rural assembly and distribution centers is required to meet market demands.

National, regional, and urban planning units can influence the overall costs of agriculture-related transportation services through careful projections of demand and analyses of investment decisions involving market facilities, transportation equipment, and institutional development assistance.

Shifting to More Energy-Efficient Forms of Transportation. Within the food sector, transportation functions within three distinct settings, each of which has particular operational and technical requirements and, consequently, unique opportunities for shifts to more energy-efficient methods.

In the local setting, products are transported from farm to storage or local market by mechanized vehicle or by human or animal power. Although human- and animal-powered transportation is still prevalent in traditional societies, mechanized vehicles have become an increasingly important means of local transportation. This trend is expected to continue, although perhaps at a somewhat slower rate than in the recent past. In local settings, transportation cost is the only value-added increment to farm gate price. Hence, at this level, transportation represents a fairly large share of product price. Because of short distances (typically on the order of 25 km one way), however, fuel is not a particularly large component of this price, and fuel price is thus not a major factor in local transportation. Because produce must be moved by whatever means are available, the key factors in the choice of transportation methods at the local level are its availability and cost. If mechanized vehicles and the fuel needed for their operation are available, these will be used regardless of energy efficiency. Subsidized fuel prices may artificially constrain fuel supplies and thereby limit the availability of mechanized vehicles, but generally speaking, the existence of such vehicles virtually assures their use for local transportation. These facts have important implications for energy use in local transportation and suggest a possible role for appropriate technologies, such as producer gas generators now being introduced for jeepneys in the Philippines.

In <u>long-distance</u> transportation, agricultural products are moved from local storage to regional terminals or markets by rail, water, and truck. In some cases, particularly with export crops, long-distance transportation may supersede local transportation as produce is moved directly from production center to regional market or storage facility. Rail and water systems are comparable in energy efficiency. Where a rail system is in place and the railhead or siding is sufficiently accessible to permit its use, rail transportation is a viable, energy-efficient option. Where rail lines do not exist, traffic density must be on the order of 1 million tons per year to justify investment in railroad infrastructure. Since this level of traffic density is quite unlikely in most cases, increased rail transportation is generally not a feasible energy conservation option. Water transportation, on the other hand, has far more potential, particularly since many developing countries have relatively undeveloped water transportation systems. Generally speaking, river transportation is three to four times more energy efficient than long-haul trucking and, where feasible, its use should be encouraged.

In the <u>urban</u> setting, agricultural products are transported by truck from regional terminals, typically wholesale markets in congested core areas, to retail facilities. In rationalizing the transportation system, these terminals could be located on the periphery of the urban area and local distribution could be handled by small LPG (liquid petroleum gas)- or electric-powered trucks whose operations (i.e., load matching) could be coordinated through the regional terminals. This assumes, of course, that electricity is not generated by fossil fuels.

Improving the Energy Efficiency of Road Transportation. One important way to increase the energy efficiency of the transportation sector is to increase the efficiency of a particular transportation mode through improved maintenance, better use of existing vehicles, and use of more efficient vehicles.

By using turbochargers, electronic injection systems, improved gear-axle ratios, etc., new truck models are 10-15 percent more energy efficient than the vehicles they replace. Use of lightweight materials also decreases tare weight, thereby permitting increased payload capacity. However, these new vehicles are more difficult to maintain, need better lubricants, and need to be properly tuned. In particular, tuning requires somewhat sophisticated and often scarce equipment. As a result, even where capital is available, these new trucks may not yet be feasible in developing countries with a shortage of skilled mechanics and adequate repair facilities.

Important improvements in energy efficiency can also be achieved by better use of existing equipment. Experience has shown that energy savings of between 3 and 4 percent can be achieved through proper tuning, appropriate lubrication, and timely changing of air filters. Correct tire pressure is also important; one tire manufacturer estimates that energy consumption could increase by 7-8 percent when tire pressures are 20 percent below optimal.

Driving behavior is important in energy conservation. Experience in Europe has shown energy savings of up to 9-10 percent by better driving. Special devices now available can indicate the instantaneous fuel consumption of a motor vehicle. These devices can be used to train truck drivers. In addition, salary bonuses related to energy conservation can be used to motivate better and more efficient driving.

Energy consumption is directly related to road gradient and curvature and to traffic congestion. All infrastructure improvements that will reduce one or more of these conditions will improve the energy efficiency of the truck fleet. Reduction in road roughness by better road maintenance, more road rehabilitation, and more road paving should also result in improvements in energy efficiency; however, these improvements often result in increases in average vehicle speed. Because speeds beyond 40-50 mph are extremely costly in terms of energy, the net result of road improvement may be increased energy consumption. However, road improvements are justified by other savings, such as reduced vehicle maintenance costs and reduced travel time. Many countries have introduced speed limits on their main highway networks as a conservation measure and have achieved satisfactory results.

More careful load management techniques could make possible the use of much larger trucks. At present, the average size of inter-urban trucks in developing countries is about 8 tons, consuming an average of about 0.04 liters per ton kilometer. Significantly larger trucks (15-20 tons) use only about 0.025 liters per metric ton kilometer, but in order for the larger trucks to be profitable larger loads must be available on a predictable basis.

Fuel Substitution. Although the transportation sector is likely to depend predominantly on the availability of petroleum products--gasoline and diesel fuel--over the next 20 years, there are limited opportunities for substituting other liquid fuels.

The most prominent of these substitute fuels in developing countries is ethanol produced from sugarcane as a partial or complete substitute for gasoline. (See previous section on mechanization.) Ethanol can be mixed in the proportion of 20 percent ethanol to 80 percent gasoline for use in conventional automobile engines. Specially designed vehicles can operate entirely on 95 percent ethanol (the constant-boiling azeotrope which is less energy expensive to produce than the purer anhydrous 100 percent ethanol required for mixing with gasoline.) Among the developing countries, Brazil has the most ambitious ethanol program. Ethanol has been mixed with gasoline to the 80-20 limit for unmodified engines, and the production of cars operating on unmixed 95 percent ethanol is under way.

As mentioned earlier, important disadvantages of ethanol synthesized from sugar cane are its high cost and the possibility of sharp competition between the food and fuel uses of the agricultural resource base. These disadvantages have drawn attention to other substitutes for automotive fuels--such as ethanol produced from cassava and methanol or producer gas produced from wood. Although both of these alternatives offer the possibility of lower-priced feedstocks and can be produced on marginal agricultural land, they still divert agricultural raw material from food production.

Alternatives to diesel fuels are also being actively pursued. Preliminary experiments indicate that blends of as much as one-third vegetable oil (e.g., coconut, soya, sunflower) to two-thirds diesel fuel may be feasible in unmodified diesel engines. There is, however, a worldwide shortage of vegetable oils and, with notable exceptions such as soybean oil in the United States, they are currently more expensive than diesel oil. Expansion of acreage, particularly of palm oil, may offer attractive future economic opportunities for tropical developing countries.

One other possibility of greater relevance to urban transportation is LPG, which can be used to power internal combustion engines. This option is probably economically feasible only in those countries with local gas production and limited markets. Sometimes this option is encouraged by pricing policies, as in Thailand where LPG production is so highly subsidized that it is diverted to domestic transportation. The use of electrically powered delivery vans could also be expanded in urban areas. In the Philippines producer gas generators are being mounted on jeepneys to produce gas from charcoal to substitute for gasoline.

In sum, possibilities for substituting other forms of energy for gasoline and diesel fuels appear more promising in urban transportation systems than in intercity transportation. In both cases, however, attention must be paid to the overall economic cost of the substitution. Increased efficiency of energy use in transportation--the main topic of this section--often will be a more economical and equitable option.

Table 3 summarizes opportunities for conserving, or making more efficient use, of liquid fuels in the agricultural transportation system.

Achieving Conservation

How can these conservation possibilities be realized? The 1973-74 and 1979-1980 crises in oil prices have led to sharp increases in the real price of transportation fuels over the past 10 years in many developing countries. This is expected to induce the introduction of many conservation methods, such as improved maintenance and the imposition of speed limits. The effect of high fuel prices on the design of more fuel-efficient vehicles in industrial countries will also lead to improvement in vehicles, most of which are imported, in developing countries.

In some countries the full impact of rising energy costs has not been passed on to transportation fuel prices. In addition, the cost of energy is frequently a relatively small part of total transportation operations, not in itself sufficient to induce consumers to take strong conservation measures. Governments should therefore review their energy pricing policies and related programs to make sure that consumers are receiving strong incentives to use energy efficiently.

TABLE 3 Opportunities to conserve energy in agricultural transportation.

	Local	Intercity	Urban
Optimizing demand for transportation	Minimize commercial traffic through relocation of storage and collection facilities	Storage facilities, both local and city level Processing, drying Improve load factors - information communication - coordinate agric. input and output transport - more common carriers rather than capture trucks	Break-bulk facilities and organized wholesaling services
Shifting modes of transportation	Mechanization if available	rail - improve existing facilities water - improve port facilities	X
Increasing efficiency	Appropriate technology Maintenance energy Energy-efficient vehicles	Maintenance Highways Speed limits Improved driving Energy-efficient trucks Larger trucks Route selection	Efficient trucks Rational break-bulk facilities
Fuel substitution	Producer gas	Ethanol Methanol Vegetable oils	LPG Electricity Producer gas from charcoal

In addition, transportation is typically a heavily regulated activity. Market entry, tariffs, route selection, backhauling, and other aspects of transportation operations are often regulated, either through explicit government transportation policies or through agricultural and other policies affecting transportation. Many of these policies have evolved over an era of low-cost energy supplies. Economic development, equity in the distribution of resources over regions and population groups, and a host of other nonenergy-related issues were the basis for these policies. With the increasing need to manage energy resources, these policies should be reexamined to identify particular energy inefficiencies and should be modified as necessary to balance use of energy against development objectives. In this light, national pricing policies for agricultural commodities should be reevaluated when they create uneconomic patterns of production, uneconomic markets, and increased transportation costs. This typically occurs when commodity support prices are set at uniform levels nationwide over the cropping season. Such policies artificially stimulate production in remote areas and encourage uneconomic surges in the movement of products at harvest time. This peaking of demand for transportation in turn encourages overcapacity and the consequent overcommitment in transportation equipment. Pricing policies should reflect actual costs for transportation and storage to achieve economic patterns of transportation.

Government support will also be needed for fuel switching, but care should be taken to see that this is not excessive with regard to economic efficiency.

Conclusions and Implications for AID Policy

Total transportation system efficiency is best encouraged through a rational approach to fuel pricing and the development of transportation enterprises. This means avoiding unnecessary regulation and distortion of the price system through subsidies. It may also mean avoiding the temptation to provide vehicles as part of farm cooperative projects or similar undertakings, since these "captive" vehicles often represent large capital expenditures and the vehicles are usually underutilized. It appears to be more effective to permit the development of transportation businesses that can serve a multitude of needs and thereby ensure efficient use of vehicles.

All these suggestions are based on the premise that transportation efficiency is desirable, especially in light of the fuel component of transportation costs. Nonetheless, it is necessary to insert the caveat that agricultural transportation fits the saying, "If it isn't broken, don't fix it." Agricultural transportation is not a big energy waster. In fact, one can argue that much more energy can and should be used for this purpose, provided it is used efficiently. National energy planners in developing countries may wish to give agricultural transportation a very high priority in any ranking of petroleum end uses and to attempt to reallocate oil saved in the industrial sector or in automobile transportation to this purpose.

AID's efforts in the area of energy conservation in agriculture-related transportation should focus on the following:

- Management training and assistance: programs should be directed toward improving local management skills and techniques, particularly in urban traffic management and in rationalizing the operation of the transportation system. In the latter area, particular attention should be devoted to increasing load factors and generally optimizing the vehicle or mode to the need for transportation (e.g., using smaller, fully loaded trucks rather than partially loaded, larger trucks on congested urban streets). Further programs should encourage management of load matching between outbound and inbound shipments to increase load factors and thus energy efficiency.

- Research activities: applied research should be encouraged and technical information and results should be transferred to developing countries, particularly in the areas of alternative fuels, fuel extenders, and appropriate technologies for local transportation.

- Technical training: lack of skilled mechanics and other technicians limits the potential for technological improvements in efficiency and may in fact reduce efficiency because sophisticated equipment that is improperly maintained or operated may use more energy than the "less efficient" equipment it replaces. Thus technical training represents an important area for AID programming.

- Infrastructure development: programs to develop and improve inland waterways and highway networks may produce significant energy savings. However, highway paving per se may not always increase the energy efficiency of transportation. Programs to develop or improve transportation infrastructure should incorporate a systems perspective and thus be selective in the types of projects and programs pursued.

Perhaps <u>the overriding goal in all these areas should be for AID to encourage the development of transportation systems that can move the maximum amount of agricultural produce to markets and consumers as quickly, cheaply, and efficiently as possible. The energy component of such a system must be kept firmly in mind, but saving energy should not be considered a higher priority than this overriding goal.</u>

POSTHARVEST FOOD SYSTEMS: ENERGY SUPPLY OBJECTIVES*

Goals for Improved Systems Appropriate for Developing Countries

To assess the potential for increasing the energy efficiency of agricultural systems, the following energy goals have been established where possible by many developing countries:

- Decrease relative dependence on fossil fuels.
- Decrease amount of imported fuels and increase national energy self-sufficiency.
- Decrease dependence on foreign technologies and expertise.
- Use energy more efficiently in order to increase the quality and quantity of food available for consumption.
- Increase the use of renewable energy sources.

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*This section is based in part on "The Potential for Renewable Energy Technologies in the Rural Postharvest Food System in Developing Countries," by Carl J. Lindblad, prepared for the Agency for International Development under purchase order AID/OTR-147-80-108, April 1981.

- o Increase the ability of personnel from developing countries and the staff of AID bureaus and missions to assess energy constraints on development projects and implement improved energy systems.
- o Increase the data base on energy use in agriculture, make it available to decision makers in developing countries, and increase local expertise for developing data bases.
- o Promote the use of energy-conservation technologies in agriculture, thus reducing the need for additional energy inputs.
- o Increase the use of agricultural production for agro-energy potential.
- o Increase the use of agricultural by-products and residues for energy production.
- o Analyze agricultural and energy systems on a site-specific basis to assess project failures and successes.
- o Use trend analysis and economic projection to determine the feasibility of using alternative energy sources.

The Role of Active Solar Energy in Food Processing

Assessment of the various energy inputs into food processing leads to the conclusion that solar energy-based technologies are the most suitable for increased near-term exploitation in developing countries. Consequently, major emphasis should be placed upon using solar energy in its various direct and indirect forms.

Solar Drying. Solar drying is most critical in:

- o Natural drying of certain crops in the field, for example, grains, legumes, and nuts.
- o Postharvest drying--when the sun does not cooperate, processing must be accelerated to facilitate timely harvesting (double cropping) or to prevent postharvest losses.
- o Reducing bulk and weight of foods for transportation, storage, and distribution; particularly perishable staples such as roots and tubers.

- Drying of foods such as parboiled rice and bulgur, which are precooked for convenience and, therefore, energy saving in preparation.

Strategies that could be used to promote solar drying include:

- Improve existing solar drying techniques by simple innovation-- black surfaces on drying patios, improved air flow, reflectors for existing dryer beds, and quick protection from rain and insects.

- Use efficient, low-cost dryers based on sound mechanical and thermodynamic principles, emphasizing indigenous construction materials.

- Supplement or substitute solar drying with heat generated from other sources--crop residues, waste heat from engines, biogas, gasification, etc.

- Investigate storage of solar energy by use of water, rocks, desiccants, or phase-change chemicals, but seek to minimize costs and complexities.

- Reduce needs for dehydration, that is, decrease the degree of water removal required through use of synergists such as salt, sugar, organic acids, sulfur dioxide, and smoke.

<u>Solar Heating</u>. Solar heating could be used increasingly to heat water for cooking, cleaning, and steam generation, to maintain thermophilic conditions in biogas generation, for alcoholic fermentation and distillation, and for household cooking and preheating.

<u>Solar Cooling</u>. Solar cooling is potentially of great importance for the preservation of perishables. Several systems are under consideration and, while still very expensive, may provide practical future possibilities.

Other Energy Alternatives

<u>Improving the efficiency of traditional fuel use</u>. More traditional energy sources must be used to provide processed foods in urban areas. New technologies can help in the long term, but conservation is necessary immediately. For example, the waste heat from engines could be utilized. The use of synergists would reduce processing or cooking requirements. In addition, a number of alternative processes would reduce energy inputs:

- o Solar energy replacing mechanical drying and cooking
- o Indigenous fermentations as substitutes for canning
- o Evaporative cooling and heat sinks (cool water, earth, shade, elevation) for mechanical refrigeration (an increasing demand as Western styles are adopted, e.g., for soft drinks, beer)
- o Cooking efficiency--soaking solutions, minimum cooking, precooking, insulated holding, use of pressure cookers, better stoves.

Biogas. Biogas production is a sound way to handle wet, unsanitary refuse while producing energy for domestic and industrial applications and fertilizer and feed for farm use. It has the advantages of being able to use a variety of substrates; to eliminate pathogens in human or animal excrement; and to improve the fertilizer value of resulting sludge relative to the raw material. The methane produced can be stored until needed and can be concentrated by compression and piped easily to point of use. Methane can be used for lighting, heating, and direct combustion in internal combustion engines. The hydrogen sulfide produced with methane can be easily scrubbed by passing it through iron filings.

However, biogas has an inconsistent success record, mesophilic requirements, high capital costs, and critical needs for management. Because the ratio of carbon to nitrogen in the raw material is important, proper charging of the fermenter is critical. Optimal gas generation is attained only when thermophilic conditions are maintained, i.e., over 30° C. Other disadvantages include problems with batch versus continuous gas generation and the facts that the end-product slurry may be hard to handle and gas storage can be difficult to handle cheaply. Further, the raw gas contains carbon dioxide, which reduces the energy content per unit volume, and hydrogen sulfide, which corrodes metal in internal combustion engines.

Keeping these advantages and disadvantages in mind, it might be practical to integrate a biogas system with a public market when food refuse and human waste are a disposal problem and modest energy needs exist.

Alcohol Fuels. The use of alcohols as fuels is frequently assigned low priority because it implies fuel production at the expense of food production, and is more efficient on a large scale than small scale. Cellulose conversion technologies--not necessarily just for alcohol but also for glucose for animal feed (single-cell protein)--are not currently economic but may become so through intensive research and development.

Direct Combustion of Dry Residues. The use of refuse on-site to fuel processing operations in sugar refineries (bagasse), oilseed mills (hulls), and copra plants (husks) should be examined for small-scale cooking applications.

Gasification. Gasifiers offer possibilities in the transportation sector and are probably applicable to small- and medium-scale food processing operations. Conversion to gas is a good way of storing solar energy on demand as biomass for internal combustion engines (electricity generation, mechanical power), solar drying supplementation, steam generators, and compression/adsorption refrigerators.

Gasifiers are simple to construct and operate but require metalworking capabilities, air draft, and fairly dry and compact biomass fuel.

Human and Animal Power. Although human beings and draft animals are often the only sources of power available, there is a need to make this power more efficient by mechanical aids, e.g., hand cranks, pedal power, and power take-off devices. The use of human and animal power is relevant to home and small-scale processes such as milling, grinding, shelling, mixing, and pressing. However, there is a question of opportunity cost. Land required to feed animals may also produce a large enough cash crop to purchase capital replacements, such as a power mill and the fuel to run it.

Water and Wind power. Technologies for extracting power from wind or the movement of water are site specific and practical where capital costs and payouts warrant their use.

Despite this useful inventory of energy alternatives, it should be emphasized that reduction of postharvest losses saves all the energy expended up to the point at which the loss occurs. It takes energy to save energy, so the potential trade-offs should be carefully assessed.

The Role of Energy Surveys

Surveys for documenting energy use, especially in rural areas in developing countries, are capital-, labor-, and time-intensive. The data produced by such surveys are clearly important for increasing our understanding of energy use in the agricultural production and postharvest systems of particular developing countries and in marginally mechanized agricultural production and postharvest systems in general. However, the reality of present food shortages, the limited resources available for mounting surveys, and the need to push forward with already known energy technologies for increased food production and processing efficiency dictate that surveys be given limited financial and managerial support compared with interventions that will have near- or long-term effects. However, limited continuous surveys to monitor energy use, output, and efficiency before and after intervention will be invaluable to assess cross-sectoral effects and relative success of energy-related interventions in the food supply system. There is ample justification for national food conservation policy bodies with adequate professional staff to identify critical areas of food loss and to recommend corrective measures. These bodies should also be able to assess opportunities for energy conservation within a nation's agricultural production and postharvest systems.

A Strategy for Increasing the Output and Efficiency of Energy Use in Food Processing Systems

Within the broad energy-related objectives cited above, the strategy of using food processing to increase the availability of food and improve the public health and quality of life in developing countries should include the following goals:

- Increase the use of energy for food processing and preservation to increase the quantity and quality of foods available, emphasizing the use of renewable fuels and decreasing, where possible, the use of fossil fuels.
- Increase fuel conservation in developing countries food systems by promoting the recycling of waste heat and the adoption of efficient food processing equipment.
- Use food processing to reduce the weight and volume of food for transportation, thus reducing the energy cost for distribution of processed food.
- Promote food processing to extend the shelf life and availability of foods, thus reducing the wastage of energy inputs for agricultural production.
- Increase the use of by-products, such as the residues and wastes from food processing, for energy generation, including production of biogas; adapt or retrofit renewable energy power sources where they are economically viable.

- Increase training at the professional and technical level for more energy-efficient food processing; and increase the trained cadre for assessing energy needs and alternatives for food processing and disseminating appropriate technologies in developing countries.

- Increase access to food technology data bases and disseminate relevant literature on energy-efficient food processing operations, projects, and technologies.

- Where culturally feasible, substitute alternative food commodities that require less energy for processing and consumption (cooking); promote food processing for commodities that are locally abundant and economically suitable as processed export goods.

These goals are part of a general strategy that would increase the availability of processed foods in developing areas. Not all of these goals can be met in any system, but they serve as a guide to the energy requirements for food processing. Growing urban populations require greater amounts of processed foods because they are often far from production areas and the ability to store perishable commodities is limited. Food processing competes with other energy needs, so conservation of processing energy is a requirement. However, conservation requires expertise to apply efficient handling, marketing, packaging, storage, and processing technologies, most of which require significant energy inputs.

The overall goal is not to reduce the total energy expended in processing food. On the contrary, the goal is to increase the amount of processed foods where food losses in the postharvest system reflect waste of both energy and food, and to do this will require more energy. However, the most desirable energy system for a particular locality, the efficiency of each system, and the economic and cultural impact of using alternative energy systems for food processing and consumption vary widely. Training and expertise are therefore crucial for making wise choices among alternative energy sources. Training deserves strong support in all development programs, especially for making appropriate choices for energy use in food processing.

Considerations to Keep in Mind

Economic Incentives in the Postharvest Food System. In the chain of events, from production through processing, storage, transportation, and marketing, any innovation introduced at each step must be economically viable or it will not be adopted. If any activity or process in the chain does not return a profit, that component will be the weakest link (or must be subsidized) and the whole operation falters.

Growth of urban populations creates a demand for low-cost food supplies. The size of that demand often causes the imposition of constraints such as price controls, import limitations, export taxes, and marketing restrictions that discourage or prevent the provision of an abundant supply of good-quality food at affordable prices because of insufficient incentives for farmers and others. This relationship is often overlooked.

Social Impact Assessment. Projects that favorably influence choice among alternative uses of energy in food processing result from changes, often dramatic, in established practices. Because an intervention that has a net beneficial effect may well have unrecognized or delayed undesirable implications, a social impact assessment should be an important part of project design, implementation, and evaluation. For example, conflict between home or village food processing and centralized, commercial enterprises may well arise during urbanization. How this affects self-sufficiency in food and energy, particularly among the poor, requires careful attention. Destabilization of women's traditional role is a well-documented example.

Energy-efficient operations, such as milling, extrusion cooking, baking, and fermentation can sharply reduce energy inputs and fuel costs. However, questions such as the following need to be asked:

- What does the innovation do to those people whose livelihoods depended upon the displaced procedure?
- How can those individuals be reabsorbed into the economy?
- Will more efficient central processing, transportation, and distribution present disincentives for cottage industry in the same way that importation of cheap food depressed local food production and reduced food self-sufficiency?

Role of Women in the Postharvest Food System. Although extensive documentation does not exist on women's labor, responsibilities, and economic benefits in the postharvest food system, it is clear that in many, if not most, rural economies in developing countries, women play a major role in the various activities from harvest to final preparation of food. More documentation on women's roles in the postharvest food system is essential. We know enough, however, to recognize the importance of sensitivity in adapting new technologies and promotional efforts to the division of labor in specific locales, paying particular attention to the role of women. Without this sensitivity in project design and implementation, unintended or unexpected and likely unfavorable displacement of established social, cultural, and economic structures and patterns will result.

Methodology for Evaluating Development
and Promotion of Appropriate Technologies

Many small, low-cost devices have been developed and are repeatedly cited in diverse reports and handbooks as having promise for use in the postharvest food system. These devices include solar crop dryers, hand- and pedal-operated grinders, evaporative refrigerators, improved cook stoves, pulpers, graters, and smokers. However, information is rarely available on the extent to which such devices have been adopted, modified, or rejected and constraints and reasons for failures are rarely reported. For relatively little expense, it would be extremely useful to examine by case study, the successes and failures of efforts to promote appropriate technologies. The case study should include a technical and social analysis and examination of the processes or approaches used to develop and promote appropriate technologies. Various approaches to such a study, including the appropriate technology "supermarket" and the model village approach, have been documented. These approaches could be evaluated to produce guidelines for future efforts tailored to user needs.

A methodology for making such appropriate technologies for processing of agricultural commodities available to developing countries is proposed here. It can be applied to any alternative energy source, and should receive high priority in the development and implementation of appropriate technologies:

- Assemble relevant information and compile an annotated bibliography on energy use in food processing.

- Examine (on-site if possible) projects in which appropriate energy systems have been used for food processing and evaluate successes and failures.

- In cooperation with local, bilateral, multilateral, and private and voluntary technical assistance organizations, develop training manuals and project management guides to promote energy-efficient systems for particular food processing operations.

  - -- Manuals should make extensive use of pictures and diagrams.
  - -- Manuals should be printed in major languages, e.g., English, French, Spanish, and Arabic.
  - -- Manuals should be loose-leaf for easy additions.

- o Develop demonstration projects to extend the most appropriate food processing systems.
  - -- Work through USAID missions and assign project staff for the duration of a project within a particular country.
  - -- Cultural assessment and site selection must be integrated and attention given to previous case studies.

- o Coordinate all project phases, including demonstration projects, with other relevant international donors and local counterparts.

- o Evaluate demonstration projects and share negative and positive findings through:
  - -- Examination of constraints
  - -- International conferences
  - -- Update of training manuals
  - -- Development of extension materials
  - -- Development of linkages for further research
  - -- Development of project management guidelines for future projects

- o Examination of training and personnel requirements and development of training materials and expertise locally and in the United States.

- o Identification of, and support for, capable counterpart personnel and organizations.

ENERGY AND THE FOOD CONSUMPTION SYSTEM

Fuel Use in the Food Consumption System

The food consumption system is defined to include homes, restaurants, food stands, hotels, and other places where food is prepared for final consumption. This system is a large consumer of energy in developing countries, generally accounting for at least 20 percent of total energy use and over 50 percent of rural energy use. Energy is used primarily for cooking but also for drying, washing, and refrigeration. A diversity of fuels are commonly used, e.g., agricultural residues, dung, kerosene, bottled gas, and electricity. Table 4 presents a matrix of energy uses by different types of establishments; and Table 5 indicates the general nature of the current energy delivery for the food consumption systems.

Traditional energy sources are the principal forms of energy of biomass, particularly in the form of charcoal and wood. The Middle East is an exception, since biomass is not readily available. The mix of wood, twigs, agricultural residues, dung, and charcoal fuels used varies according to the country. In rural areas, fuels for household use are generally collected free of charge, while in urban areas fuels are primarily purchased. Energy used in cooking is estimated at 0.5-0.7 tons of air-dried wood per capita annually. As incomes increase, use of commercial fuels for cooking expands in both rural and urban areas. There is increasing use of liquefied petroleum gas (LPG) as a substitute for kerosene by upper-income urban families in areas where it is readily available, as in Southeast Asia and North Africa. The LPG distribution network, however, does not generally extend beyond the major towns.

TABLE 4 Fuel mix in the food consumption system.

	Char-coal	Wood	Agricultural residues (including dung)	Coal bri-quettes	Kero-sene	LPG	Electri-city
Urban household	X	X			X	X	X
Rural household		X	X	X	X		
Hotels	X				X	X	X
Restaurant	X	X			X	X	X
Food stands	X	X			X		

TABLE 5 Current energy delivery for the food consumption system.

Source	Conversion device/process	Product
Petroleum	Refineries	Kerosene LPG
	Generators	Electricity
Biomass	Cutting	Fuelwood
	Digesters	Agricultural residues Methane gas
	Kiln	Charcoal
	Caking	Dung cakes
Coal	Carbonization plants	Briquettes
Hydroelectricity		Electricity

The current food consumption system is characterized by low efficiency of energy conversion. Household cooking processes generally average between 5 and 10 percent efficiency compared with 30 percent for a modern stove. Fire in a developing country often serves multiple functions: cooking, keeping insects away, preserving food, security, social interaction, lighting, and heating. Therefore, energy efficiency considerations by themselves may not determine what is socially desirable and acceptable.

Cooking requirements vary according to the type of food and quantity being cooked (Table 6). Fuel use may vary depending on degree of wetness, temperature, and duration of heat required. The availability and moisture content of particular crop residue fuels, e.g., jute sticks or corn cobs, is seasonal. Use of residues may incur costs to the production system through reducing soil nutrients and organic matter and increased erosion.

Impact of High Oil Prices and Scarcity of Traditional Fuels on Cooking Patterns and Nutrition

The demographic revolution of the late 1950s and 1960s and the explosive rise in oil prices in the 1970s led to a crisis in the availability of cooking fuels in developing countries. Deforestation pervades the Third World because of the increased demand for biomass fuels. Major shifts in fuel consumption patterns are occurring in urban areas where the middle-income and poor families can no longer afford to use kerosene, butane, and LPG. These families are being forced to substitute fuelwood and charcoal for fossil fuels. This phenomenon further aggravates the problem of deforestation.

If the increasing urban demand for firewood and charcoal can be met through increased supply and development of alternative heating technologies, the rural areas can better supply their own needs. However, the problems arise when rural areas must meet the energy requirements for both urban and rural cooking.

Increasing cost and scarcity of fuels can lead to a large increase in human energy expended on fuel collection, especially by women and children.

Higher fuel costs and reasons of convenience have an impact on urban consumption patterns and cooking processes. Urban residents make increasing use of bread, sandwiches, torillas, chapatis, stable ready-to-eat cereal products, and other convenience meals that are precooked by commercial vendors. These products shift cooking from the

TABLE 6 Characteristics of cooking heat required for different foods.

	Low heat	High heat
Wet	Stews: meat, fish	
	Stews: vegetable	Porridge/foufou
	Beans	Rice
	Hominy: maize, sorghum	Maize on cob (boiled)
	Boiled sweet potatoes	Stir fry
	Boiled potatoes	Soups
	Boiled squash, pumpkin,	Boiled eggs
	marrow, papaya	Teas, coffee
	Couscous	Candies
	Bulgur wheat	
	Curries	
	Soybean curd	
	Custard	
	Tamales	
	Beer	
Dry	Roast meat	Scones and bread
	Roast corn	Chapatis
	Roast peanuts	Tortillas
	Roast squash	Sweet breads and cakes
	Baked potatoes	
	Baked sweet potatoes	
	Preparation of semolina, beef jerkey, fish jerkey, parched corn	

individual household and allow for economies of scale. At the same time, the demand for wheat products goes up, entailing foreign exchange costs. We need:

- Better documentation of this trend toward vended foods reported for cities in Africa, India, and Sri Lanka, and its relationship to energy costs

- Experimental work on foods made from wheat substitutes that can be prepared with the same convenience and greater economy for the consumer: cassava cake, maize, millet cake, etc.

The recent abundance of low-cost fuels has obscured the extent to which some areas now have diets developed under earlier conditions of scarce fuel. A basic book that reviews cookery styles should be prepared, and foods that require a minimum of energy in cooking consistent with cultural patterns should be developed: semolina and couscous in North Africa, polenta in Italy, Japanese-style noodles (ramen), and glutinous rice, Chinese stir frying, the bread (baked at local bakeries rather than in the home)/cheese diet of much of Europe.

The following questions should be considered. As fuels become scarce and expensive, what foods are dropped because preparation becomes too expensive or infeasible? What effect does this have on human nutrition? As cooking is done less often, what effect does this have on nutrition? What other costs lead to the abandonment of particular foodstuffs?

Some Technological Alternatives

Production of Biomass. Analysis of the impact of increasing oil prices and increasing scarcity of traditional fuels leads to the conclusion that generation of biomass (particularly for charcoal) is critical to satisfying energy needs for cooking in urban areas and, thereby, relieving pressure on the rural areas.

There are current opportunities for taking advantage of the new awareness of the importance of biomass production, the need to satisfy requirements for energy, and the increasing information about technical and biological possibilities. These opportunities include:

- Collection, selection, storage, and distribution of genetic material to ensure adequate supplies of much more diverse selected genetic material than is currently available; this would remove one major constraint on the production of biomass.

- Reconsideration of policy options concerning land use, ownership, and rights with a view to supporting revegetation and renewable fuelwood production, rather than current, widely operating policies that favor devegetation of, for instance, common forests and inhibit commercial fuelwood production.

- Development of (based on the above) a more effective mechanism for enabling rural folk to have access to genetic and technical resources that meet their perceptions of need and will lead to their spontaneous diffusion. This would include providing access to a wide range of seed, seedlings, and related processing technologies from a local multipurpose nursery--rural development center in a local "technology supermarket" (such as is proposed in Mauritania*). Subsidizing rural revegetation is at least as justifiable in terms of societal benefit as subsidizing electrification or kerosene.

- Densification of biomass has promise for utilizing biomass that has not been used as a fuel source because of its low heat content per unit volume; there are opportunities for using tropical grasses (e.g., Imperata cylindrica, alang-alang) and forestry wastes in this fashion.

- Strengthening of forest services through training of multipurpose foresters and supporting the integration of forest services into agroforestry production systems--to help rural people reforest and learn from local practices that work rather than to enforce forest use laws.

Charcoal--Improved Kilns, Stoves, and Other Devices. Improved charcoal kilns of many types and sizes--metal drum, retort, brick beehive, dome--have been tested in a variety of circumstances. Few have been adopted, and most charcoal production in developing countries is carried on by itinerant entrepreneurs, using traditional pit or mound methods. Where the wood is gathered free from the commons for the cost of labor, there is little incentive to acquire a relatively costly, difficult-to-transport device to improve the efficiency of charcoal recovery. In many countries, particularly in arid countries where trees are scarce, there is a remarkably sophisticated and efficient system of contractual relationships among charcoal makers, transporters, and consumers which provides employment and income to many people at the expense of the countries' dwindling forest

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*"Environmental Degradation in Mauritania," National Research Council, National Academy Press, Washington, D.C., 1981.

resources. This system has proved difficult to alter, even in extreme situations in which the charcoal has to be transported hundreds of kilometers. The capital investment and political desire to achieve a balance of use with regeneration that includes rather than displaces present charcoal producers have eluded most countries.

Successful fuelwood plantations for production of charcoal are operating in a limited number of locations, notably in Brazil and Argentina. Much more serious attention by governments, communities, and their technical assistance donors needs to be given to this aspect of national energy supply. Charcoal use is likely to increase even further with the adoption of other technologies--such as producer gas generators--that will generate electricity and power fishing boats or trucks. Technologies for increasing the efficiency of production (kilns and retorts) and use (stoves, briquettes, and char gas) should be promoted wherever possible.

Biogas. Biogas generation requires considerable capital investment, a plentiful and regular source of substrate, preferably animal dung, and a fair level of technical competence to obtain sufficient quantities of gas to justify the effort. With notable exceptions, successfully operating biogas generators are typically associated with fairly sophisticated integrated systems of waste management based on cattle, swine, or poultry production, in which the gas generated is a valuable by-product rather than the main product. The Chinese experience, in which public health and nutrient conservation needs are the main objective of the extensive biogas program, and the Indian experience with community and household gobar gas generators, are consistent with this viewpoint.

Improved Cooking Stoves. Despite a great deal of effort concentrated on the design and diffusion of improved cooking stoves based for the most part on fuelwood, success has been mixed. Some communities and governments have adopted new technologies with enthusiasm, but design, cultural, and cost factors have hindered more widespread adoption.

As yet, there is no demonstrable connection between the introduction of "efficient" cooking stoves and a reduced rate of consumption of fuelwood, though this is usually the justification for the effort. There is considerable variation in the way in which efficiency of cooking stoves is measured and reported. Indeed, improvement in efficiency and reduction in fuel consumption attributed to devices are often assumed, not tested or measured; and thus far there is no published evidence of a reduction in fuelwood consumption resulting from large-scale introduction of improved stoves. Much of the information on diffusion of improved stoves concerns the relatively affluent who have sufficient resources to acquire the technology and for whom access to fuelwood is not a critical limitation. Thus even where stoves are constructed and used as their designers intended, they may use available fuel more efficiently for additional purposes, rather than reduce overall fuel use. Little critical information is available about the desperately poor and the impact of the technology on, for example, reducing the use of animal dung for fuel. In addition, scientists have demonstrated that when traditional (three-stone) cooking is done carefully, efficiencies equal to those of well-designed chula or lorena stoves can be obtained. Doubtless, those suffering from fuelwood shortages use their supplies carefully. Improved stoves should be introduced to rural and urban areas but should not be expected to solve problems of fuel shortages.

Recent advances in solar cookers (coupled with higher fuel costs) have made some types of solar cooking more attractive. Past attempts to introduce solar cookers have had very limited success, but the time may have come when some forms of solar heating can be used more widely.

Solar Heating. In the near term, solar-heated hot water introduced into the cooking cycle will have a major impact on energy use in food preparation. A major portion of food preparation relies on boiling, steam, or hot water. If households can start wet cooking processes with solar-preheated water, savings in fuel consumption would be on the magnitude of 40-60 percent, especially if water for tea and coffee is included. If current estimates that 60 percent of the energy required for agriculture is consumed in cooking are accepted, the domestic adoption of solar-heated hot water could result in energy savings for the agricultural sector of the magnitude on 30 percent. Solar-heated hot water would also have health benefits for bathing and washing.

Hot Pots. Solar heating can be used to boil stews as well as some other dishes that depend on wet cooking; the cooking process can then be completed by placing the heated dish in a fireless, insulated cooker in which cooking continues as long as the heat is retained.

REFORESTATION

Reforestation for fuel wood purposes or the production of biofuels is a top priority in the development of alternatives to fossil fuels and should receive major emphasis in AID's assistance to developing countries.

More than half of the energy used in the production and consumption of food is in the processing and final preparation of food for eating. Fuelwood has been and is the major source of this energy. In many parts of the developing world the demand for fuelwood has been so great that large areas have been denuded of trees and shrubs, resulting in, erosion, severe water losses, flood damages and effects on oxygen replenishment. Furthermore, sources of fuelwood are receding from population centers, including villages or metropolitan areas. The cost in human time and effort to gather firewood for households is accelerating at a rapid rate, and the energy consumed in hauling firewood for use in larger metropolitan areas is an ever-increasing expenditure of scarce liquid-fuel sources--and probably import costs. At the present accelerating rate of firewood consumption, the supplies within reasonable access to population centers will become the most limiting factor in the food supply for hundreds of millions of people.

Therefore, it is recommended that AID obtain a cadre of forestry specialists in AID or available to AID and devote attention to the following goals:

- Identify areas that are most in need of reforestation, determine what fuel crops are most appropriate for such areas (possibly a combination fuel- and food-producing trees) and explore means of motivating host countries--in both the public and the private sectors--to plant such crops.

- Launch a training program for foresters in developing countries.
- Set up demonstration programs in several cooperating countries.
- Provide financial assistance for large and small reforestation projects in selected areas until they become self-sustaining.
- Develop and support fuelwood projects that will provide sustained energy sources for food processing and preparation and a better quality of life.

APPENDIX A

Annotated Bibliography

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Konandreas, P.A. and Green, R. 1976. Interaction of energy and food prices in less developed countries: comment. American Journal of Agricultural Economics 58(3):592-594.

Leach, G. 1976. Energy and Food Production. IPC Science and Technology Press, London, United Kingdom.

Leach, G. and Slesser, M. 1973. Energy Equivalents of Network Inputs to Food Producing Processes. University of Strathclyde, Glasgow, Scotland.

Lipton, M. 1975. Energy and Agriculture in Poor Countries. University of Sussex, Falmer, Brighton, United Kingdom. South Asia imports 5-12 percent of the food grains it consumes. Food, fertilizers, pesticides, and agricultural oil inputs comprise a large and growing share of imports. Prices of regional exports, such as tea, jute, and textiles, have risen, but slowly. Thus the rising price of farm-linked imports depletes the foreign exchange reserves needed for growth and development. There are four possible solutions. First, the poor countries can replace imported energy-intensive farm inputs by "appropriate technologies." Second, they can go on using the extensive mixture of farm inputs, but transform them more efficiently into import-saving farm outputs. Third, food output can be raised by increasing the share of outlay and effort devoted to producing it. And a fourth policy is to emphasize nonfarm development.

Lockeretz, W., ed. 1977. Agriculture and Energy. Academic Press, Ltd., London, United Kingdom. This volume of proceedings of a conference held at Washington University, St. Louis, Missouri, USA, June 17-19, 1976 is divided into nine sections dealing with energy use in agriculture: statewide and national analyses; crop production; irrigation; tillage; fertilizers and plant nutrients; livestock production; nondepletable energy sources; agriculture in developing countries; and implications of energy problems for U.S. agricultural policy.

Loehr, R.C. 1978. Methane from Human, Animal and Agricultural Wastes. Renewable Energy Resources and Rural Applications in the Developing World. Westview Press for the American Association for the Advancement of Science, Boulder, Colorado, USA. This paper discusses the conversion of biomass into methane by anaerobic digestion. It is pointed out that the use of alternative energy technologies in rural areas of developing countries should be aimed at reduction of human drudgery, minimum capital investment and operating expense, and production of energy in a form convenient for storage. In addition, where biomass conversion is concerned, agricultural productivity should be increased, the efficiency of the use of biomass (wood, cattle dung, crop residues) must be increased, and the use of plant fuels in general must be decreased to prevent deforestation and maintain soil tilth.

Makhijani, A., and Poole, A. 1975. Energy and Agriculture in the Third World. Ballinger Publishing Co., Cambridge, Massachusetts, USA.

Mayer, J. 1981. Saving energy in the food system. The Professional Nutritionist 13(1):1-4. Examines energy required to produce foods and looks at how some of the energy could be saved without compromising the nutritional quality of the diet.

Mellor, J.W. 1979. World Food Strategy for the 1980s--Content, Objectives, and Approach. Paper presented at the International Conference on Agricultural Production: Research and Development Strategies for the 1980s. International Food Policy Research Institute, Washington, D.C. USA. Improved food production and distribution can be accomplished only through broad economic development, which is now complicated by problems of increasing land scarcity and rising energy prices. Solving one of these problems tends to exacerbate the other.

Pachauri, R.K. n.d. Energy and Development in the Third World. Administrative Staff of College of India, Hyderabad, India.

Pfulg, F. 1978. Practical paths to plant power. Ceres 11(5):19-22. Bioconversion processes are presented as being especially relevant for regions handicapped by lack of transport and sophisticated technology. The article shows the enormous impact that the technology of biogas and some similar solar techniques could have on agricultural ventures using them. It concentrates on strictly practical aspects and deals exclusively with the developing countries.

Pimentel, D., ed. 1980. Handbook of Energy: Utilization in Agriculture. CRC Press, Inc., Boca Raton, Florida, USA.

Pimentel, D. 1977. Workshop Report on Energy Needs, Uses and Resources in the Food Systems of Developing Countries. College of Agriculture and Life Sciences, Cornell University, Ithaca, New York, USA. Purpose of the workshop was to identify the major energy constraints associated with food production, processing, storage, transport, and preparation in the food system. Potential programs and policies were identified that would be effective in overcoming energy-related barriers to improving food supplies and nutrition among the rural poor in developing countries.

Pimentel, D., Dritschilo, W., Krummel, J., and Kutzman, J. 1975. Energy and land constraints in food protein production. Science 190:754-761. Analyzes energy and land demands for both animal and vegetable protein production in the U.S., and examines world food supply as it relates directly to world population density, dietary standards, and food production technology.

Pimentel, D., Hurd, L.E., Bellotti, A.C., Foster, M.J., Oka, I.N., Sholes, O.D., and Whitman, R.J. 1973. Food production and the energy crisis. Science 182(4111):443-449.

Pimentel, D., Lynn, W.R., Macreynolds, W.F., Hewes, M.T., and Rusk, S. 1974. Workshop on Research Methodology for Studies of Energy, Food, Man and Environment. Phase I. Center for Environmental Quality Management, Cornell University, Ithaca, New York, USA.

Pimentel, D. and Pimentel, M. 1979. Food, Energy and Society. Resource and Environmental Science Series, College of Agriculture and Life Sciences and Division of Nutritional Sciences, Cornell University, Ithaca, New York. John Wiley & Sons, New York, New York, USA. The aim of this book is to explore the interdependencies of food, energy, and their impacts on society in order to provide a basis for planning and implementing policies of individuals and nations as they face the inevitable dilemma of how everyone can be fed, given the limited resources of the earth.

Price, D.R. 1980. Where farm energy goes. In: Cutting Energy Costs. The 1980 Yearbook of Agriculture. U.S. Government Printing Office, Washington, D.C., USA. Even though total consumption of energy in agricultural production is low relative to other major sectors, it is essential.

Price, D.R. 1979. Fuel, food and the future. In: Critical Food Issues of the Eighties, edited by M. Chou and D. P. Harmon. Pergamon Press, Inc., Elmsford, New York, USA. General overview of energy consumption in agricultural systems. Examines how much fuel is used to produce food and looks at where adjustments might be made by conservation, substitution, or use of alternative and renewable energy sources.

Revelle, R. 1976. Energy use in rural India. Science 192:969-975.

Rifkin, M. 1975. International Symposium on Energy, Resources and the Environment (5th) Held at Kuala Lumpur, Malaysia on 17-20 February 1975. Mitre Corp., McLean, Virginia, USA. Energy scenarios for the future; livestock and urban waste as future energy resources; impact of energy resources on agriculture in a developing country; energy, fertilizer, and food; resource management and international cooperation with special reference to Malaysia; national energy policy as it affects economic development.

Shaw, M.D. 1980. Impression of China after 30 years and thoughts on energy use in Chinese agriculture. In: Glimpses of Agricultural Mechanization in the People's Republic of China. Report of the delegation of 15 ASAE members on their technical inspection in China, August 18 - September 8, 1979. American Society of Agricultural Engineers, St. Joseph, Michigan, USA.

Slesser, M. 1973. Energy subsidy as a criterion in food policy planning. Journal of the Science of Food and Agriculture 24:1193-1207.

Smerdon, E.T. 1977. The role of energy in food production--a perspective. In: Energy Use Management, edited by R.A. Fazzolre and C.B. Smith. Pergamon Press, Inc., Elmsford, New York, USA. Paper analyzes energy use in agricultural production with particular reference to future food production in developing countries. The historical relationship between crop yields and external energy input is provided as a point of departure to assess future energy needs if developing countries are to approach their food production potential. The energy cost for the various essential production inputs is summarized and presented. Paper concludes that the energy requirement for increased food production must be carefully considered as nations formulate their future energy and food policies.

Smerdon, E.T. 1976. The Role of Energy in Food Production in LDCs: A Perspective. Office of Agriculture, Bureau for Technical Assistance, Agency for International Development, Washington, D.C., USA.

Soedjatmoko. 1981. Turning Point in Development: The Food-Energy Pivot. Paper prepared for the Inter-governmental Meeting of Development Assistance Coordinators in Asia and the Pacific, February 23-28, 1981, New Delhi, India. Paper concentrates on threat to the welfare of peoples in the Asia and Pacific region resulting from the synergistic effect of the energy and food crisis.

Stout, B.A., Myers, C.A., Hurand, A., and Faidley, L.W. 1979. Energy for World Agriculture. FAO Agriculture Series No. 7. Food and Agriculture Organization of the United Nations, Rome, Italy. This publication provides information and guidance on a vital aspect of world agriculture: the more effective use of energy. It stresses that the present energy crisis is due not so much to a shortage of supply as to an overdependence on nonrenewable resources (especially petroleum) which are distributed unevenly throughout the world. This book provides a comprehensive and well-documented assessment of present and future applications of energy in agriculture, with emphasis on future technological prospects for the use of renewable resources.

Terhune, E.C. 1977. Prospects for increasing food production in less developed countries through efficient energy utilization. In: Agriculture and Energy, edited by W. Lockeretz. Academic Press, Inc., New York, New York, USA.

Timmer, C.P. 1975. Interaction of energy and food prices in less developed countries. American Journal of Agricultural Economics 57(2):219-224.
Tuve, G.L. 1976. Energy, Environment, Populations, and Food: Our Four Independent Crises. John Wiley & Sons, New York, New York, USA. Explores the limitations imposed by capital supply and manpower when the four problems of energy, environment, populations, and food are jointly considered...Summarizes past experience, present status, and future prospects in each of the four interrelated fields.
Vilstrup, D. 1980. Less energy, more food. In: Cutting Energy Costs. The 1980 Yearbook of Agriculture. U.S. Government Printing Office, Washington, D.C., USA. Examines the food processing industry and its critical dependence on adequate supplies of energy.
Wittwer, S. 1980. Agriculture in the 21st Century. Paper prepared for the Agricultural Sector Symposia, January 11, 1980, World Bank, Washington, D.C., USA.

ENERGY FLOWS AND CONSUMPTION IN VARIOUS AGRICULTURAL SYSTEMS

Anonymous. 1981. SAM: the Mexican food system. IFDA Dossier 25:17-30. Crisis in the Mexican agricultural sector led the government to launch, in 1980, the Mexican Food System. The basic features are: (1) self-sufficiency; (2) combating concentration of ownership and income, a major constraint; and (3) a new system of food distribution, selected subsidies, and nutritional education. SAM is a complex system of activities tackling the problem in a comprehensive manner, from production through consumption.
Arinze, E.A., Schoenau, G., and Bigsby, F.W. 1979. Solar energy absorption properties of some agricultural products. Technical Paper of the American Society of Agricultural Engineers 79-3071.
Checci and Company. 1980. Senegal Food and Energy Study. Prepared in collaboration with Brookhaven National Laboratory, Upton, New York, USA.
Clark, C. and Haswell, M. 1970. The Economics of Subsistence Agriculture. MacMillan, London, United Kingdom.
Commoner, B., Gertler, M., Klepper, R., and Lockeretz, W. 1975. The vulnerability of crop production to energy problems. In: Research Applied to National Needs. Washington University, Center for the Biology of Natural Systems, St. Louis, Missouri. National Science Foundation, Washington, D.C., USA. The energy consumed in producing 14 field crops under a variety of conditions has been determined. The cost of this energy in both 1970 and 1974 has also been calculated. The energy considered includes both direct consumption (for field equipment, crop drying, irrigation pumping, and hauling) and indirect consumption through purchased inputs

(fertilizers and pesticides). For each crop, the impact of energy price increases has been expressed through two indices involving the increased amount paid for energy to produce one unit of crop.

Commoner, B., Gertler, M. Klepper, R., and Lockeretz, W. 1974. The effect of recent energy price increases on field crop production costs. In: Research Applied to National Needs. Washington University, Center for the Biology of Natural Systems, St. Louis, Missouri. National Science Foundation, Washington, D.C., USA. The cost of the energy used to produce 14 field crops in a total of 29 different production situations has been determined. The following kinds of energy consumption are considered: fertilizers; pesticides; operation of field equipment; crop drying; irrigation; and hauling. The change in the costs of these energy requirements between 1970 and 1974 has been computed, assuming the same production technology.

Ernst, D. 1978. Fuel Consumption Among Rural Families in Upper Volta, West Africa. Prepared for the Eighth World Forestry Congress, Jakarta. Food and Agriculture Organization of the United Nations, Rome, Italy.

Goering, T.J. 1979. Tropical Roots Crops and Rural Development. World Bank Staff Working Paper, No. 324. Washington, D.C., USA. Tropical root crops (TRCs) are important sources of calories for low-income groups in developing countries, and have considerable development potential because of their ability to convert solar energy to carbohydrates even in adverse agroclimatic conditions where sustained production of traditional food crops is not possible. This paper examines the potential role of these crops as sources of human food and livestock feed and as raw materials for industrial processing. It concludes that the most promising immediate possibilities for expanded use are as food and feed.

Heichel, G.H. 1978. Stabilizing agricultural energy needs: role of forages, rotations, and nitrogen fixation. Journal of Soil and Water Conservation 33(6):279-282.

International Institute for Applied Systems Analysis. 1979. On Energy and Agriculture: From Hunting-Gathering to Landless Farming. International Institute for Applied Systems Analysis, Laxenburg, Austria. An energy analysis of agriculture shows very coherent patterns of evolution from the neolithic age up to this century. All technical advances were in fact exploited toward intensification and the ratio of food output to energy input was held remarkably constant over such a long stretch of time. New agricultural practices in developed countries linked to massive energy "subsidies" from fossil fuels have disrupted the trends, substantially altering these practices. Low-tillage techniques, hormonal and genetic pesticides and herbicides, nitrogen-fixing in grains, and other emerging technologies satisfying this constraint are briefly described and assessed in this paper.

Khan, M.H. 1975. The Economics of the Green Revolution in Pakistan. Praeger Publishers, New York, New York, USA. Analysis of a survey on the adoption of new seeds and on the income and employment effects of the new technology. Indicates no great hope for agricultural growth and economic equity in Pakistan.

Newcombe, K. 1976. Energy use in the Hong Kong food system. Agro-Ecosystems 2:253-276.

Practical Concepts, Inc. 1980. Energy in the Food System, Dominican Republic: Conclusions and Recommendations, and Introduction. Prepared in collaboration with Brookhaven National Laboratory, Upton, New York, USA.

Rappaport, R.A. 1971. The flow of energy in an agricultural society. Scientific American 225(3):116-132.

Singh, C.B., Kahlon, S.S., Randhawa, G.S., and Panesar, B.S. 1975. Annual Report: Energy Requirements in Intensive Agricultural Production Programme. ICAR Coordinated Project. Punjab Agricultural University, Department of Farm Power and Machinery, Ludhiana, India.

Stevens, R.D. 1977. The Green Revolution in Developing Nations and Energy Constraints. Staff Paper 77-60. Michigan State University, East Lansing, Michigan, USA. Increasing costs of energy will slow somewhat the growth in agricultural production, but these increasing costs will not cause a decrease in the amount of food available per capita in developing nations. Discusses two alternative concepts of the "green revolution" which will lead to better understanding of current agricultural growth in developing nations. Explores to what extent high-cost energy will affect agricultural production in developing nations by focusing on agricultural mechanization and the use of chemical fertilizers.

Terhune, E. 1977. Energy use in crop production: vegetables. In: Energy Use Management, edited by R.A. Fazzolare and C.B. Smith. Pergamon Press, Inc., Elmsford, New York, USA.

Thiesenhausen, W.C. 1974. Peasant Prospects: Growth and Development in the Rural Sector. Paper prepared for the Fifth Annual Meeting, Latin American Studies Association, San Francisco, California, November 14-16, 1974. The Land Tenure Center, University of Wisconsin, Madison, Wisconsin, USA. Agrarian policy strategy makers in Latin America need to consider the equity-production-energy-protein crisis that Latin America faces. A special effort should be made to channel fertilizer and the petroleum products, increasingly scarce in 1974, to the reform and small-scale farm sector dedicated to growing and selling foodgrain. More thought should be given to converting large farms producing livestock on land-extensive farming systems to vegetable-protein crops which are within the purchasing capacity of the poor.

Vermeer, D.E. 1976. Food, farming, and the future: the role of traditional agriculture in the developing areas of the world. Social Science Quarterly 57(2):383-396. Insufficient attention is being paid to the traditional agricultural sectors of developing countries and their potential contribution to world food supplies. The applicability of Western technology to developing areas is questionable: energy-intensive agricultural systems are uneconomical; widespread agricultural mechanization suffers from a lack of qualified personnel; total land clearing can ruin an ecologically delicate environment and it threatens the social structure, often causing selective migration of the most able-bodied to the cities; and land reform may damage land by bringing it into permanent use. The accumulated wisdom in traditional systems must be understood and used to its full advantage so that developing countries may more fully satisfy their internal needs for foodstuffs.

Warnken, P.F. 1976. Impact of rising energy costs on traditional and energy intensive crop production: the case of Nicaragua. Canadian Journal of Agricultural Economics 24(2):15-22. Fossil-based agricultural input price increases have shifted the competitive advantage from energy intensive agriculture to traditional agriculture in Nicaragua. A decline in output prices would make energy-intensive agriculture uneconomical and reduce aggregate output of four major food crops, posing serious policy dilemmas for national development.

Wittmus, H., Olson, L. and Lane, D. 1975. Energy requirements for conventional versus minimum tillage. Journal of Soil and Water Conservation 30:72-75.

FARM EQUIPMENT, MECHANIZATION, AND DRAFT POWER

Anonymous. 1978. Agricultural Technology for Developing Nations: Farm Mechanization Alternatives for 1-10 Hectare Farms. Proceedings of a Special International Conference, May 23-24, 1978. University of Illinois at Urbana-Champaign. Sponsored by the American Society of Agricultural Engineers, the Interfaith Center on Corporate Responsibility, and the University of Illinois at Urbana-Champaign. Funded by a grant from Deere and Company. Purpose of conference was to provide information about farm mechanization as one element for relieving the food shortage in developing countries. Attention was given to the socioeconomic issues involved with agricultural technology transfer, and to the engineering and marketing problems associated with small-farm technology.

Bodenstedt, A.A. 1977. Agrotechnical progress and rural development. Sociologia Ruralis 17(1/2):29-42. Agrotechnical progress tends to be valued in terms of the economic rationality of industrialized countries, implying a certain way of using natural resources. During the past two centuries agricultural mechanization has been implemented through industrialization, and therefore the two terms "mechanization" and "industrialization" have become confused. To understand the problem of adoption of agrotechnical progress in developing countries, their attitudes to natural resources and agricultural production need to be considered as part of their social structure.

Boyd, J. 1973. Tools for Agriculture, a Buyer's Guide to Low Cost Agricultural Implements. Intermediate Technology Publications, London, United Kingdom.

Datta, R. and G.S. Dutt. 1981. Producer gas engines in villages of less-developed countries. Science 213:731.

Frost, J. 1980. Small scale manufacturing of agricultural equipment in developing countries. Agricultural Engineer 35(4):89-92. The equipment proposed for manufacture must be designed for and tested in the correct environmental conditions. Its weight is an important consideration as it may need to be transported long distances in the country of manufacture. Its price may be justified by increased yield rather than labor savings. Other factors in the operation include the long-term availability of raw materials, energy, and labor skills and the correct choice of manufacturing tools and equipment.

Gemmill, G. and Eicher, C.K. 1973. The Economics of Farm Mechanization and Processing in Developing Countries. Research and Training Network No. 4. Agricultural Development Council, Inc., New York, New York, USA.

Giles, G.W. 1975. The reorientation of agricultural mechanization for the developing countries: policies and attitudes for action programme. In: FAO. The Effects of Farm Mechanization on Production and Employment. Report of the Expert Panel. Food and Agriculture Organization of the United Nations, Rome, Italy.

Gulvin, H.E. 1953. Farm Engines and Tractors. McGraw-Hill, New York, New York, USA.

Harrington, R.E. 1980. Lessons on farm mechanization for developing nations. In: Glimpses of Agricultural Mechanization in the People's Republic of China. Report of the delegation of 15 ASAE members on their technical inspection in China, August 18 - September 8, 1979. American Society of Agricultural Engineers, St. Joseph, Michigan, USA.

Inns, F.M. 1980. Agricultural machinery manufacture in developing countries: the potential contribution to agricultural and industrial development. Agricultural Engineer 35(4):100-103. The place of mechanization in the development process is discussed and it is concluded that modest productivity increases from large numbers of small farms are preferable to high production from a favored few. Effective marketing and machinery based on local needs are required. Crop production systems based on animal draught and small tractors encourage the development of scarce machinery management skills, a major objective being timely completion of land preparation, sowing, weeding, and harvesting. Machinery recommended for local manufacture includes equipment for irrigation crop processing and storage, and energy converters such as wind and water mills and biogas generators.

Kashkari, C. 1979. Effective utilization of animal energy in developing countries. In: Changing Energy Use Futures, edited by R. A. Fazzolare and C.B. Smith. Proceedings of the Second International Conference on Energy Use Management, October 22-26, 1979, Los Angeles, California. Pergamon Press, Inc., Elmsford, New York, USA. Work animals constitute a vital energy resource in the developing world. Animals are used for plowing, water-lifting, oil extraction, sugarcane crushing, and many other agricultural chores. Millions of bullock carts used to haul loads compose a gigantic transportation system in developing countries. The work animal is an integral part of the village energy scene. The prosperity of the village is closely linked to the health of the animals.

Krendel, E.S. 1979. Man and animal-generated power. In: Standard Handbook for Mechanical Engineers, 7th rev. ed. McGraw-Hill, New York, New York, USA.

McKeon, C.E. 1980. Agricultural machinery manufacturing plants in People's Republic of China. In: Glimpses of Agricultural Mechanization in the People's Republic of China. Report of the delegation of 15 ASAE members on their technical inspection in China, August 18 - September 8, 1979. American Society of Agricultural Engineers, St. Joseph, Michigan, USA.

Makanjuola, G.A. 1978. Agricultural Mechanization in Nigeria: the Prospects and Promises. University of Ife Press, Ile-Ife, Nigeria. Attention is focused on six aspects of agricultural mechanization in Nigeria: (1) the importance and role of agricultural mechanization as a vehicle for agricultural production; (2) the problems faced by agricultural engineering as a profession; (3) the present state of mechanization in Nigerian agriculture, highlighting the main problems and difficulties; (4) the appropriate type and level of mechanization; (5) the contribution of the University of Ife to agricultural mechanization in Nigeria; and (6) the challenges of ensuring that future mechanization programs are successful.

Malaysia, Universiti Pertanian Malaysia. 1979. Agricultural Engineering in National Development: a Bibliography. Universiti Pertanian Malaysia, Serdang, Selanor, Malaysia. This bibliography covers mechanization of crop cultivation, livestock farming, crop and food processing, pest control and fertilization; the social, economic, and educational aspects of agricultural engineering; energy sources; farm buildings and waste management; soil and water conservation and pollution control.

Mann, H.S., Singh, R.P., and Pande, P.C. 1980. Utilizing solar energy for agriculture and development in India: problems and prospects. Agricultural Mechanization in Asia 11(4):15-19.

Moens, A. 1977. Mechanization of tropical agriculture. Zeitschrift fur Auslandische Landwirtschaft 16(4):360-371. Development of the mechanization of tropical agriculture is an essential element of world development. As increased food production is of worldwide importance, agriculture must have high priority in sharing limited world energy resources. Only through increased energy supplies can farmers in the tropics truly contribute to increased food production and economic and social improvements. Agriculture is characterized by small holdings, low farm income, and low labor costs. Mechanization will, therefore, only be successful through the development of appropriate machine designs that meet the needs of small farmers and that can be manufactured economically.

Nweke, F.I. 1978. Farm mechanization and farm labor in Ghana. An analysis of efficiency and impact on domestic food production. Zeitschrift fur Auslandische Landwirtschaft 18(2):171-187. In 1960-1975, about 80 percent of the energy used on farms in Ghana was human although large resources of imported tractors and bullock power were underutilized partly because of government control policies and partly because of the short season and the nature of the land. If mechanization becomes more efficient and effective demand for farm products increases, mechanization will become more important as there are still considerable areas of uncultivated land, farm labor supply is falling, and demand for food is increasing as population rises, especially in the towns. Mechanization could be made more efficient by the complete transfer of tractor ownership to the private sector, by additional irrigation to lengthen the agricultural season, by a reduction in the number of brands and types of tractor imported to ease maintenance, and by development of tractors adapted to Ghana's special conditions.

Ortiz-Canavate, J., Hills, D.J., and Chancellor, W.J. 1981. Diesel engine modification to operate on biogas. Transactions of the American Society of Agricultural Engineers 24(4):808-813.

Rockefeller Foundation. 1975. The Role of Animals in the World Food Situation: A Conference Held at the Rockefeller Foundation. Rockefeller Foundation, New York, New York, USA. How animals and the feeding of animals relate to the food/population balance. Includes comparative efficiency of animals in converting feedstuffs into human food.

Sharma, A.C. 1977. Farm management machinery decisions. East Africa Journal of Rural Development 10(1/2):158-182. This study is aimed at (1) choosing among the alternative power units and their machinery systems for mechanizing stationary operations on crop farms; and (2) examining possible adjustment opportunities on the farms operated with such a power unit and an associated machinery system.

Skromme, L.H. 1980. Grain production, harvesting and handling mechanization in People's Republic of China. In: Glimpses of Agricultural Mechanization in the People's Republic of China. Report of the delegation of 15 ASAE members on their technical inspection in China, August 18 - September 8, 1979. American Society of Agricultural Engineers, St. Joseph, Michigan, USA.

Stout, B.A. and Downing, C.M. 1977. Increasing the productivity of human, animal, and engine power. In: Food Enough or Starvation for Millions? International Association of Agricultural Economists, Oak Brook, Illinois, USA.

Stout, B.A. and Downing, C.M. 1976. Agricultural mechanization policy. International Labour Review 113(2):171-187.

Thompson, H.G. 1980. Tillage machinery and cultural practices. In: Glimpses of Agricultural Mechanization in the People's Republic of China. Report of the delegation of 15 ASAE members on their technical inspection in China, August 18 - September 8, 1979. American Society of Agricultural Engineers, St. Joseph, Michigan, USA.

VanDemark, N.L. 1976. Increased productivity from animal agriculture. In: Potential Increases in Food Supply Through Research in Agriculture. A report to the Science and Technology Policy Office, National Science Foundation, prepared by a panel formed in fulfillment of NSF Grant No. STP 75-13987. The Agricultural Experiment Stations, New York State College of Agriculture and Life Sciences, Cornell University, Ithaca, New York, USA.

Van Gilst, W.J. 1974. Farm Equipment and Fossil Fuel Consumption in Agriculture. Food and Agriculture Organization of the United Nations, Rome, Italy.

Ward, G.M., Sutherland, T.M., and Sutherland, J.M. 1980. Animals as an energy source in Third World agriculture. Science 208(4444):570-574. An approach to development based on animal agriculture systems is suggested that might initiate a self-sustaining, more productive agriculture requiring only small inputs of fossil fuel energy.

Wijewardene, R. 1978. Systems and energy in tropical farming. Proceedings of the American Society of Agricultural Engineers, Palmer House Hotel, Chicago, Illinois, December 18-20, 1978. American

Society of Agricultural Engineers, St. Joseph, Michigan, USA. This report endeavors to analyze the constraints--both environmental and physical--to the productivity of the small farmer in the humid tropics. Discussed is the development and adaptation of tools to translate the most recent appropriate techniques applicable to the small farmer.

FERTILIZERS

Allen, G.R. 1980. The Impact of Petroleum Price Increases on Fertilizer Marketing Costs in Developing Countries. FAO/FIAC Ad Hoc Group on Fertilizer Marketing, Rome, Italy.

Ames, G.C.W. 1974. Some Causes and Consequences of the Petroleum Crisis on Agricultural Development. Faculty Series, Division of Agricultural Economics, College of Agriculture, University of Georgia, Athens, Georgia, USA. The effect of the oil crisis on farm development in India, Latin America, and elsewhere is discussed, especially in relation to the small-scale farm. The higher cost of inputs should be offset by more subsidies, package programmes, and cheaper credit. The development of local fertilizer plants must be given priority.

Blouin, G.M. 1974. Effects of Increased Energy Costs on Fertilizer Production Costs and Technology. Bulletin Y-84. National Fertilizer Development Center, Tennessee Valley Authority, Muscle Shoals, Alabama, USA.

Brown, R.B. 1980. Fertilizers: Applications, Economics, and Production. 1964-July, 1979. (Citations from the NTIS Data Base.) National Technical Information Service, Springfield, Virginia, USA. This bibliography is divided into three parts. Part 1, General Studies, includes application rates, yield, production, irrigation problems, synthesis, utilization in aquaculture, and trace element studies. Part 2, Tree Fertilization, covers fertilizer effects and application. Part 3, Economics, includes impact of use, shortages, effects, and production management.

Craswell, E.T. and De Datta, S.K. 1980. Recent Developments in Research on Nitrogen Fertilizers for Rice. IRRI Research Paper Series No. 49. International Rice Research Institute, Los Banos, Philippines.

Craswell, E.T. and Vlek, P.L.G. 1979. Fate of fertilizer nitrogen applied to wetland rice. In: Nitrogen and Rice. International Rice Research Institute, Los Banos, Philippines.

Dosik, R.S. and Falcon, W.P. 1979. Energy and agriculture in developing countries. In: Land Management Issues and Development Strategies in Developing Countries, edited by S. Lin and S. Ramakrishnan. Lincoln Institute Monograph. Lincoln Institute of Land Policy, Washington, D.C., USA. Part 1 reviews the available information on rural energy use in developing countries. Part 2 takes a more detailed look at the energy implications of the rapid rise in the use of chemical fertilizer which is the most important productivity-increasing input for developing countries. Part 3 examines the problems and prospects of the methane generator as a nonconventional rural energy source.

Economic and Social Commission for Asia and the Pacific. 1980. News in Brief: Comparative Fertilizer Situation Indicators for Selected Countries in the ESCAP Region. Economic and Social Commission for Asia and the Pacific, Bangkok, Thailand.

Federal Energy Administration. 1975. Economic Impact of Shortages on the Fertilizer Industry. A report prepared by Arthur D. Little, Inc., Cambridge, Massachusetts, USA.

Herdt, R.W. and Barker, R. 1975. Possible Effects of Fertilizer Shortages on Rice Production in Asian Countries. Asian Productivity Organization, Tokyo, Japan.

Hignett, T.P. 1980. Fertilizer Studies for Developing Countries. Paper prepared for the 30th Fertilizer Industry Round Table, Atlanta, Georgia, USA.

Hoeft, R.G. and Siemens, J.C. n.d. Do fertilizers waste energy? Crops and Soils 11:12-14.

Hopper, W.D. 1962. The economics of fertilizer use--a case study in production economics. Indian Journal of Agricultural Economics 17:12-22.

Hughes, H. and Pearson, S. 1974. Principal Issues Facing the World Fertilizer Economy. Report of a Seminar on Fertilizers. Agricultural Development Council and the World Bank, Princeton, New Jersey, USA.

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Harper, J.M. and Jansen, G.R. 1977. Low cost extruders for supplemental foods. League for International Food Education Newsletter June:1-4. The operational mechanics, uses, and costs of extrusion cookers are explained. Such cookers can process a wide variety of mixtures of cereals and oilseeds or cereals and legumes as well as wheat, rice, and sorghum in combination with soybean, cottonseed, peanuts, and dry beans. The ground extruded product provides a nutritious supplemental food which is of significant benefit in less developed countries. Two manufacturers of low-cost extrusion cookers and countries where they are in use are listed.

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U.S. General Accounting Office. 1976. Hungry Nations Need to Reduce Food Losses Caused by Storage, Spillage, and Spoilage; Report to the Congress. U.S. Government Printing Office, Washington, D.C., USA. To abate hunger and malnutrition, developing countries not only must increase food supplies by increasing production, reducing food demand, and slowing population growth, but also must reduce the loss of food after harvest resulting from spillage, storage, and spoilage.

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APPENDIX B

List of Workshop Participants

NATIONAL RESEARCH COUNCIL

Emery N. Castle, President, Resources for the Future, Washington, D.C., *Chairman*

A. Richard Baldwin, Vice President and Executive Director, Cargill, Inc., Minneapolis, Minnesota

Robert Bates, Professor of Food Technology, University of Florida, Gainesville

Bernard Chatelin, Transportation, Water and Telecommunications Department, World Bank, Washington, D.C.

Elizabeth Colson, Professor of Anthropology, University of California at Berkeley

Christopher Delgado, Research Fellow, International Food Policy Research Institute, Washington, D.C.

John J. Drea, Jr., National Research Program Leader, Biological Control of Pests and Insect Taxonomy, Beltsville Agriculture Research Center, Beltsville, Maryland

Joy Dunkerley, Senior Research Associate, Resources for the Future, Washington, D.C.

Travis Hignett, International Fertilizer Development Center, Muscle Shoals, Alabama

Gideon D. Hill, Manager, New Product Development, E.I. duPont de Nemours, Wilmington, Delaware

J. Bruce Liljedahl, Agriculture Engineering Department, Purdue University, Lafayette, Indiana

Carl Lindblad, Development Consultant, Washington, D.C.

Marianne Millar, Argonne National Laboratory, Argonne, Illinois

Mohinder Mudahar, International Fertilizer Development Center, Muscle Shoals, Alabama

Hugh Popenoe, Director, International Programs in Agriculture, University of Florida, Gainesville

Lyle Reeser, Agricultural Consultant, Caterpillar Tractor Company, Peoria, Illinois

Ronald Ridker, World Bank, Washington, D.C.

Harold Riley, Department of Agricultural Engineering, Michigan State University, East Lansing

Ernest Smerdon, Vice Chancellor for Academic Affairs, University of Texas System, Austin, Texas

Bill Stout, Professor, Agriculture Engineering Department, Texas A & M University, College Station

PARTICIPANTS, U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

Pamela Baldwin, Program Analyst, Office of Energy, Bureau for Science and Technology

John Blumgart, Chief of the Special Development Problems Division, Office of Development Resources, Bureau for Africa

Douglas Caton, Supervisory Agricultural Economist, Rural Development Division, Bureau for Management and Budget

Carl Duisberg, Energy Officer, Office for Development Resources, Bureau for Latin America and the Caribbean

Worth Fitzgerald, Energy Officer, Office of Technical Support, Bureau for Near East

Tejpal Gill, Tropical Soils Specialist, Office of Agriculture, Bureau for Science and Technology

Lawrence Heilman, Deputy Director for Technical Operations, Office of Development Resources, Bureau for Africa

Ray Hooker, Agricultural Economist, Office of Technical Resources, Bureau for Asia

Robert Ichord, Agricultural and World Development Energy Advisor, Office of Technical Resources, Bureau for Asia

William Judy, Agricultural Research Officer, Office of Development Resources, Bureau for Africa

Stephen Klein, Energy Policy Advisor, Bureau for Program and Policy Coordination

Patricia Koshel, Economist, Office of Energy, Bureau for Science and Technology

Felipe Manteiga, Assistant Agricultural Development Officer, Office of Development Resources, Bureau for Latin America and the Caribbean

Robert Morris, Food Loss Specialist, Office of Agriculture, Bureau for Science and Technology

George Self, Program Economist/Energy Advisor, Office of Technical Support, Bureau for Near East

Emmy Simmons, Agricultural Economist, Rural Development Division, Office of Policy Development and Program Review, Bureau for Management and Budget, AID Project Coordinator

James Walker, Associate Director of Research, Office of Agriculture, Bureau for Science and Technology

OTHER PARTICIPANTS

Compton Chase-Lansdale, Ferguson Bryan and Associates
Beverly Carlsen, Bureau of the Census, Washington, D.C.
James Gibbs, Bureau of the Census, Washington, D.C.

NRC/BOSTID STAFF

Rose A. Bannigan, Assistant to the Director, Workshop Coordinator
Michael G.C. McDonald Dow, Deputy Director
H. Dale Langford, Editor
Augustus Nasmith, Professional Associate
Carol R. Richmond, Administrative Secretary
Wendy D. White, Librarian
Dennis Wood, Professional Associate