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ENERGY AND AGRICULTURE: AN OVERVIEW

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SUMMARY AND CONCLUSIONS

i. This overview is premised on the World Bank's expectation that over the next decade the world price of energy, as indicated by petroleum prices, is likely to rise more rapidly than the prices of most agricultural products. This paper examines possible implications of these changing relative prices for agriculture and rural development, with a view to identifying issues which bear upon the Bank's lending program. The paper notes that agriculture globally accounts for less than 5 percent of commercial energy use, but that consumption of this type of energy can be expected to increase rapidly as agricultural modernization proceeds. It is pointed out that within agriculture worldwide, commercial energy is much less important as a source of power than human labor and draft animals. And while the world "energy problem" is commonly viewed as pertaining largely to commercial and, in particular, petroleum-based energy, the problem of shrinking supplies of fuelwood is no less pressing in many countries. Increasingly, adequate supplies of energy, both commercial and noncommercial, are as important to economic growth and development as land, labor and capital.

ii. Over the past 15 years the consumption of commercial energy in world agriculture appears to have grown by approximately twice the rate of growth of agriculture. With rising relative prices for energy, and uncertainties concerning reliability of supplies, a major question is the extent to which future agricultural growth can be made less dependent on commercial energy. Prospects for significant "de-linking" in the short-term (1-5 years) appear to quite limited. Much of the growth of developing country

agriculture in recent years had its origin in the relatively (commercial) energy-intensive production technology embodied in the Green Revolution, viz., high-yielding crop varieties, substantial quantities of chemical fertilizers and pesticides and controlled water supplies. Present indications are that this technology will continue to be the major source of growth in most countries. This indication, coupled with the continued requirements for increased food and agricultural raw materials, suggest that governments should accord priority to agriculture in the allocation of limited commercial energy supplies, while simultaneously pursuing the search for less energy-intensive agricultural production and processing systems.

iii. Over the medium-term and beyond a number of possibilities exist to reduce the commercial energy dependence of agriculture. The paper notes that the major users of commercial energy in agriculture are in the production of chemical fertilizers and pesticides, the manufacture and use of farm machinery and equipment and, increasingly in many developing countries, the construction and operation of irrigation systems. Possibilities for energy conservation or substitution exist in each of these areas, but realization of these possibilities would require more vigorous research and development work. Of prime importance are government pricing policies for energy which reflect its economic value and encourage conservation and the development of efficient alternatives. Without attempting to be exhaustive, some of these opportunities are indicated below.

iv. Over the medium term the most promising possibilities for commercial energy substitution may lie in the area of fertilizer, particularly nitrogen. Chemical nitrogen accounts for as much as 85 percent of commercial energy use in fertilizer production and more than 35 percent of total commercial energy use in agriculture. The link between food production and energy availability in this area is critical and the extent to which future food needs are met will depend in large part on the availability to farmers of adequate supplies of reasonably priced nitrogen fertilizer. Better utilization of chemical nitrogen through improved timing of application and placement, as well as the development of improved types of chemical nitrogen, offer conservation possibilities. Equally important are measures to increase nitrogen supplies fixed biologically by suitable bacteria and algae in association with appropriate plant hosts. The Azolla-Anabena technology in particular, appears to have promise as a partial substitute for chemical nitrogen in some tropical rice-growing regions, although this approach is sensitive to temperature, requires additional labor and may be vulnerable to disease. Research and development work in this area of nitrogen fertilizer complementation warrants attention. Similarly, biological control of insect pests and weeds is increasingly used in commercial practice and, with proper development, could be extended.

v. The rapid increase in the use of tractors and powered farm machinery in developing country agriculture reflects a combination of social and economic factors. Shortages of human labor or draft animals at peak periods of power demand are explanatory factors in some situations, as is the desire by larger land owners to replace work crews with easier-to-manage tractor services. Subsidized fuel or loan capital for tractors and machinery purchase has frequently encouraged mechanization beyond levels indicated by purely economic considerations. Increase draft power will be required as the intensity of agricultural production increases and cultivation is extended to more marginal lands. Selective mechanization, encouraged by proper pricing policies, will be appropriate in many cases. But, in addition, there is need to encourage wider and more efficient use of draft animals as a source of motive power. The required area of research and development, badly underfunded at present, includes efforts to increase the productivity of draft animals by better feeding, management and genetic upgrading and by developing improved animal-powered equipment for transport and field operations. Efforts to improve the quantify and quality of livestock feed are of key importance. Where local supplies of liquid fuels are not readily available, the development strategy for agriculture should allow a significant role for animal power.

vi. Irrigation is likely to become an increasingly important claimant on commercial energy supplies, as development extends to marginal lands with inadequate or undependable water supplies. The design of the irrigation system is a major determinant of energy consumed in construction or operation. Energy expended in pumping dominates energy use in irrigation and measures to reduce the required volume of pumped water warrant prioity. In many situations, economic and energetic considerations suggest that investment should be directed primarily toward improving the efficiency of water use in existing systems by reducing losses in water conveyance and distribution. Canal lining and precision land leveling appear to be increasingly attractive investments. Where options exist in the design of new systems, surface distribution systems are frequently preferable because of lower energy costs in construction and operation.

vii. The fisheries industry, in particular, has been adversely affected by the sharp increase in costs of petroleum because this input typically accounts for a higher proportion of operating expenditures than do fuel costs in other rural-based industries. The economics of larger fishing vessels operating in distant waters appear to have become less attractive relative to smaller vessels operating closer to port. Rising fuel costs will encourage continued adjustent to low-energy methods of fishing and fish processing. For small craft there is likely to be a continued move away from gasolene toward diesel engines and increased use of sail power. Among larger vessels, fuel savings appear possible through improved hull design, more efficient propulsion systems, and proper speed selection in operation.

viii. Higher energy costs will also encourage significant adjustment in agricultural processing and distribution and, over a longer time period, in the location of agricultural production. Transportation costs are rising faster than product prices in many cases and bulky low-value products are increasingly unable to bear the costs of long distance transport. Local production of commodities formerly imported from considerable distance will become increasingly attractive, as will processing activities which serve to reduce bulk and weight. Many processing and cold storage operations, which are typically energy intensive, will become less attractive in developing countries and will tend to be replaced by simpler methods which are less demanding of commercial energy, e.g., sun-drying and salting. Internationally, higher ocean freight costs will tend to increase CIF prices of agricultural products and encourage domestic production and a higher degree of national self-sufficiency.

ix. Increased relative prices for energy will provide new opportunities for agriculture as a source of commercial energy. Biomass energy production on a global basis is perhaps 10 times the energy consumed each year in the form of gas and oil and the caloric energy contained in the world's grain crop is moe than twice the amount of commercial energy going into its production. But less than one percent of the sun's energy is actually converted to biomass energy by plants. Even a small increase in this efficiency of photosynthesis, as seems possible over the medium- and longer-term with careful plant breeding and genetic engineering, would greatly increase the biomass energy produced from plants. This appears to merit continuad basic research work, but directly applicable results in the next few years are not likely.

x. Apart from food grains, the most important biomass energy products are the fuelwood, charcoal and crop residues used in domestic space heating and cooking and, increasingly, as alternative fuel sources for agroindustrial processes. The world's fuelwood situation is deteriorating and tbe growing reliance on crop residues and dung as fuel in many countries is posing increased threats to the longer-term ability of their soile to sustain agricultural production. The fuelwood crisis warrants a high priority by the development community and every country should be encouraged to have a long-term national fuelwood or rural energy program.

xi. Rising prices for petroleum products vis-a-vis agricultural products provide increasingly attractive opportunities to produce fossil fuel replacements in the form of vegetable oils or biomass-based alcohol. But with these increased opportunities go potential problems, as market forces become increasingly able to bid agricultural resources (including land, fertiliser, water, and managerial skills) away from food and export crop production and into energy cropping. Where these technical possibilities exist, careful analysis is required to ensure that the land use ultimately chosen is that which maximizes its net present social value, taking into account financial and economic considerations as well as more difficult-to-measure variables pertaining to the pattern of land holdings, income distribution, employment, food availability and environmental effects. By nature of their rural orientation, biomass energy projects have the potential to affect, for better or worse, the welfare of large numbers of low income groups. Because the employment effects of such programs are frequently uncertain, and because higher food prices impact disproportionately on the poor, biomas energy programs may well affect these groups adversely. In land abundant countries, these programs may be sound in economic, social and environmental terms. In general, they should be pursued with extreme caution.

xii. Biogas has been portrayed as a decentralized source of rural energy which utilizes low-value feedstocks such as crop residues and animal wastes. In a few countries biogas technology has indeed become a valuable supplementary energy source. Nevertheless, experience to date suggests that these feedstocks are rarely free in economic terms and generally have important alternative use as soil conditioners or fuel for the poor who may not be situated to utilize biogas technology or the production therefrom. With continued research and development, the usefulness of this technology can be extended. Because the technology, economics and social dimensions of biogas continue to involve considerable uncertainties, it is adviseable that, before major investments or national programs are undertaken, a much more systematic approach be made to research and evaluation. In particular, it would seem useful to examine carefully the Chinese experience, of which relataively little is known outside of China and development of which, according to some reports, appears to be slowing .

xiii. The emerging energy situation has implication for more general development strategies. Technical possibilities suggest that biomass energy could play a substantially larger role in the future than it does today. But realization of those possibilities would depend heavily on the effectiveness of the research and development effort, both nationally and internationally, across a wide array of activities pertaining to energy production, conversion, conservation and economic and social issues. In terms of research on biomass energy production, the longer-term work on increased photosynthetic efficiency hes been mentioned. Applied research is needed to undergird national fuelwood programs and, in particular, to identify fast-growing species suitable to particular climates, soil, topography and social environments. Energy conversion research is needed in applied areas such as charcoal production, pyrolosis of organic wastes, fermentation technology and anerobic digestion, solar drying of agricultural products, and draft animal breeding, management and equipment development. A particularly valuable research breakthrough in energy conversion work would be the identification of organisms and engineering processes that can convert cellulose and lignins of agricultural residues and othar low value materials to alcohol, thereby reducing the potential land use conflict which emerges in grain- or sugar-based alcohol programs.

xiv. In energy conservation research, important gains could be realized from developing more energy efficient cook stoves and heating devices, identifying other nitrogen-fixing organisms suitable for a wider range of cropping systems, climates, etc., and developing improved engines and pumps to reduce costs in lifting water. Further development and extension of minimum tillage technology warrants continued piority. For some of these research activities, a mechnism for international financial support may be warranted. For most of them, an improved mechanism is necessary to exchange national research results and developoment experience.

xv. In addition to technical research, there is need for improved socio-economic research on energy-related issues. The techniques of energy accounting or energy audits are poorly developed but are proving useful where they have been carried out. The concept of energy intensity of particular production processes should be developed and incorporated in planning and project development. A data base could usefully be established which would permit investment decisions to be taken with a greater awareness of their implications for future energy demand. More needs to be known of the energy, employment and economic trade-offs between small-scale, decentralized agroindustrial activities and larger-scale ventures. A plausible hypothesis is that small-scale enterprizes (wood-fired bakeries, low-technology sugar mills, coal-based nitrogen plants, etc.) are profligate energy consumers, even though they may have the advantages of using local energy sources and fostering decentralized development.

xvi. Finally, there is the risk that the burden of adjustment to higher energy prices may fall disproportionately on the rural sector. In the short term agricultural production costs are likely to rise more rapidly than product prices and possibilities of passing higher costs on to consumers are limited for most agricultural commodities. In situations where rationing of commercial energy supplies is required, the politically-weaker agricultural sector may fare less well than other groups. In terms of domestic energy production, there is the danger that national energy policy will view agriculture and the rural sector as a ready source of renewable energy to provide substitute fuels for the more affluent urban minority. The resulting pattern of development, characterized by a shift of control over rural resources to nonfarm groups and permitted through default by politically-weak farm groups and ministries of agriculture, may well work to the detriment of the rural sector. Adjustments to a changed energy environment should be equitable and equitable access to energy resources is becoming as important as access to food, jobs and public services.

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"While other nations subsist upon the annual and ceaseless income of the harvest, we are drawing more and more upon a capital which yields no annual interest but, once turned to heat and light and motive power, is gone forever."

W.S. Jevons in The Coal Question, (London, 1865)

Chapter I. BACKGROUND AND PERSPECTIVE

1.01 The basic objective of this paper is to identify issues emerging from the world energy situation which relate to the Bank's lending strategy and the design of projects in agriculture and rural development. The paper is one of a series of recent Bank studies which discuss energy issues in the context of Bank operations. 1/ One of the features of this exercise is

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1/ Studies include: (i) David Hughart, Prospects for Traditional and Nonconventional Energy Sources in Developing Countries; Bank Staff Working Paper No. 346 (Washington, 1979); (ii) D.G. Fallen-Bailey and T.A. Byer, Energy Options and Policy Issues in Developing Countries; Bank Staff Working Paper No. 390 (Washington, 1979); (iii) Christian Orrego, Evaluation of Microbial Technologies Involved in Fuel Production, Agriculture and Forestry; Background paper prepared for the Office of the Bank's Scientific Advisor, (draft) January 1979; and (iv) World Bank, Renewable Energy Resources in the Developing Countries (November 1980). An earlier paper which examined the root crops as an energy source was T.J. Goering, Tropical Root Crops and Rural Development; Bank Staff Working Paper No. 324 (Washington, 1979). A study of biomass alcohol was contained in the Bank's Alcohol Production from Biomass in the Developing Countries, (September 1980). A key policy document which built upon some of the earlier work was the Bank's Energy in the Developing Countries, (August 1980). A recent background paper on natural rubber provides an example in which higher prices for fossil fuels open new opportunities in natural rubber production: World Bank, Natural Rubber Development: A Background Paper (draft) March 10, 1981).

its focus on agriculture as a user and a source of energy. The exploratory nature of the paper should be emphasized. Some of the issues discussed are expected to warrant further study with a view to drawing out more fully the policy implications for Bank operations. 1/

1.02 Energy and agricultural prices. Changing relative prices for energy and agricultural products are among the key factors which underlie the rationale for this paper. Between 1971-73 and 1977-80 real prices of petroleum in the world market rose by 270 percent while prices of agricultural products fell by 5 percent. 2/ Looking ahead, the Bank projects real prices of petroleum to increase by more than 80 percent between 1978-80 and 1990 while agricultural prices are expected to rise by about 5 percent. In addition to higher prices for petroleum products, prices for agricultural production inputs such as petroleum-based chemical fertilizers are expected to increase more rapidly than prices of most agricultual prices. Alternative price scenarios could be envisaged and point estimates of projected prices may be wide of actual developments. Nevertheless, the assumption

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1/ A policy brief for a paper on energy and agriculture was discussed by the Operational Vice Presidents on May 12, 1980. At that meeting it was decided that the next step should be the preparation of a more detailed paper to determine which issues warrant further study in the context of the Bank's policy work. This paper is in response to that decision.

2/ Economic Analysis and Projections Department, "Commodity Price Forecasts - Updating," Internal memorandum of November 12, 1980; also Economic Analysis and Projections Department, Price Prospects for Primary Commodities, Report No. 814/80 (January 1980).

Table 1: PRICE MOVEMENTS FOR SELECTED COMMODITIES
(1977 constant dollars)

	Petroleum 1/ ($/bbl)	Urea 2/	TSP 3/	Rice 4/	Wheat 5/	Cotton 6/	Natural Rubber 7/	Petroleum	Total Agriculture
		$/metric ton						Weighted Index 8/ ..... 1974-76 = 100 ...	
1971-73	4.4	150	158	375	171	1803	946	31	92
1978-80 9/	14.9	130	102	282	122	1327	1013	115	87
1990 (proj.)	27.4	186	152	380	163	1700	1150	212	91

1/ Average OPEC petroleum price; OPEC government sales weighted by OPEC output. Figure indicated for 1971-73 is for 1972-73 only.

2/ FOB Europe, bagged. Figure indicated for 1971-73 is for 1973 only.

3/ Tripe superphosphate, FOB US Gulf ports. Figure indicated for 1971-73 is for 1973 only.

4/ Thai 5% broken, FOB Bangkok.

5/ Canadian No. 1 Western Red Spring, in store Thunder Bay.

6/ Mexican SM, 1 1/16 inch, CIF Northern Europe.

7/ RSS No. 1, spot New York.

8/ Weighted by 1974-76 developing countries' export values.

9/ Figures for 1980 are EPD estimates.

Source: EPD, "Commodity Price Forecasts-Updating," Internal Memorandum of November 12, 1980; also EPD, Price Prospects for Primary Commodities, Report No. 814/80 (January 1980).

that over the next few years real prices of petroleum and derived products will increase more rapidly than prices of most agricultural products seems plausible on the basis of underlying trends and current knowledge of the structure of petroleum and agricultural markets.

1.03 Dimensions of adjustment. The global mix of agricultural products and the location of production have evolved over a period of relatively cheap prices for energy. Recent sharp increases in energy costs and prospects for continued relative increases in energy prices will affect various aspects of agricultural growth and development. The extent of the impact, and effects on individual crops or production and processing systems, will depend in large part on the importance of particular types energy in the production, processing and distribution of those crops. These relationships are complex and higher energy prices will not always operate to the disadvantage of agriculture. To identify these impacts more clearly it is necessary to view agriculture as both a user and a potential source of energy. Rising real costs of energy thus provide both challenges and opportunities for this sector. The challenges relate in large part to agriculture as a user of energy, as producers face steadily increasing costs for key energy-related inputs. On the other hand, rising energy prices present new opportunities to agriculture as possibilities expand for economic production of biomass. Annex Figure 1 ilustrates these concepts within a particular production systems.

1.04 An understanding of possible impacts requires a clear distinction among the various types of energy consumed or produced in agriculture. The "energy crisis" of recent years has focused largely on the sharp increase in prices of fossil fuels. In this view the energy problem relates largely to commercial energy, defined generally as energy sold in the course of commerce or provided by a public utility. 1/ Globally, commercial energy accounts for about two-thirds of total energy consumption. But in most developing countries this proportion is considerably less than half. This paper considers both commercial and noncommerical energy use and production in agriculture.

1.05 The time frame of the analysis is an additional important dimension. Agriculture's adjustment to higher energy prices will be more complete the longer the time period involved and the more important energy is in the production, processing and distribution of the agricultural output in question. In the short run (up to 2 years), producers may be made worse off by increased energy costs because they frequently have limited

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1/ Commercial energy, a term almost synonymous with conventional energy, is defined to exclude wood or other traditional fuels, although these are widely traded. The balance of energy supplies, or noncommercial energy, is made up largely of renewable energy, the supply of which is partly or wholly regenerated in the course of the annual solar cycle. Renewables include the important category of biomass fuels which are combustible and/or fermentable material of vegetable origin, e.g., wood, charcoal, rice husks, dung cakes and fermentable sugars and starches, See World Bank, Energy in the Developing Countries, op. cit., p. iv.

The distinction between commercial and noncommercial or nontraded energy sources is not clear-cut in many situations. In areas of intensive land use or scarcity of new arable land, where competitions for energy supplies is high, there may be no "free" gathering of energy sources. As Manibog has pointed out, in these circumstances a hidden market is likely to be operating in which the permission to gather agricultural residues or fuelwood is granted in exchange for a service or a gift in kind which does not necessarily have to be paid at the moment of gathering. Cf. Fernando Manibog, "Patterns of Energy Utilization in a Philippine Village", draft paper (December 1979).

opportunity to pass energy price increases on to consumers. Since costs of commercial energy are not a high proportion of total variable costs in many types of agriculture, production in the short run is not likely to be curtailed significantly by increased energy prices after the production cycle has started. 1/ In the medium term (3-10 years), greater adjustments are possible with regard to such factors as the location of production, the production mix, the production and processing systems. Over the longer term, general equilibrium tends to be reestablished and higher energy costs are passed on to consumers to the degree necessary to retain enough resources in agriculture to produce the required food and raw materials. This paper focuses largely on adjustments possible in the short and medium term.

Chapter II. AGRICULTURE AS A USER OF ENERGY

2.01 Toward a profile of energy use. Precise data on global energy use in agriculture are not generally available. But existing studies clearly suggest that a large part of total energy use in agricultural production is of a "noncommercial" type and that agriculture accounts for a small part of global use of commercial energy. Specifically, among developing market economics about two-thirds of total motive power used in

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1/ Some examples could be cited. In the United States it is estimated that fuel costs alone (i.e., excluding important fossil energy-related inputs such as chemical fertilizers and pesticides) account for about 16, 11 and 9 percent of variable costs of production for wheat, corn and cotton, respectively. (Emory Castle, World Food and Population: Congressional Roundtable, Washington, undated p. 6). Production systems based on deep-well irrigation, such as in the Southwestern United States, are much more fossil-energy intensive. In these systems fuel only for pumping may account for 25 percent of variable production costs.

agricultural production is provided by human labor. 1/ Just over a quarter is provided by draft animals and less than 10 percent comes from tractors. Global figures would show a substantially higher proportion for tractors and less from human labor.

2.02 Estimates of commerial energy use in agriculture are probably more reliable. The FAO estimates that in 1972/73 consumption of commercial energy in world agriculture totalled 175 million tons of petroleum equivalent (tpe). 2/ This was just under 4 percent of global consumption of commercial energy in that period. Developing countries accounted for only 18 percent of commercial energy consumption in agriculture. Globally, fertilizes and farm machinery together accounted for 96 percent of commercial energy use, irrigation and pesticides each for another 2 percent. Among developing countries, chemical fertilizer alone accounted for more than two-thirds of commerial energy consumption while farm machinery production and use absorbed just over 20 percent. Among developed countries, farm

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1/ FAO, Energy in Agriculture and Rural Development; Excerpts from a paper presented to the Committee on Agriculture (Rome, undated). These estimates refer to 1974-76. As noted later, motive power is only part of energy use in agriculture.

2/ This includes indirect and direct energy consumption, i.e., energy consumed in the manufacture of, e.g., farm machinery, as well as that required for its use. Typically, energy utilized in the operation of farm machinery is about twice as much as that needed in its manufacture.

Table 2. COMMERCIAL ENERGY USE IN AGRICULTURE, 1972/73 1/

	Million tons of petroleum equipment	Fertilizers	Farm Machinery	Irrigation	Pesticides
		---------- percent ----------			
Developed countries	144.2	40	57	1	2
Developing market economies	21.2	64	28	7	1
Asian centrally-planned economies	9.5	76	10	8	6
Total developing countries	30.7	68	22	8	2
Total	174.9	45	51	2	2

1/ Crops and livestock production only.

Source: FAO, The State of Food and Agriculture, 1976. (Rome, 1977), p. 97.

machinery is the largest consumer of commercial energy (57 percent), while fertilizers absorb about 40 percent. 1/

2.03 As agriculture modernizes, the proportion of commercial energy in total energy use rises steadily. Typically, the first agricultural operation to be mechanized as development proceeds is water lifting, a reflection of the fact that traditional irrigation methods (the Persian wheel, rope and bucket, etc.) are constrained by the availability of human or animal power relative to water requirements. 2/ This is generally followed sequentially by the mechanization of land preparation, harvesting and drying. Because these operations typically utilize commercial energy, commercial energy use rises rapidly as these changes take place.

2.04 The effects of a rapidly modernizing agriculture on commercial energy use are perhaps best illustrated by recent developments in the Indian States of Punjab and Haryana over a period which include the Green

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1/ Perhaps the most reliable data on commercial energy use pertains to United States agriculture. It is estimated that in 1977-78 the US food system accounted for just over 23 percent of commercial energy use in the country. Agricultural production alone consumed only 4 percent of total commercial energy supplies, while preparation and packaging absorbed 17 percent and transportation and distribution took just over 2 percent. Within agricultural production, field operations and farm transport account for almost 40 percent of total energy consumed in production while fertilizers consumed nearly 34 percent. Irrigation accounts for about 11 percent of energy consumption in production. Cf. OECD, The Energy Problem and the Agro-Food Sector, General Report for the Meeting of Experts, Paris, May 19-22, 1980, pp. 18, 22.

2/ Analysis of the potential to use animal and human power for irrigation in Chad indicated that even with costly diesel fuel and low cost labor, mechanically-powered irrigation systems were economically advantageous. Additional study is required to determine the extent to which this result is generalizable over a wide range of circumstances. Cf. R. Revelle, "Energy in LDC Rural Development;" Keynote speech, AID/OST Symposium on Science, Technology and the Problems of Development, Atlanta, Georgia, May, 1975.

Table 3. ENERGY CONSUMPTION AND GROWTH OF AGRICULTURAL PRODUCTION IN THE INDIAN STATES OF PUNJAB AND HARYANA (1961-62 = 100)

Item	1961-62	1966-67	1972-73
Agricultural Production	100	126	186
Draft Animal Power	100	106	132
Power for Irrigation	100	311	2334
Energy in Chemical Fertilizer	100	545	1750
Total Energy Consumption	100	126	256
Elasticity of Total Energy Consumption with Respect Agricultural Production	1.0 (1961-66)	2.2 (1966-72)	

Source: Adapted from R.N. Senapati, op. cit.

Revolution. Between 1961-62 and 1966-67, i.e., the period just prior to the introduction of high-yielding cereal varieties, total energy consumption (viz, electricity, diesel fuel and the diesel equivalent of animal power) rose only as rapidly as agricultural production, i.e., 26 percent. Between 1966-67 and 1972-73, the period characterized by the rapid expansion of high-yielding varieties, total energy consumption rose more than twice as fast as agricultural production, largely as a result of the sharply increased use of chemical fertilizer and irrigation. 1/ This Punjab-Haryana experience is likely to be typical of many areas where increased production derives in large part from the introduction of fertilizer-responsive crop varieties produced under conditions of effective irrigation and drainage.

2.05 Other studies confirm the inherent fossil-energy intensity of present agricultural production strategies which tend to be based heavily on fertilizer-responsive crop varieties, controlled water use and significant inputs of agro-chemicals. The FAO's study of Agriculture: Toward 2000 examines the commercial energy requirements of achieving the target growth in agricultural output for the developing market economies of 3.7 percent p.a. (as compare with the 2.8 percent annual growth rate achieved in the 1970s). 2/ It is projected that this agricultural growth rate would

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1/ R.N. Senapati, "Energy Consumption and Agricultural Development in Punjab and Haryana," Indian Journal of Agricultural Economics, July, 1976.

2/ FAO, Agriculture: Toward 2000, C 79/24, (Rome, July 1979).

require an increase of about 8 percent p.a. in the consumption of commercial energy, i.e., each 1 percent growth of agricultural production is associated with an increase of more than 2 percent in the use of commercial energy. These coefficients are notably similar to those evidenced in Punjab and Haryana during the 1966-67 to 1972-73 period (Table 3). This projected growth of about 8 percent in commercial energy use in agriculture compares with 6 percent annual growth in total use of commercial energy in developing countries between 1976 and 1990. 1/ International comparisons clearly indicate the close correlation between commercial energy use in agriculture and cereal yields per unit of land and per agricultural worker (Annex Table). The evidence suggests that higher land and labor productivity in developing country agriculture would, with currently available technology, require substantially more commercial energy.

2.06 Energy in fertilizers and other agro-chemicals. Increased use of chemical fertilizer has been a major source of agricultural growth in recent years. As shown above, fertilizer also accounts for a large portion of commercial energy consumption in agriculture. Among the major fertilizer nutrients, chemical nitrogen is by a considerable margin the most energy-intensive fertilizer product. 2/ Much of this energy is fossil fuel

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1/ World Bank, World Development Report, 1979 (Washington, August 1979), p. 35.

2/ Estimates of energy use in fertilizer production in the United States are indicative of this point. In 1974, 85 percent of total energy for fertilizer production was consumed in production of nitrogen, 11 percent in phosphate production and 4 percent in the manufacture of potash and mixtures.

based. About two-thirds of chemical nitrogen fertilizer is made from ammonia derived from natural gas or naphta; nearly 20 percent comes from ammonia derived from fuel oil and most of the balance from coal. More than 1.5 tpe is required per ton of chemical nitrogen produced; nitrogenous fertilizers contain about 6 times as much energy as other fertilizer nutrients. As noted in para. above, prices of nitrogenous fertilizers are projected to increase more rapidly than agricultural products, although somewhat less rapidly than prices of crude petroleum. 1/ Future growth of agriculture will depend to an important degree on the availability of adequate supplies of nitrogenous fertilizes at remunerative prices. Possibilites to reduce the dependence of future agricultural growth from chemical nitrogen supplies are considered in Chapter III.

2,07 Most pesticides are petroleum based and have been subject to sharp price increases in recent years. They are the most energy-intensive chemical input in modern agriculture, although quantities used per ha are usually small. 2/ They are of increasing importance in modernized agriculture and their ready availability is frequently critical to the success of intensive cropping systems. Ready availability is probably a more important determinant of their use than is the financial cost of using them. Of

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1/ An alternative view is that the real price of nitrogenous fertilizers will fall as oil exporting countries develop production facilities based on low cost natural gas. Cf. K.O. Campbell, Food for the Future, University of Nebraska Press.

2/ Roughly estimated, the manufacture and packaging of 1.0 kg of fossil-fuel based pesticides (herbicides rodenticides, insecticides, etc.) require about 2.3 kg of petroleum equivalent.

the estimated 3 million tpe of commercial energy consumed annually by agriculture in developing countries in the mid-1970s, some 8 to 9 percent was accounted for by pesticide use. 1/ Additional commercial energy is used in application of these materials. Chapter III (paras.) discusses alternative approaches to pest control which offer some promise of being less (commercial) energy intensive and perhaps more readily available.

2.08 Energy and farm machinery. Among various types of farm machinery, tractors are by far the largest consumers of commercial energy. Efforts to reduce the dependence of agriculture on commercial energy therefore naturally focus on the possibilities of slowing the rate of tractorization. This poses the question of how tractorization affects agricultural growth and productivity. This issue has been at the center of a sometimes emotional choice-of-technique debate for more than 20 years. A recent survey of the numerous studies which have been generated by this issue suggests that the debate about the benefits of tractors has essentially been between two apparently contradictory views. 2/

2.09 The substitution view looks at tractors and draft animals as two different power sources which technically are near perfect substitutes,

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1/ D. Pimentel, Workshop Report on Enegy Needs Uses and Resources in the Food Systems of Developing Countries, Cornell University, December 1977.

2/ H. Binswanger, The Economics of Tractors in South Asia: An Analytical Review; Agricultural Development Council and the International Crops Research Institute for the Semi-Arid Tropics, New York and Hyderabad, 1978.

i.e. any operation which a tractor and implements can perform is assumed to be also feasible by a combination of animal power, animal-drawn implements and hand labor. Under this view the switch from animal power to tractor power is primarily guided by factor prices (or factor scarcities). Thus, if the opportunity cost of labor and the cost of maintaining bullocks become sufficiently high, it will make economic sense to shift to tractors. Similarly, a relative rise in commercial energy prices would tend to increase the cost of purchasing and operating a tractor and thereby slow the pace of tractorization. Under the substitution view, the question of tractorization is thus primarily an issue of appriate timing of the tractor investment, as determined by changing relative prices for labor, bullocks and tractor services.

2.10 Under the alternative net contributor view, in its more extreme forms, inadequate power is considered to be a primary constraint to agricultural production, almost regardless of factor prices. In this view, the greater power of tractors allows more thorough or deeper tillage than with bullocks. Tractor-drawn equipment such as seeders and levellers permit a higher degree of precision and thereby impact favorably on crop yields. This view also argues that tractors may be able to reclaim land which cannot be tilled by animal power. Finally, the higher power and speed of tractors is presumed to allow more timely operations, thus contributing to higher yields, increased double cropping and greater labor reqirements. In this view tractorization can therefore contribute to increased production without necessarily displacing labor.

2.11 A great deal of empirical research has been undertaken in recent years to illuminate the debate on the impacts of tractorization. Conclusions are conditional to the agro-economic environment which is studied. Where abundant underutilized land is available, the rapid expansion in cultivated area made possible with tractors is frequently a valid argument in favor of wider use of tractors. But even in these circumstances, the higher cost of tractor services resulting from increased energy costs will probably justify some use of draft animal power. Elsewhere, in land short areas such as much of South Asia, surveys of tractor use fail to provide convincing evidence that tractors are responsible for substantial increases in cropping intensity, yields, timeliness and gross returns. The fairly consistent picture emerging from these surveys supports the view that tractors in these circumstances tend to substitute for labor and bullock power and therefore, while contributing little to agricultural growth, may have adverse effects on employment and income distribution. 1/

2.12 Evidence strongly suggests that, except in situations where tractors make possible the expansion of cultivated area, financial returns to tractors from agricultural operations in many circumstances, such as those in the Indian sub-continent, may be close to zero. These returns

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1/ A study in the World Bank of tractors in Pakistan reaches essentially the same conclusion. See J. McInerny and G. Donaldson, The Consequencies of Farm Tractors in Pakistan, World Bank Staff Working Paper No. 210, February, 1975.

are likely to deteriorate further as fuel prices rise. But this conclusion poses the puzzle of why farmers around the world in circumstances not unlike those described above continue to invest in tractors. The explanation is undoubtedly complex and varies from location to locatin. Typically, farm tractors are introduced for various reasons, of which production impact may not be the most important. Noneconomic considerations related to prestige and the aura of modernity are sometimes important. On larger farmers, management with tractors is less onerous than managing teams of laborers, nothwithstanding the greater financial benefits which low-cost labor may convey to the landowner. Nonagricultural benefits of tractors in, e.g. road transport, may also be important. For these and perhaps other reasons, the numbers of tractors in agriculture are likely to continue to grow rapidly, despite relative increases in fuel costs. Nevertheless, the evidence noted above suggests that increased tractorization is not always required for faster agricultural growth. In these circumstances, rational pricing policies for fuel and capital allocation for tractor purchases, together with development programs to foster draft animal use, can help to to slow the introduction of tractors and moderate the growth of commercial energy use in agriculture.

2.13 The use of drying equipment for agricultural products is another particularly energy intensive operation and can have potentially important negative consequences for rural income distribution if casual labor employed in drying operation is displaced. As more intensive crop production systems are introduced, the need for artificial drying frequently increases as harvest seasons are pushed into periods of less favorable weather. Traditional drying systems based on the sun use little commercial energy but employ considerable human labor, frequently that of the the elderly, women or children. The introduction of automated flow-through drying systems make large new demands on commerical energy supplies and may displace sizeable numbers of casual laborers who can be hired at low wage rates for part-time work. Drying costs to farmers may well go up, if the full cost of commercial energy is passed back to producers. Nevertheless, circumstances exist where artificial drying may be economically advantageous. These include situations where labor shortages and the potential for expansion or intensifiation of agriculture exist; where substantial grain losses and/or quality deterioration may result without artificial drying; or where excess, low-cost drying heat is available from on-going processing operations, e.g., rice hull-powered steam boilers.

2.14 Energy and irrigation. On a global basis, irrigated cropland constitutes about 15 percent of the world's cultivated land but accounts for nearly 30 percent of total food production. In terms of soil suitability, the potentially irrigable area is believed to be at least twice the present irrigated area. Lack of water is the major constraint and providing the needed supply is increasingly costly in financial and energetic terms. But various approaches exist to supply the required water and each has different implications for energy use.

2.15 Three types of energy use in irrigation can be distinguished. 1/

1/ This section relies on E. Smerdon and E. Hiler, "Energy in Irrigation in Developing Countries: An Analysis of Energy Factors to be Included in a National Food Policy;" A study prepared for the Agency for International Development (Washington: December 1980), pp. 7f.

The first is the energy cost of constructing the water supply and the conveyance and distribution system to the farm turn-out. A second is the energy expenditure required to construct the irrigation system at the farm level. The third is the recurring energy cost of operating the system. Thorough analysis would include the energy cost of manufacturing the materials used in the system as well as the energy required in construction of the works. Typically more efficient systems, i.e., those with relatively low water losses and wastage, are more costly to construct in financial terms but may offer important energy savings in operation. Determining the proper balance between investment cost and operating costs to maximize net present returns from irrigation investmant requires careful economic analysis.

2.16 For surface water supplies, energy expenditure is largely in the construction and maintenance of the reservoir and the canal distribution and drainage network. Little pumping is normally required since these systems can often utilize gravity flow from upstream reservoirs. The water may have to be transported long distances from reservoir to place of use, thereby requiring considerable energy expenditure in the materials and construction of the conveyance chennels.

2.17 In irrigation systems supplied by groundwater, the irrrigated fields are often directly above the supply. Long conveyance is not required but the water must be lifted to the surface by means which usually require large amounts of commercial energy. Pumping dominates energy expenditure in irrigation. 1/ Roughly estimated, between one-quarter and one-half of the irrigated area in developing countries is supplied from groundwater at depths of a few meters (using hand or animal powered lifting devices) to 40 meters or more (power driven pumps). Many ground-water supplies in developing countries are in alluvial plains and near coast lines where water tables may be 5-10 meters from the surface. 2/

2.18 Estimates have been made of the energy requirements of particular types of irrigation systems which use either ground and surface water sources. Results are best interpreted as orders of magnitude since these estimtes will be heavily influenced by local conditions and underlying assumptions regarding the efficiency of system components. In general, surface irrigation systems at the farm level which draw water from surface sources are the most energy efficient, while sprinkler and trickle farm

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1/ To irrigate one ha with 1000 mm/yr from a groundwaters source at a depth of 10 meters requires lifting to the surface 10,000 tons of water. The energy equivalent of the work required for this task is approximately equal to that in 27 liters of diesel fuel. With a diesel engine efficiency of 25 percent and a pump efficiency of 55 percent, more than 190 liters of diesel fuel would be required for water lifting.

2/ In the Western United States, by contrast, the average pumping lift exceeds 50 meters, a fact which makes some of these deep well systems economically vulnerable to higher energy costs. Within recent years, several thousand hectares of irrigated cropland on the High Plains of the Southwest have gone out of irrigated agriculture for this reason. Under United States' conditions, consumption of commercial energy use in maize production under irrigation (Texas, parts of Nebraska) is more than 50 percent greater than the US average and nearly twice as high as in rain-fed corn production systems (Illinois, Iowa). Cf. UN Conference on New and Renewable Sources of Energy; Technical Panel on Biomass Energy, Appendix H (New York, December 1979).

Table 4. INDICATIVE ESTIMATES OF ENERGY REQUIRED PER YEAR TO PROVIDE NET IRRIGATION OF 1000 MM/HA 1/

Type of Farm Irrigation System	Irrigation Efficiency (percent)	Energy for Installation of Farm System	Surface Water Supply			Groundwater Supply (50 m Lift)		
			Energy to Provide Supply	Pumping Energy	Total Energy	Energy to Provide Supply 2/	Pumping Energy	Total Energy
		000 kcal 3/						
Surface Irrigation	50	111	178	760 4/	1,049	308	13,432	13,850
Surface Irrigation with IRRS 5/	85	291	178	746 4/	1, 215	308	8, 200	8,799
Hand-Moved Sprinkler	75	193	178	8,955	9, 326	308	17, 403	17,904
Trickle 6/	90	1,006	178	4,928	6, 112	308	11, 985	13,299

1/ Systems are designed to meet a peak water use rate of 8.4 mm/day.

2/ To drill and equip well.

3/ Can be converted to tpe with the equation 1 kcal = 10^{-7} tpe.

4/ To overcome friction head loss and provide a small elevation of water to ditch level. In systems where canal water is supplied at sufficient elevation to permit gravity flow, pumping energy is zero except for energy required for the irrigation runoff recovery system.

5/ Irrigation runoff recovery system.

6/ Designed for orchard crops.

Source: Adapted from J. Batty and J. Keller, "Energy Requirements for Irrigation," Handbook of Energy Utilization in Agriculture, ed. by D. Pimental, CRC Press; (Boca Raton, Florida, 1980), pp. 35-44. Reported in Smerdon and Hiler, op. cit., p. 19.

systems drawing from groundwater are the most energy-intensive. As Table 4 indicates, the energy requirements of pumping dominate energy use in irrigation.

2.19 Measures to reduce pumping requirements, through either construction of low energy systems or improved efficiency of water use in existng systems, would seem to offer the best returns to investment in irrigation development. Improved water management at the farm level, watercourse improvement and precision land levelling all appear to be important. The energy required for pumping increases directly in proportion to total pumping lift and in proportion to water lost in each component of the irrigation system. A simple example illustrates possible energy savings. Assume 600 mm of net irrigation are required per ha for a particular crop. If this water is transmitted from a tubewell through a poorly-maintained watercourse with 50 percent loss (watercourse conveyance efficiency of 50 percent) and applied to poorly-levelled fields with a field application efficiency (portion of water provided to the farm which is delivered to the plant root zone) of only 65 percent, then 1.85 hectare-meters of water must be pumped for each hectare irrigated. If the canal is renovated to improve watercourse conveyance efficiency to 70 percent and farmers' fields are precision-levelled to increase field application efficiency to 80 percent, then only 1.07 hectare-meters of water must be pumped to provide the necessary irrigation. About 40 percent savings in pumping energy results.

2.20 <u>Energy in agricultural processing and distribution</u>. It has been pointed out that the food system in developed countries accounts for about 20 percent of total commercial energy consumption, but that most of this is absorbed in off-the-farm processing and distribution activities which tend to use sizeable quantities of commercial energy. Among these activities are canning, artificial dehydration, chilling and freezing and reconstitution of highly-processed concentrates. With increased energy costs, the economic feasibility of some of these processes becomes questionable. In the design of food processing activities in developing countries, careful attention is warranted regarding the type of processing activities to be undertaken, as well as the energy efficiencies of those processes. There seems to be wide scope for improved energy efficiency in processing through the introduction of more efficient burners and and boilers, insulation, the recycling of waste heat, etc. More attention also needs to be given to low energy processing and preservation techniques such as smoking, sun drying, salting and fermentation. Annex provides an example of how a major food processor improved the efficiency of energy use and employed lower-cost energy sources.

2.21 The current mix and location of agricultural production worldwide and within countries has evolved in an era of relatively cheap commercial energy and in response to a combination of many economic and technical factors. A major factor in this regard is the cost of transporting agricultural products and, in more commercialized agriculture, production inputs. In developed countries, agricultural products are frequently shipped long distances for further processing or to consumption centers. Much of this produce moves by truck, a transportation mode which is relatively sensitive to costs of fossil fuel. With sharply higher truck transport costs, the mix of commodities in a production zone and the location of processing are beginning to change. 1/ Products which embody large amounts of energy in processing or distribution are the first to be affected. Bulky, low-value products are being shipped shorter distances and processing involving bulk and weight reduction will be encouraged nearer to the point of production. The same principles will apply in developing countries and may alter relative economic returns to bulky, low-value crops (cassava, sugar cane, fuelwood) vis-a-vis crops with higher value to weight ratios (natural rubber, oilseeds, spices). Over time the choice of transport mode may increasingly shift to that for which transport costs are less sensitive to energy costs e.g., rail or barge, provided efficient, timely service can be assured.

2.22 Similar principles apply to agricultural commodities moving in international trade. With significantly higher transport costs, a smaller fraction of commodities is likely to be traded as CIF-FOB differentials narrow or disappear in importing countries. This shift will reinforce the domestic pressure toward higher degrees of national self-sufficiency in

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1/ In the United States the long-distance shipment of bulky products such as fresh produce from California may be substantially affected. Production opportunities nearer to consumption centers are becoming more attractive, despite less favorable growing conditions. Delivered prices of California vegetables on the East Coast have risen enough to encourage expanded production in Florida. Poultry production is likely to be located closer to consumption centers. Remote production zones will be most affected. Higher transport costs, together with other new agricultural technologies, are promoting further changes in the location production. A large producer of ethanol for the US gasohol program considers it possible to produce winter vegetables economically under glass in an environment enriched by carbon dioxide and heated by fermentation heat obtained through the alcohol production process. Some displacement of fresh produce from California, Florida and Mexico is considered economically feasible. Cf "Generous Maverick: Andreas Takes Risks and ADM Wins", Wall Street Journal, January 15, 1981, p. 17.

basic foods to meet food security objectives. Transportation costs are rising faster than product prices. In the 1960s ocean freight accounted for about percent of CIF grain prices; in the 1970s this had increased to percent. In the 1970-79 period, international freight rates for wheat doubled and rose three-fold for products such as frozen beef.

2.23 Energy and fisheries. Fisheries accounts for a very small part of global food calorie production (about 1 percent) but is a more important source of high quality protein for human consumption (providing about 4 percent of world protein supplies). Greater motorization of the fishing fleet and increased processing has sharply increased fossil fuel consumption in the industry. The initial impact of the sharp increase in commerical energy costs since 1973 has been considerably greater on the fishing industry than on other rural-oriented production activities because fuel tends to account for a higher proportion of operating costs in this industry. This proportion has risen from about 10 percent in the commercialized sector of the industry a decade ago to as much as 50 percent today. 1/ The industry also has been adversely affected by sharply higher prices for much of its fishing gear, viz., nets, lines, floats, etc., most of which is manufactured from petroleum-based materials.

2.24 Because of the perishability of the product and its high water content, the marketing, processing and storage of fish may also consume

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1/ A. Laing, "Fisheries: Little Energy Saving Expected," in Span, 1975, pp. 34f. and World Bank, Fishery Development: Sector Policy Paper, Agriculture and Rural Development Department, (draft, May 1980), p. 58.

sizeable amounts of commercial energy. The extent and type of processing are important determinants of energy consumption. Increased processing has led to increased energy consumption. During the 1950s about 50 percent of the world's fish catch was consumed fresh. By 1977 this had declined to 30 percent largely in response to expanded freezing and canning. During this period the proportion of catch which was canned rose from about 7 to 14 percent, while the share to be frozen increased from less than one to 17 percent. On the other hand, the curing of fish, which is the least commercial energy intensive form of processing, declined from 33 to 11 percent of the catch. It is estimated that salt dried or smoked fish requires less than one-tenth the commercial energy per protein unit compared with that required by the processing and marketing of imported frozen fish. 1/

2.24 Typically, large trawler operations tend to require considerably more commerical energy per ton of catch than do smaller in-shore vessels. Norwegian data suggest that the coastal fleet requires only 10 percent as much fuel per ton of landed catch as do trawlers. 2/ This relationship is altering the economics of trawler operations in favor of smaller vessels and increased focus on closer fishing grounds. Higher fuel costs also may reduce the attractiveness of fishing for unconventional species (e.g., krill) in distant waters.

1/ E. Reusse, "The Energy Waste in Food Marketing," FAO, CERES (Rome, November-December 1980), p. 27.

2/ A. Endal, Norwegian Small Scale Fishery Technology, Institute of Fishery Technology Research, Trondhein, Norway, (undated), p.4.

2.25 Rising fuel costs will require continued adjustment toward more enegy-efficient methods of exploitation and processing. Low energy fishing methods, including longlines, traps and net seines, will become more attractive in financial terms. For small craft there is likely to be a move from gasolene to diesel power and increased use of sail power. Among larger vessels there appears to be considerable scopes for fuel saving through proper speed selection in operations and improved design in the propulsion system.

Chapter III. AGRICULTURE AS A SOURCE OF ENERGY

3.01 Agriculture is essentially the human activity which converts solar energy, plant nutrients and water to biomass energy by means of plants and animals. Agriculture's potential as a source of energy depends essentially on the amount of these resources which are available and the efficiency with which they are combined in usable form. The incidence of solar energy varies a great deal with lattitude and climate; its usual order of magnitude is between 1,000 and 1,800 tpe/ha/year in a temperate climate. However, the photosynthetic efficiency of most plants (the portion of solar energy converted to biomass energy) is only 0.4-0.8 percent over the whole year. Biomass potential is therefore less than 10 tpe/ha/year in temperate regions. In well-watered tropical regions where the incidence of solar energy is higher and conditions for plant growth are good, annual biomass production (in terms of dry matter content) can range up to 40 tons. 1/ Worldwide it is estimated that annual biomass energy production is about 10 times the energy consumed annually in the form of

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1/ OECD, op. cit., pp. 61f.

gas and oil. Among the most valuable forms of biomass energy from agriculture is the annual production of some 1,600 million tons of grain for human and animal consumption. This process of biomass energy production is highly efficient in terms of commercial energy. The energy required for fertilizer production, human and draft animals, operation of farm tools and machinery and irrigation needed for this volume of grain is roughly equivalent to 235 million tons of petroleum equivalent, while the energy contained in the grain amounts to 535 million tpe. 1/

3.02 Fuelwood. The conversion of biomass to useful energy can occur through thermochemical (including direct combustion) or biochemical processes. Annex illustrates the range of processes and resulting energy forms. Apart from grain, the most important biomass energy source is fuelwood. Other important biomass energy sources include charcoal, crop residues and animal dung. 2/ Together these materials may account for 20-25 percent of total energy consumption in the developing world. About three quarters of the populations of these countries use these materials primarily for cooking. As fuelwood supplies dwindle and costs rise (either in financial terms or in terms of effort to secure fuel-wood), people have turned increasingly to burning dung and agricultural residues. This depletion of forest resources contributes to ecological degradation and the

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1/ With this (limited) concept of energy flow, the energy balance of grain production (ratio of energy output to energy input) is about 2.3.

2/ See the Bank's Renewable Energy Sources in the Developing Countries (1981). This section draws on this document which is essentially the report of the Bank's Task Force on Renewable Energy.

burning of dung and crop residues similarly deprives the soil of nutrients and organic conditioning material. The current use of dung for fuel may "cost" some 20 million tons of foregone food grain production annually.

3.03 The direct combustion of fuelwood for cooking and heating is very energy inefficient. Energy use in cooking on open fires may be five times greater than cooking with a kerosene stove. Even where simple wood burning stoves are used, more than 90 percent of the heat is often wasted. Improved cooking stoves offer simple, low cost means to enhance the efficiency with which fuelwood is used. 1/ More efficient use of wood resources can also be achieved through the production of charcoal, a material which can be made from almost any wood material, including the large volumes of wood other than commerical timber which are a by-proudct of commerical timber and agricultural land clearing activities. Typically, charcoal braziers have an efficiency of 15-20 percent (i.e., 15-20 percent of the heat of energy combustion is actually utilized in cooking) or more than twice that of unimproved wood stoves. But much charcoal is inefficiently produced in poorly-designed kilns. In traditional kilns the conversion rate of wood to charcoal may be as much as 5:1, while with improved kilns only 3.0-3.5 tons of wood are required to produce a ton of charcoal.

1/ Much work has been done by FAO and other agencies to develop cheap, more efficient stoves from locally-available materials such as mud, bricks, metal or cement. A simple stove developed in Guatemala reduced fuelwood requirements by half. Cost was about $5 per unit. Similarly, a closed heath design in Indonesia reduced wood requirements by about half under experimental conditions. A number of Bank-supported fuelwood projects have included components to develop and introduce more efficient stoves. More effort is needed to disseminate these simple improved technologies.

Further energy savings with charcoal are obtained in transport of this material since the heat content per ton is about twice as high as in fuelwood. 1/

3.04 Vegetable oils as diesel fuel substitutes. The liquid fuel requirements of developing countries typically include various combinations of gasolene, diesel fuel and the heavier fuel oils. Effective gasohol programs or programs to use biomass alcohol in pure alcohol engines can reduce gasolene requirements significantly (para. below). But these programs do little to reduce crude oil requirements for diesel and fuel oil. Research efforts are therefore underway to identify and develop alternative energy sources for these components of the crude oil barrel. Much of the work has centered on the use of annual or perennial vegetable oils as potential diesel oil substitutes or extenders. Results suggest that there are no serious technical barriers to the use of a considerable range of vegetable oils in diesel-type engines, either alone or in a blend with diesel fuel, although further testing is required to determine longer-term effects on engine life. Research work has been carried out on, e.g., oils from soybeans, sunflower seed, peanuts, rapeseed, and palm oil 2/ The

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1/ R. Revelle, "Energy Dilemmas in Asia: The Needs for Research and Development," Science, Vol. 209, July 1980, pp. 164f.

2/ Other potentially useful plant sources of hydrocarbons exist. Some of the genus Euphorbia produce a milk-like emulsion of hydrocarbons in water. Euphorbia lathyrus is reportedly producing the equivalent of 10 bbl of hydrocarbons per acre in experimental conditions. In Brazil Copaifera langsdorfi produces a hydrocarbon with proporties similar to diesel fuel in quantities of up to 25 bbl per 100 mature trees (about one acre). Further research and development are required before the economic merits of these materials can be determined. See "Unlike Money, Diesel Fuel Grows on Trees," Science, October 1979, p. 436.

Philippine government recently initiated a program to test coconut oil as a diesel fuel replacement. 1/ Although heats of combustion are similar, and substantially exceed that of ethanol, each vegetable oil has somewhat unique chemical and physical proporties which affect its use as a diesel oil replacement. 2/ Most oils react with oxygen and may deteriorate in storage more quickly than diesel oil. Several tend to be more viscous at ambient temperatures and require pre-heating for effective use. Resin or coke build-up in engines may be a problem with some oils unless appropriate additives can be found. Field trials in Brazil are being conducted with a 30-70 percent soybean-diesel oil mixture. The Brazilian government announced a 1981 goal of substituting vegetable oils for 6 percent of the country's diesel fuel consumption. In that country initial efforts are to increase areas planted to peanuts, sunflower, rape and soybeans in the near term. Government asssistance also is being directed to increasing palm oil production for this purpose in the Amazon Basin.

1/ The Wall Street Journal, "Filipinos Cocodiesel is Fueling Vehicles and Buoying Price of Coconut Oil Crop," May 29, 1981, p. 40.

2/ Heats of combustion for diesel oil, ethnanol and various vegetable oils are:

Product	Kcal/liter
No. 2 Diesel fuel	9,320
Peanut oil	8,860
Corn oil	8,790
Cottonseed oil	8,720
Soybean oil	8,660
Sunflower seed oil	8,520
Ethanol	5,590

Source: Smerdon and Hiler, op. cit., p. 42.

3.05 The yield advantage of oil palm over other oil bearing plants is impressive. Using presently-available planting materials and good management practices, palm oil yields of 4-5 tons/ha/yr can be achieved. Possible breakthroughs in plant breeding and selection techniques promise yields which are significantly higher. These yields compare with oil yields from sunflower, safflower and rapeseed of 0.7-0.9 tons per ha under rainfed conditions, soybean oil yields of 0.3-0.4 tons/ha and coconut oil yields of perhaps 1.3 tons/ha under good management. One ha planted to impoved (clonal) oil palms could yield perhaps 5 tons of palm oil annually, or about 5,400 liters in terms of liquid fuel. If planted to sugar cane, as in the Brazilian alcohol program, ethanol production/ha/yr would be in the range of 3,500 liters (50 tons of cane @ 70 liters/ton). Moreover, the adverse environmental consequences of vegetable oil processing, while not insignificant, are considerably less than those of biomass alcohol production. The technology for extracting vegetable oils is a relatively simple process which is adaptable to smaller-scale operations than those commonly employed in ethanol production. Year-round production of palm fruit also permits efficient use of plant and equipment.

3.06 A major outstanding question is the economics of vegetable oil such as a liquid fuel. Recent (February 1981) palm oil prices, CIF, Northwest Europe, are in the range of $600/ton. Crude petroleum at $32/bbl, FOB Persian Gulf, is equivalent to about $225/ton while diesel fuel prices have recently been reported in the range of $300/ton. The Bank is projecting steady declines in real prices for palm oil as large plantings, especially in Malaysia, come into production. Yield gains from research now underway could further expand production over the medium term and hasten the price decline. In the immediate future, relative world prices of vegetable oils and diesel oil are not likely to favor significant diversion of vegetable oils to fuel use. However, in isolated locations where delivered prices of diesel fuel are high and vegetable oils are available, relative prices already make attractive the use of vegetable oils in diesel engines. This use can be expected to grow.

3.07 Biomass alcohol. Among the biochemical conversion processes for biomass are the processes employed in the production of ethanol or methanol. 1/ Ethanol is produced commercially from saccharine materials such as sugarcane, sugar beets and molasses and from starchy materials such as maize and root crops. Development work is underway to produce ethanol from cellulosic materials including wood and agricultural residues, but commercially proven technologies are not yet available. Methanol can be produced by distillation of wood although much current production is synthesized from carbon monoxide and hydrogen obtained from natural gas or coal. With known commercially-proven technology, methanol produced from renewable materials is of limited potential as a vehicle fuel because it is generally more expensive than methanol produced from natural gas and coal. Moreover, methanol-gasolene blends present considerably greater technical and environmental problems than the ethanol blends which are being increasingly used in countries such as Brazil and the United States.

1/ See World Bank, Alcohol Production from Biomass in Developing Countries, op. cit., for a discussion of the technology and economics of biomass alcohol production.

3.08 The energy balance in ethanol production is generally not a serious problem in sugarcane-based systems where excess, low-value fuel (bagasse) is available. But the efficiency and cost of energy use is important in systems where outside fuels must be purchased, as in maize-based alcohol production. Good progess is being reported in developing more energy-efficient fermentation and distillation processes in these systems. The economics of biomass alcohol production are heavily dependent on the economic value of the biomass feedstock (since the feedstock accounts for more than two-thirds of total production costs), and are therefore location specific. At present very few countries appear to have the potential for low-cost production of alcohol feedstocks. No less troublesome are difficult distributional issues involved in biomass energy cropping, irrespective of whether it will be fuelwood, starch or sugar crops for ethanol or vegetable oils as diesel fuel substitutes. Because these programs are rural based, they have the potential to affect for good or bad the well being of large numbers of low income rural residents. These programs offer the possibility of creating new rural employment in biomass production activities, but whether this would be positive in net terms requires a determination of future employment without the program. The net employment effect may be overstated, particularly where new biomass pro-uction systems involve mechanization. If these programs displace food crops or reduce food production below without project levels, the resulting higher food prices impact negatively and disproportionately on the welfare of low income groups. Environmental considerations are also important in energy cropping programs such as biomass alcohol because of the large volumes of processing effluent which result. Low cost, energy-efficient means of dealing with the associated environmental problems are proving to be elusive.

3.10 The distributional concerns with energy cropping extend beyond national boundaries. As others have pointed out, biomass fuel alcohol greatly extends the claim, of those who own or use automobiles, over the world's arable land supply.1/ Per capita grain consumption in developing countries averages about 180 kg/yr, while in the affluent countries, where much more grain is fed to livestock, direct and indirect consumption of grain per capita is about 725 kg/yr. At average world grain yields, these figures imply that each consumer in the developing world requires about 0.10 ha to meet his grain needs, while in the affluent country the figure is 0.40 ha. Where automobiles are powered by alcohol dervied from sugarcane, each automobile, driven on average some 15,000 km/yr, would require at least another three-quarters of a hectare for fuel alcohol production. The fuel vs food concern has frequently been couched in terms of competing uses for limited land supplies. But it should be recognized that energy crops also compete for scarce investment capital, fertilizer, water, entepreneurial skills, extension services, etc. In an environment of rising fossil fuel prices, relative to agricultural prices, the usually dominant economic strength of automobile owners suggests that they will be in good position in bid ever larger shares of these resources away from food production.

1/ L. Brown, Food or Fuel: New Competition for the World's Cropland, Worldwatch Paper No. 35, Worldwatch Institute (Washington, 1980).

3.11 Biogas. This form of energy, containing 55-65 percent methane, is obtained from the anaerobic decomposition of a wide range of organic materials. The production process is complex and involves at least two kinds of bacteria. The process is sensitive to temperature, acidity or alkalinity and to the type of feedstock used. Because low value feedstocks such as animal and human wastes, crop residues, etc., can be used, biogas production has attracted considerable attention as a low-cost, decentralized farm or village energy source. China and India both have sizeable biogas programs which continue to expand. The initial Indian program was criticized on grounds that the benefits from the units went to the relatively wealthy families who had the cattle, land and credit needed to build and use these facilities. 1/ The Indian program is now emphaizing community-sized plants for which adequate and reliable supplies of feedtock can be provided and from whch gas production can be distributed more widely. The Chinese biogas program, much the world's largest, is now reported to include more than 7 million units, mainly in communes where local organization facilitates their construction and where intensive animal (largely swine) production systems provide readily-collectible quantities of dung as feedstock. The continued development of lower-cost, more efficient designs in China has contributed to the widespread use of biogas, although there is some indication that expansion of the program in slowing and some older units are being abandoned. 2/

1/ World Bank, Renewable Energy Resource ... op. cit., p. 12.

2/ V. Smil," ".

3.12 Despite numerous studies on the economics of biogas, no consensus has emerged. The various conclusions reflect widely different assumptions about the economic value of the feedstock, the quantity and value of the labor required to operate the digester and the economic value of gas and sludge as fuel and fertilizer. Technical, economic and social problems remain with these devices, including the need to lower construction costs, improve reliability of the design and the production system, determine appropriate sizes for common use and establish effective incentives for collecting animal and human wastes. Micro-biologic research is also necessary to identify organisms which can function effectively over relatively low temperature ranges (5-45 C) and utilize high ratios of crop and other residues to animal and human wastes.

3.13 Biological fixation of nitrogen. It has been pointed out (para. .) that chemical fertilizer, and nitrogen in particular, accounts for a large share of global consumption of commercial energy in agriculture. Each year crop production removes some 140 million tons of nitrogen from the world's soils. Some 45 million tons are replaced through the use of chemical nitrogen and an additional 90 million tons of the deficit are made up though the natural fixation of atmospheric nitrogen by micro-organisms living in symbiotic relationship with certain plants. The best known and widely exploited form of biological nitrogen fixation (BNF) is by the bacteria genus Rhizobium in relationship with some 12,500 species of the plant family Leguminosis. Under good conditions, this relationship can fix 110-220 kg nitrogen/ha/yr, 1/ thereby sharply reducing the amount of chemical nitrogen needed to met crop requirements. In comparison, a maize crop yielding 4 tons of grain per ha removes about 115 kg of nitrogen from the soil. 2/

3.14 The Rhizobium-Leguminosis interaction is limited largely to rainfed agriculture and therefore of less potential as a nitrogen source to, e.g., the world's most important food grain, viz., rice. But with 78 percent of the atmosphere made up of nitrogen, it should not be surprising that nature also has a means of making some of that nitrogen available to wet land crops such as rice. This is through the symbiotic interaction of the blue-green algae Anabena with the water fern Azolla. Azolla is widely-distributed in the rice growing regions of the tropics and temperate zones and grows on the water of irrigated rice fields or in cropping systems with rice. When grown in association with Anabena, and with appropriate temperate and nutrient conditions, Azolla doubles its mass in 3-5 days and accumulates 30-40 kg of nitrogen/ha in 2 weeks. 3/ Under experimental conditions, five crops of Azolla produced a total of 117 kg of nitrogen/ha in 106 days. The Azolla-Anabena technology has been used as a supplementary

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1/ D. Pimental, . p. 43.

2/ M. McVikar, G. Bridger, L. Nelson, eds., Fertilizer Technology and Usage, Proceedings of a Short Course of the Soil Science Society of America (Madison, Wisconsin, 1962) p. 113.

3/ International Rice Research Institute, Utilization of the Azolla-Anabena Complex as a Nitrogen Fertilizer for Rice, Research Paper Series, No. 11 (Los Banos, November 1977).

nitrogen source in the Orient for more than 400 years and is now used commercially on some two million ha of rice lands in China and Vietnam. It has recently been adoptad in the United Stated where it is yielding the equivalent of up to 75 percent of the nitrogen fertilizer requirements of paddy rice culture in some areas of California. 1/

3.15 Animal draft power. Draft animals provide more than a quarter of all motive power in developing country agriculture (para.). In India bullocks occupy less than 10 percent of the arable land but account for well over half of total motive power in agriculture. 2/ A major advantage of bullocks and other draft animals is their ability to utilize as feed sources grasses and agricultural wastes with limited alternative use. It is worthwhile to note that much of the world's land is too steep, wet, dry or cold to produce food crops for humans but which frequently can be harvested by ruminants and used as a source of low-cost draft power and other valuable animal products. The need to maintain the animals during off season periods is a disadvantage, as is their possible competition for land which might be put to other higher-valued uses. In engineering terms, the conversion efficiency of draft animals (efficiency of converting biomass to output power) is generally estimated to be less than 5 percent,

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1/ C. Orrego, "Evaluation of Microbial Technologies Involved in Fuel Production, Agriculture and Forestry," Background paper prepared for the World Bank Science Advisor, draft, January 1979.

3/ See M. Tikku, "India Sticks to Bullock Power," Far Eastern Economic Review, (Hong Kong; 1980). pp. 41-2; N. Ramaswamy, Occasional Paper No. 10, Indian Institute of Management (Bangalore, 1978).

a point often stressed by those sceptical of the merits of draft animal power. 1/ But this is of limited relevance if the animals convert low value crop residues into useful energy.

3.16 Moreover, the frequent comparison of horsepower of draft animals and tractors is misleading when based on "engineering equivalence," rather than "economic equivalence" in terms of actual work capacity. An example illustrates this point. Studies of draft animal use in agriculture commonly assume that a draft animal develops 0.5-0.7 horsepower (hp). Useful energy is estimated in terms of hp hours determined by multiplying this estimate by the number of hours of farm work done by a draft animal each year. Thus, an "engineering equivalence" study would imply that a 35-hp tractor would be equivalent to about 35 pairs of bullocks (1 bullock = 0.5 hp), while in terms of actual work done during the peak period (or in terms of the number of bullock pairs replaced by a tractor in a given farm situation), a tractor may be equal to only 5 or 6 pairs of bullocks. With this adjustment, a draft animal would provide 6 times the useful energy commonly estimated under "engineering equivalence" assumptions and may increase the energy efficiency of draft animals several times from the usual figure noted above.

3.17 In numerous circumstances additional motorized power will be required to increase agricultural production. This may include situations where the timeliness of operations is critical to more intensive

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1/ This increases to 15-20 percent when the energy value of dung is included and would rise stil further if the contribution from milk and by-products were added.

cultivation systems, in difficult terrain, where opportunities for extensive new land development exist, and to meet high power requirement in land shaping operations, etc. But elsewhere the increase in fossil fuel prices will make the draft animal option increasingly attractive in financial/economic terms. Where animal power is widely used development emphasis could usefully be directed towards improving the animal-power comlex around which farming systems are built. This could take several forms. First in the shorter term, efforts should be made to improve the animal as a power unit by better feeding, health and management and, in the longer-term, by selective breeding and genetic upgrading. The principal constraint, and the one to which development priority must be given in efforts to improve animal powered agriculture, is the inadequate quantity and quality of livestock feed. There is also need to improve the means by which animal power is utilized and transformed into productive farming activity. This requires improvements in the design of traditional yokes and implements and of the introduction of new types of equipment to be powered by animals. In view of the present and likely (greater) future importance of draft animals in agriculture, this type of research and development work appears to be greatly underfunded. 1/ In countries such as Bangladesh the shortage of

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1/ Barwell and Howe have emphasized the contribution which could be made to agricultural productivity by better designed draft animal carts and collars. See their contribution in UNIDO, Appropriate Industrial Technology for Low-Cost Transport for Rural Areas (New York, 1979). The Bank is supporting a research project which examines the technical and institutional constraints to more effective use of animal power in Indian agriculture. Several of the international agricultural research centers have begun to develop tools and equipment for use by draft animals.

draft power is already a key constraint on agriculture and wider, more effective use of draft animals offers the most practical option. 1/

3.18 Conservation as an energy source. In many circumstances, conservation may be the most effective means to reduce dependence of agriculture on commercial energy. In farm machinery applications, improved designs and properly adjusted equipment can cut energy consumption sharply. The International Rice Research Institute has developed an axial flow pump which is reported to be two to three times as efficient as the common centrifugal design. In the production of biomass alcohol, the energy required for distillation is equivalent to about 50 percent of the heat of combustion in the alcohol. Where no low cost energy source is available (as in the use of grain feedstocks) to energize the process, energy efficiency is a key determinant of economic viability and conservation becomes an important objective in plant design.

3.19 In field operations minimum tillage offers potentially large fuel savings. 2/ Although part of the fuel savings are lost through increased energy expenditures on herbicides, work at the International Institute for

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1/ See the Bank's recent economic report, Bangladesh: Current Economic Situation and Review of the Second Plan; Report No. 3309-BD (February 23, 1981) and, in particular, Annex XI, "The Livestock Sector: Problems, Prospects and Policy Requirements." This annex is the first Bank sub-sector review which explicitly recognizes the importance of livestock as the primary source of draft power and which addresses the constraints to increased effectiveness of animal power.

2/ Defined simply as a crop production system in which the crop is planted either without tillage or with just sufficient tillage to allow proper seed placement and coverage for germination. Usually no further cultivation is done and weeds are controlled by hand weeding or chemical herbicides.

Troipical Agriculture (IITA) indicates possible net energy savings of up to 75 percent over mechanized systems. 1/ Reported effects on crop yields vary. In the IITA study, yields under no tillage systems were higher than with conventional systems. Results elsewhere indicate some reduction in yields with minimum or zero tillage. Experimentation work on this technology continues as a promising means of reducing both energy and labor requirements. In the United States, commonly assumed to heve a very (fossil-fuel) energy intensive system of agriculture, the practice of minimum tillage has expanded rapidly in recent years but even today it is applied to less than 20 percent of the arable land.

3.20 The possibility has been noted of commercial energy savings by increased reliance on biological nitrogen. Other savings are possible through improved types of chemical fertilizers, e.g., slow-release, as well more effective timing of fertilizer application and placement near the root zone of the plant. Only about 30 percent of the nutrients applied through chemical fertilizers in developing countries is used by the plants. The balance is lost through leaching and aeration. Even a modest reduction in these losses through improved fertilizers would yield potentially large savings in petroleum-based feedstocks.

3.21 Good possibilities also exist to reduce commercial energy use in pest control, particularly insects, through improved pesticide application methods or by the use of biological control. Traditional methods of

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2/ R. Wijewardene, Systems and Energy in Tropical Farming, American Society of Agricultural Engineers, Paper No. 78-1511, 1978.

insecticide application typically involve spray volumes of perhaps 250 liters/ha in ground operations and 20 liters/ha in aerial spraying. Considerable commercial energy is required in the transport and high-pressure dispersal of these materials. With new systems of low volume applications, spray volumes can be reduced to as little as 5 liters/ha. 1/ Under a related "electrodyn system," electrical energy is applied to oil-based spray materials to atomize these materials and facilitate controlled deposition with very low energy consumption. This approach, suitable for insecticides, fungicides and herbicides, promises improved drift control and employs a hand-held application with no moving parts. 2/

3.22 Biological control is increasingly viewed as an environmentally sound, effective and relatively simple approach to the pest problem in agriculture. 3/ Successful programs establish a regulatory system in which natural enemies keep the pest in control with little further outside effort or expense. Chemical control, in contrast, requires regular, often frequent, repetition for an indefinite period and carries risks of environmental damage or the development of resistant strains among the pest population. While biological control has the disadvantage that certainty

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1/ A. Vavers, "On Conserving Energy in Agrochemical Application," Span, March 1980.

2/ R.A. Coffee, "Electrodynamic Energy: A New Approach to Pesticide Application," in Proceedings of the 1979 British Crop Protection Conference.

3/ Biological control is the method of controlling pests, whether of plants, animals or man, by exposing them to their natural enemies. Perhaps the simplest example is the use of cats to keep down mice.

control are variable in different circumstances, it has the increasingly important advantage that it uses little or no commercial energy. It is most commonly used in the control of insect pests, but has important application in weed control as well. 1/ In the United States biological control by nature or imported natural enemies of insect pests is employed more extensively than pesticides. Opportunities appear to be good for much wider application. Several years ago a Latin American country imported $10 million of chemical pesticides to protect a cotton crop worth $60 million. Some studies suggested that biological control agents, including insect viruses, could reduce expenditure by 50 percent. It has been suggested that up to a third of the insect pest problems of the Western Hewisphere is amenable to control by no more than 16 different viruses. 2/

1/ For a discussion of applications, see Commonwealth Agricultural Bureau, Biological Control Service: 25 Years of Achievement, (Slough, England; undated).

2/ C. Orrego, "Evaluation of Microbial Technologies ..., op. cit., pp. 10f.

ENERGY AND AGRICULTURE: AN OVERVIEW

Commercial Energy Use and Cereal Output Per Hectare and Per Agricultural Worker, 1972 1/

Region	Energy/Ha	Energy/Agr. Worker	Output/Ha	Output/Agr. Worker
	tpe		kg	
Developed Countries				
North America	0.49	13.39	3,457	67,882
Western Europe	0.67	2.00	3,163	5,772
Oceania	0.26	5.95	976	20,746
Others	0.47	0.46	2,631	2,215
Sub-Total	0.60	2.60	3,100	10,508
Developing Countries				
Africa	0.02	0.02	829	538
Latin America	0.10	0.21	1,440	1,856
Near East	0.09	0.11	1,335	1,386
Far East	0.04	0.03	1,328	781
Sub-Total	0.05	0.05	1,255	877
Centrally-Planned Economies				
Asia	0.06	0.04	1,815	911
Eastern Europe and the USSR	0.22	0.69	1,682	4,109
Sub-Total	0.14	0.16	1,744	1,518
World	0.19	0.24	1,821	1,671

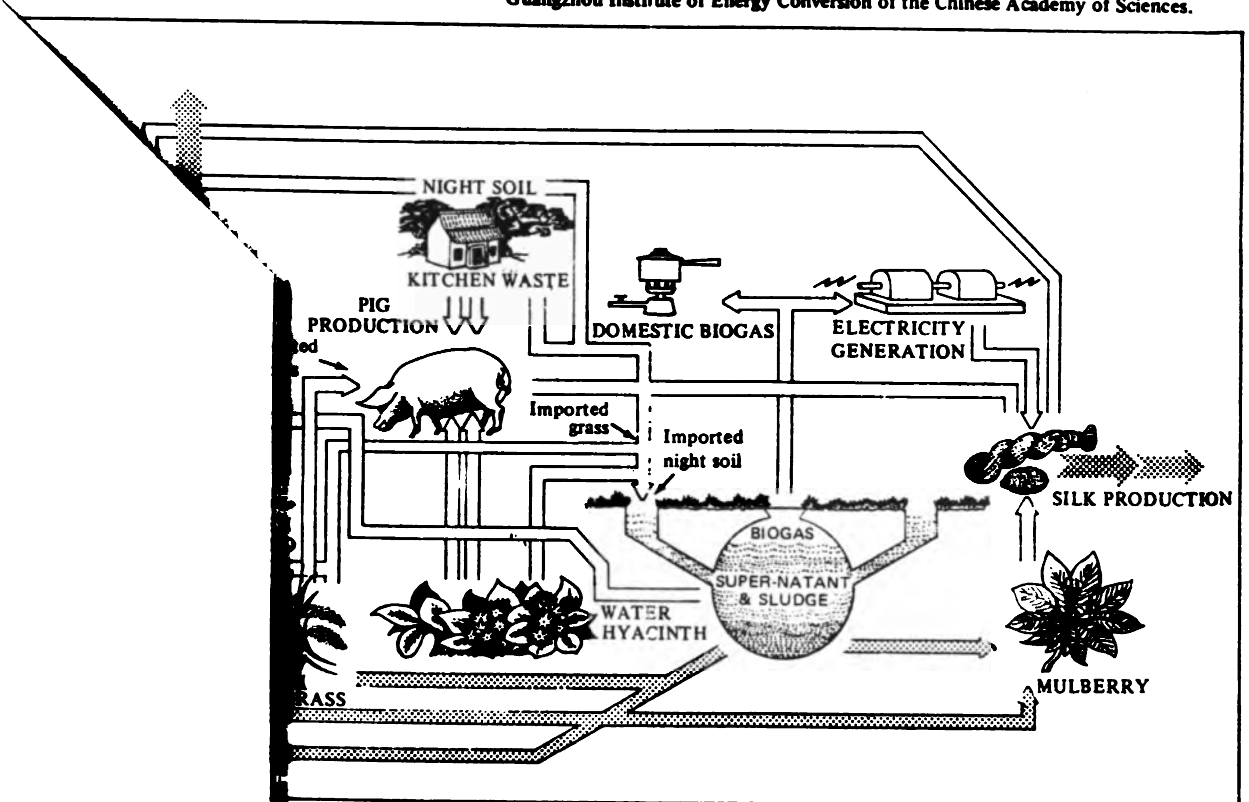
1/ Excludes human and animal draft, energy in manure, etc.

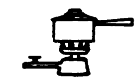
Source: B.A. Stout, "An Overview of Energy in Developing Countries", A Paper Presented at the 1977 Winter meeting of the American Society of Agricultural Engineers; Chicago, December 1977. The figures are based on FAO data.

of the Pearl River Delta, in Guangdong Province of China, is the Leliu
ommune are divided into 29 production brigades. In one of these, a
dern technologies into a complex system for generating agricultural pro-
d, energy and fertilizer. The system supports the livelihood of about
ge agriculture practised in the area which includes fish ponds, pig
ith some recycling of waste products. The system requires the
electrical energy, as well as chemical fertilizers, although to
s and semi-processed fruits which more than cover the
ommunity produces for its own consumption vegeta-
s for energy and fertilizer produciton have markedly improved agricultural production but also set more rigid requirements in matching the various components of the system. The resulting increase in living standard has been accompanied by a significant improvement in sanitary conditions.

The electricity generated by the biogas-powered generator covers 40 percent of the production team's electricity consumption, the remainder of which is supplied by the local power grid. In addition, biogas utilization has largely replaced the dependence on wood for cooking and coal for drying. Similarly the sludge from the digesters has reduced the previous dependence on chemical fertilizers.

The plans are underway to further improve the system by incorporating more efficient biogas digesters and adding solar water heaters for family residences. Preliminary tests suggest that a 5.5 m^3 biogas digester and a 0.72 m^2 pond-type solar heater may supply up to 90% of the energy previously provided by firewood for a family of four. The system has been developed with assistance from the Guangznou Institute of Energy Conversion of the Chinese Academy of Sciences.





Biogas

Eighty-four family biogas digesters have been installed and 7 other digesters with a total volume of 235 m^3 are operated on a communal basis with biogas storage in two 45 m^3 balloons. The family digesters operate mainly on night soil from the family and the waste of its pigs, supplemented by Napier grass, banana waste, water hyacinth bulbs and kitchen waste. The communal digesters also consume silkworm waste and night soil. The biogas generated by family digesters is burned for cooking and lighting. The biogas from the communal digesters powers an internal combustion engine which drives a 12 kW electric power generator at the rate of 1.5 kWh per m^3 of biogas. The electric power is used to operate electric lights and a pulveriser. The waste heat from the motor is channeled into the silkworm cocoon drying shed. The supernatant from the digesters is added to the fish ponds to serve as nutrient for algae growth while the sludge is utilized on a variety of fields throughout the village. The village digesters consume daily two tons of waste material. A family biogas digester of about 1 m^3 requires about two man-days to construct from materials (cement, bricks, sand, lime and water) In this sub-tropical region, the digesters operate year round except for cleaning periods totalling about three days per year.

plemented by some chemical fertilizers for Napier grass fertilizaton. Annual productivity is about 310 tonnes per hectare.

Pigs

Raised for sale and local consumption, pigs consume mainly water hyacinth leaves, imported grasses and kitchen waste. Their waste is a valuable component for biogas-digester operation. The Napier grass which they chew is regurgitated and added to the biogas-digester input.

Water hyacinth

This aquatic weed is harvested from nearby rivers and fed to pigs which consume the leaves. The bulbs are added to the biogas-digester input. Annual productivity exceeds 1,000 tons, wet weight, per hectare of water surface.

Bananas

Another product for cash sale, bananas are also produced on about one hectare. Most of the bananas waste is fed to the biogas digesters.

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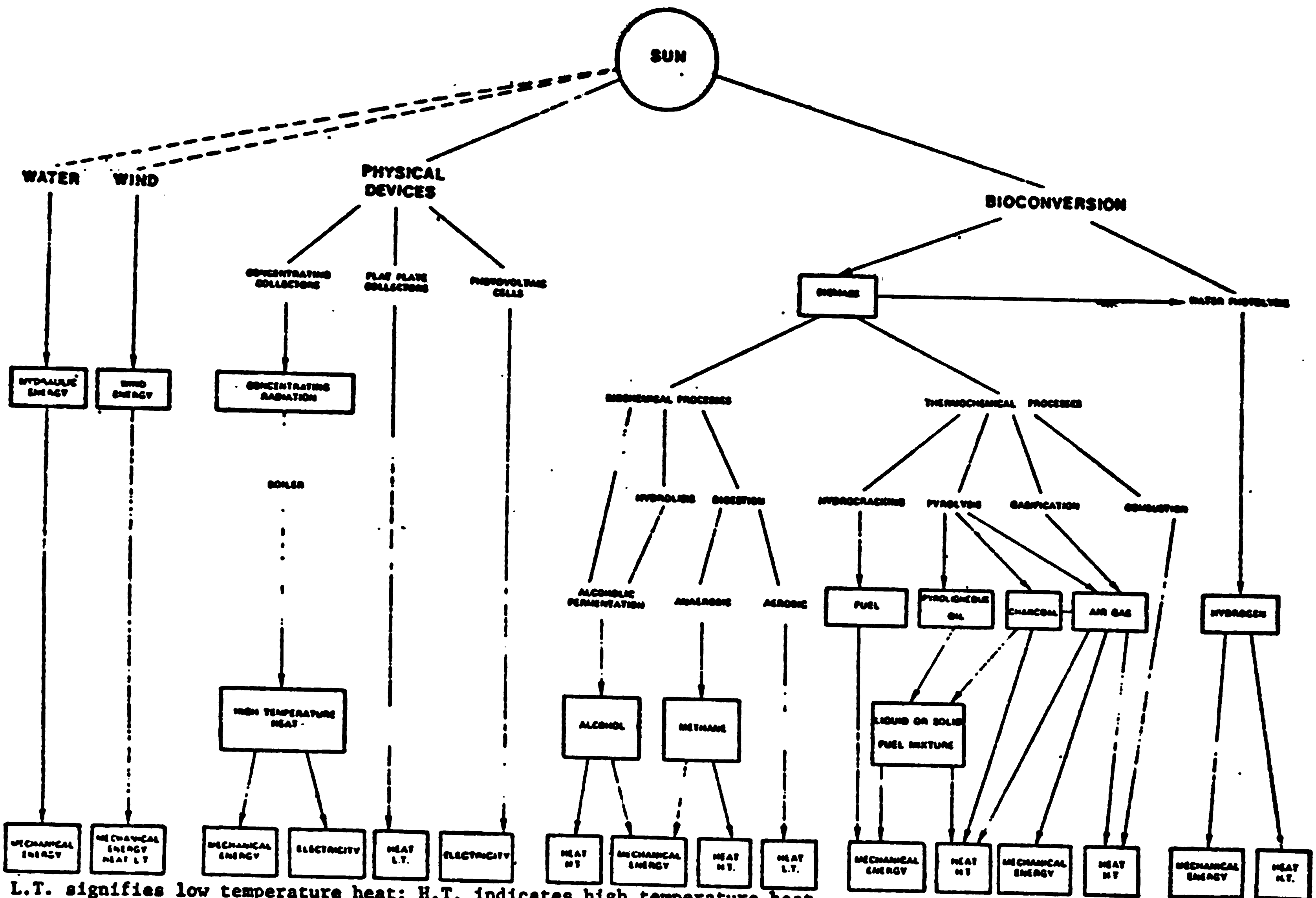
ANNEX
Figure 1

ENERGY AND AGRICULTURE: AN OVERVIEW

Alternative Processes for the Conversion and Use of Solar Energy 1/



1/ L.T. signifies low temperature heat; H.T. indicates high temperature heat.

Source: FAO and Economic Commission on Agriculture, New and Renewable Energy in Agriculture, Annex No. 2, April 1980.

ENERGY AND AGRICULTURE: AN OVERVIEW

Adjustment to Higher Energy Prices: An Example in Food Processing 1/

1. Government studies indicate that in the United States the food system accounts for more than 20 percent of total commercial energy consumption. Of that share, it is estimated that farm production accounts for about 18 percent and food processing for nearly 30 percent. The remainder is consumed in distribution, commercial and home refrigeration and meal preparation. This example illustrates how one large California food processor adjusted to higher prices for fossil fuels by conservation and a shift to lower-value biomass energy sources.

The Setting

2. California's canning industry is the largest regional concentration of this type of food processing in the world. Canned tomatoes from California account for about 85 percent of the national supply and California is the only United States' source of cling peaches and fruit cocktail. Peak seasonal employment by the industry provides jobs for 60,000 people in the state. Aggregate industry sales revenues are estimated at upwards of $3 billion annually. Purchases of these fruits and vegetables by the industry account for about 5 percent of the state's total farm revenues.

1/ Adapted from a paper by Mr. William F. Allewelt, Jr., President, Tri-Valley Growers, Inc., presented at the Agri-Energy Round Table, New Orleans, Louisiana, February 1980.

3. In the canning industry, energy use is dominated by boiler heating requirements. Until 1974, the California industry's boilers were fueled almost exclusively by natural gas. Natural gas was favored as a clean burning heat source that was relatively cheap since it was efficiently delivered in the summertime "off season" over a transmission system established to supply higher demands in the winter months from residential users.

4. In the period immediately following the oil embargo in 1973, regulators signaled a progressive reduction of natural gas allocations to California canners, and a possible total cut-off by the late 1970s. Fuel oil appeared to be the only practical alternative. Examination of this alternative exposed several major difficulties. It was established that fuel oil usage by the canning industry in the peak August-September period would outstrip what could be supplied by the total production capacity of all West Coast refineries. This meant that extensive storage systems would have to be established by the canneries to build up supplies in the off-season. However, municipal zoning limitations prevented the installation of storage tanks by canneries located in some urban areas. Moreover, air quality standards made it evident that some canneries simply could not use oil for their boilers.

<u>A Course of Action</u>

5. Faced with this situation, Tri-Valley Growers, a major fruit and vegetable canner in California, began its planning to establish a course of action that would minimize risks of an absolute cut-off of energy sources and provide for least cost procurement of alternative supplies. The

initial point of attack was to systematically audit every element of energy use to identify immediate conservation opportunities. It was soon confirmed that significant savings could be achieved under new more rigorous standards for energy conservation. Through a combination of some simple steps and major capital investments, Tri-Valley was able to achieve more than a 20 percent improvement in the efficiency of energy use in operations as compared to pre-1974 standards. It is expected that this can be improved upon over time as older installations are phased out and replaced by more energy efficient equipment.

6. A casualty of this energy audit was termination of processing operations on three commodities for which peculiarities of frequent plant start-ups and shut-downs required substantial nonproductive use of energy. This action responded to the reality that as energy costs increased, profitability would decline rapidly for these products for which higher costs could not be passed on to consumers through higher prices.

7. The next phase was to prepare as rapidly as was economically feasible to use fuel oil as an alternate boiler fuel. The siting of Tri-Valley canneries in rural locations enabled a somewhat less restrictive set of regulatory conditions on boiler operations than was faced by other processors. Adquate storage space for fuel oil was available and on-site storage at all locations was expanded. A forty-acre parcel of land located adjacent to the company's main plant was acquired for future storage. All boilers adaptable to optional use of natural gas or oil were converted to fuel oil.

Toward Biomass Energy

8. By a quirk of pricing of the regulatery commission for California's public utilities, fuel oil proved to be less costly to Tri-Valley

than natural gas. Thus, although natural gas continues to be available to California's canning industry, conversion to oil has been economically advantageous. However, since 1973, natural gas rates to commercial users in California have increased nearly 80 percent. In view of these steady price increases, a third and continuing phase of Tri-Valley's energy program has been a search for technology that will enable the firm to utilize replaceable fuels in its boilers. Tri-Valley annually generates more than 15,000 tons of woody refuse material with a heating value of about 8,000 BTU per pound. This includes peach, olive, cherry and apricot pits, and almond and walnut shells. Nearly 35,000 tons of other waste vegetative material also have been disposed of annually. Until recently, this material was considered to be largely without economic value.

9. A first step to utilize these renewable energy sources was to install a scroll-type burner system in a conventional water tube boiler. Peach pits are ground to a 1/32 inch particle size and burned in this boiler in suspension with 20 percent or less of natural gas or oil as an auxiliary fuel. This boiler produces in a summer's operation about 10 percent of the total steam load required by all of Tri-Valley's factories operated seasonally. It consumes 4,000 tons of peach pits annually, nearly the total quantity deriving from the firm's peach canning operations.

10. A recent relocation of one of Tri-Valley's canning operations necessitated the purchase of a new boiler capable of producing 50,000 lbs of steam per hour. The principal canned products manufactured at this plant are produced from dried beans. These operations are not seasonal, but conducted on a year-round basis. The boiler selected for this

installation will operate exclusively on biomass material and will utilize particle sizes as great as 3" in diameter and with moisture contents as high as 50 percent. In maximum operation it will consume more than 25,000 tons of biomass annually. This boiler is an adaptation of the type used commonly with logging and milling installations where wood scraps are the fuel source.

Co-generation of Electricity

11. Because this boiler operates nearly year-round, it was logical to examine its capability for co-generation of electricity. Determinations were encouraging and it was subsequently decided to fit it to supply steam sufficient to generate 4,500 KW/hour. Tri-Valley's consumption of electricity is about 40 million KW on an annual basis, but ranges from a low of less than 2 million per month in the winter period to a peak of 9 million in August. The potential annual output of this co-generation system would supply about two-thirds of the firm's total electrical needs, but the system would not conform to seasonal demand loads. Tri-Valley is working with the public utilities that presently supply its operations for a "swapping" arrangement under which the utility would absorb Tri-Valley's power surplus in low demand periods and return it during times of high demand.

Future Development

12. Tri-Valley is examining the feasibility of the manufacture of liquid fuel. The firm already possess most of the critical ingredients for this venture with a biomass-fueled steam source, co-generation capabilities and a seasonal supply of feed stock from cannery waste. It is exploring