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# THE FOURTH A.C. NEISH MEMORIAL LECTURE
# FOOD, ENERGY, AND THE ENVIRONMENT

David Pimentel*

## Introduction

At present the world population is 4.3 billion ($10^9$) and is projected to reach 6 to 7 billion by the turn of the century (NAS 1977). The population is expected to continue growing and shortly after 2100 reach anywhere from 10 to 16 billion, a level 2 to 4 times the present number (Fig 1). Population numbers of this magnitude can be expected to strain the resources of the world to provide adequate food and other essentials for society. Competition for land and water by agriculture and other sectors of society will be intensified. Demands will increase for fossil energy which is vital to agriculture, public health, industry, and other sectors of human society.

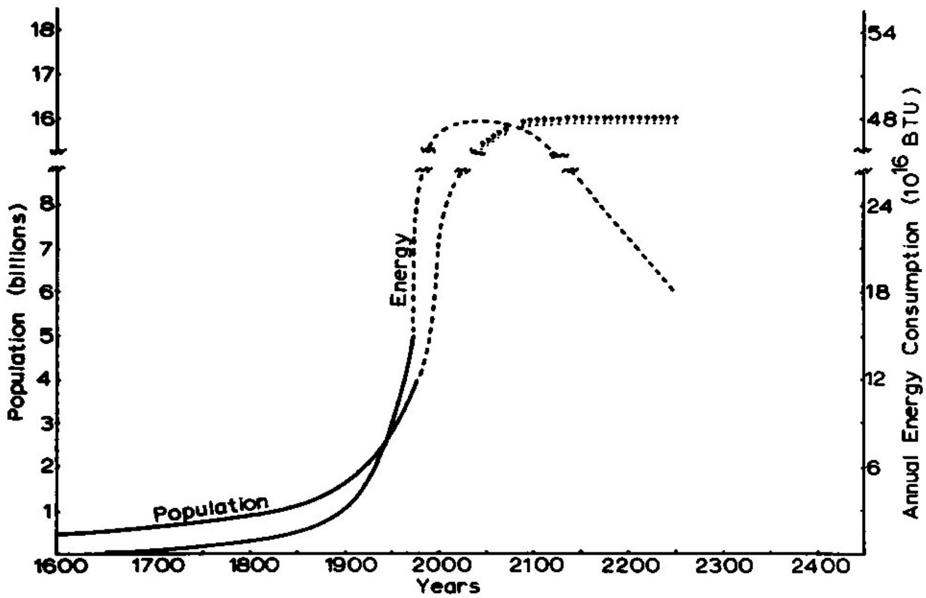


Fig 1. Estimated world population numbers (__________) from 1600 to 1975 and projected numbers ( . . . . ) (????) to the year 2250. Estimated fossil fuel consumption (__________) from 1650 to 1975 and projected ( . . . . ) to the year 2250 (after Pimentel et al. 1975).

* *College of Agriculture and Life Sciences, Cornell University, Ithaca, N.Y. 14853*

Before we can even attempt to find answers to these vast supply/demand problems concerning our vital resources, the interdependencies of food, land, water, and energy and the entire world ecosystem must be understood. This is because each in a way is related to another and each is an integral part of the whole system. Discussions based on only energy or only land needs in the food system are not effective because all are functionally interrelated components of what we call the human ecosystem (Fig 2).

Energy use in the agricultural sector, especially in industrialized nations, is increasing more rapidly than in any other sector of the economy (Leach 1976; Pimentel & Pimentel 1979). In agricultural systems, energy is used to produce fertilizers, pesticides, and farm machinery. Also, large quantities of fuel are used directly in the operation of the farm machinery.

In addition to greater use of fossil energy, increasing crop and livestock yields through intensive management practices are resulting in serious degradation of land and water resources as well as contributing to environmental pollution. Indeed, soil erosion is a serious problem throughout the world and, even now, is responsible for significant reductions in the productivity of this valuable natural resource (Eckholm 1976; Pimentel et al. 1976).

Of concern also is that water resources are being mined extensively in many parts of the world (Dunne & Leopold 1978). In addition, current irrigation practices are causing salinization and waterlogging of some agricultural soils (Eckholm 1976; Pimentel & Pimentel 1979). Both conditions reduce the productivity of the soil. The widespread use of fertilizers and pesticides to increase yields is causing pollution of the natural environment, including vital water resources. Further, in some areas agricultural chemicals have become a serious hazard to public health as well as to valuable fish, birds, and insects (NAS 1977).

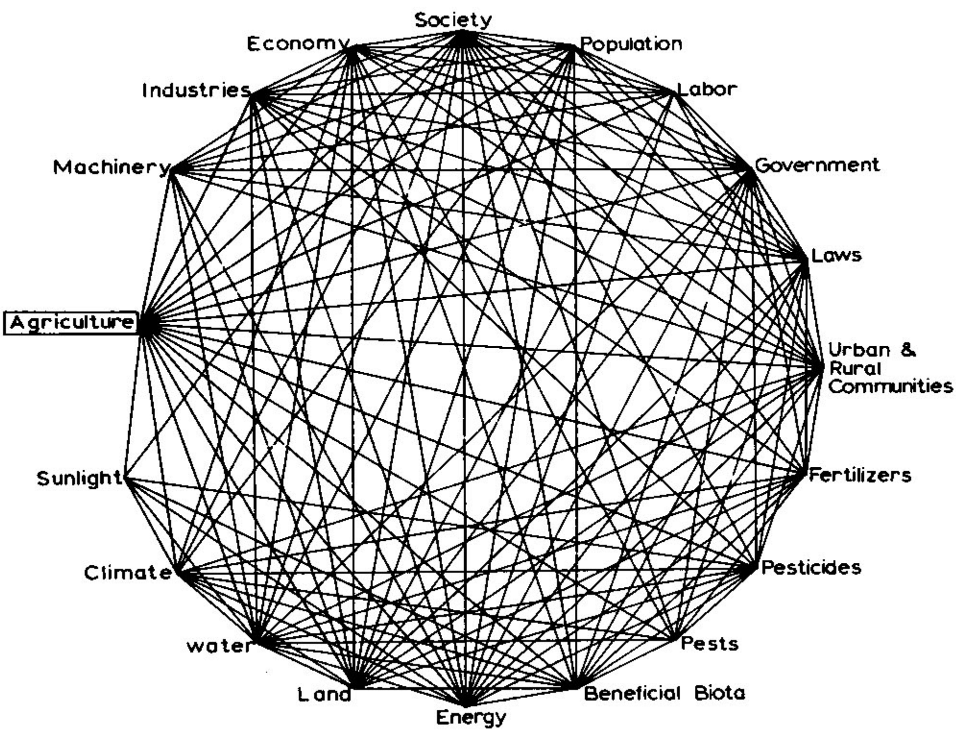


Fig 2. The interdependency of agriculture and the ecological and social system.

Human society can no longer afford to waste energy and degrade land and water resources while producing its food supply. If society expects to meet its future food needs, it must start now to modify present practices, to develop alternatives to present practices, and to develop new strategies of agricultural production that will enable society to meet the critical needs for human food in the coming decades. In this paper, I examine current energy, land, and water resource use in the food systems of industrial societies and then analyze alternative technologies that have the potential for an ecologically sound food system, one with a conservative energy input.

## Energy Use in the Agricultural and Food System of North America

*Crop and Livestock Production*

In industrialized nations, fossil energy has become as vital a resource for crop and livestock production as land and water. Yearly, each North American consumes as food the equivalent of 1500 *l* of oil. This amount of energy in the form of food represents about 17% of all the fossil energy used in Canada and the United States (Pimentel & Pimentel 1979). The energy inputs for the food system of Europe are similar to North America. The United Kingdom used 16% for their food system while Sweden uses 10 to 20% for only production and distribution (Leach 1976; Olsson 1978). Actual agricultural production uses about 6% of total United States energy and in the United Kingdom about 5% is used (Leach 1976). Food processing, packaging, transport, storage, and home preparation use the remainer.

The major uses of energy in agricultural production are for fuel to run farm machinery and for the production of fertilizers and pesticides (Table 1). Both pesticides and nitrogen fertilizers are produced directly from energy resources.

**Table I.** Energy inputs per hectare in United States corn production (Pimentel & Pimentel 1979).

| **Inputs** | **Quantity/ha** | | **kcal/ha** |
|---|---|---|---|
| Labor | 12 | hrs | 5,580 |
| Machinery | 31 | kg | 558,000 |
| Diesel | 112 | *l* | 1,278,368 |
| Nitrogen | 128 | kg | 1,881,600 |
| Phosphorus | 72 | kg | 216,000 |
| Potassium | 80 | kg | 128,000 |
| Limestone | 100 | kg | 31,500 |
| Seeds | 21 | kg | 525,000 |
| Irrigation | 780,000 | kcal | 780,000 |
| Insecticides | 1 | kg | 86,910 |
| Herbicides | 2 | kg | 199,820 |
| Drying | 426,341 | kcal | 426,341 |
| Electricity | 380,000 | kcal | 380,000 |
| Transportation | 136 | kg | 34,952 |
| Total | | | 6,532,071 |
| **Outputs** | | | |
| Corn Yield | 5,394 | kg | 19,148,700 |
| kcal output/kcal input | | | 2.93 |
| Protein yield | 485 | kg | |

**Table II.** Energy inputs and returns for various food and feed crops produced per hectare in the United States (from Pimentel & Pimentel 1979).

| Crop | Crop Yield (kg) | Yield in Protein (kg) | Crop Yield in Food Energy ($10^6$ kcal) | Fossil Energy Input for Production ($10^6$ kcal) | kcal Food/feed Output/kcal Fossil Energy Input | Labor Input (manhours) |
|---|---|---|---|---|---|---|
| Corn | 5,400 | 485 | 19.1 | 6.5 | 2.9 | 12 |
| Wheat | 2,060 | 247 | 6.8 | 2.8 | 2.4 | 7 |
| Oats | 1,730 | 242 | 6.7 | 2.2 | 3.1 | 6 |
| Rice | 6,160 | 462 | 22.4 | 14.4 | 1.6 | 17 |
| Sorghum | 3,030 | 344 | 10.5 | 5.4 | 2.0 | 12 |
| Soybean | 1,880 | 640 | 7.6 | 1.8 | 4.2 | 10 |
| Beans, dry | 1,460 | 325 | 5.0 | 2.7 | 1.8 | 10 |
| Peanuts | 3,720 | 320 | 15.3 | 10.9 | 1.4 | 19 |
| Apples | 17,920 | 36 | 9.6 | 18.0 | 0.5 | 175 |
| Oranges | 19,040 | 193 | 6.8 | 18.3 | 0.4 | 173 |
| Potato | 34,380 | 722 | 19.7 | 16.0 | 1.2 | 35 |
| Spinach | 11,200 | 358 | 2.9 | 12.8 | 0.2 | 56 |
| Tomato | 49,620 | 496 | 9.9 | 16.6 | 0.6 | 165 |
| Brussels Sprouts | 12,320 | 604 | 5.5 | 8.1 | 0.7 | 60 |
| Alfalfa | 6,830 (dry) | 1,127 | 15.4 | 2.5 | 6.2 | 13 |
| Tame Hay | 5,000 (dry) | 200 | 8.6 | 1.7 | 5.0 | 16 |
| Corn Silage | 31,020 | 393 | 25.3 | 6.3 | 4.0 | 15 |

**Table III.** Energy inputs and returns per hectare for various livestock production systems in the United States (Pimentel 1980).

| Livestock | Animal Product Yield (kg) | Yield in Protein (kg) | Protein as kcal ($10^3$) | Fossil Energy Input for Production ($10^6$ kcal) | kcal Fossil Energy Input/ kcal Protein Output | Labor Input (manhours) |
|---|---|---|---|---|---|---|
| Broilers | 2008 | 186 | 744 | 7.3 | 9.8 | 7 |
| Eggs | 910 | 104 | 416 | 7.4 | 17.8 | 19 |
| Pork | 490 | 35 | 140 | 6.0 | 42.9 | 11 |
| Sheep (grass-fed) | 7 | 0.2 | 0.8 | 0.07 | 87.5 | 0.2 |
| Dairy | 3270 | 114 | 457 | 5.4 | 11.8 | 51 |
| Beef | 60 | 6 | 24 | 0.6 | 25.0 | 2 |
| Dairy (grass-fed) | 3260 | 114 | 457 | 3.3 | 7.2 | 50 |
| Beef (grass-fed) | 54 | 5 | 20 | 0.5 | 25.0 | 2 |
| Catfish | 2783 | 384 | 1536 | 52.5 | 34.2 | 55 |

Pesticides are made primarily from petroleum while nitrogen fertilizer is made primarily from natural gas.

Food crops vary as to the amount of energy used in their production. Corn, a fairly typical grain crop, requires about 600 ℓ of gasoline equivalents per hectare. This amounts to an expenditure of about 1 cal of fossil energy for 3 cal of corn produced (Table I). Most grains produced in Canada and the United States yield from 2 to 3 cal of grain per fossil-energy calorie expended (Table II).

Producing other types of food crops, however, is not as energy efficient as grain production. For example, in apple and orange production, about 2 cal of fossil energy are expended per 1 cal of fruit produced (Table II). Culturing vegetables requires from 1 to 5 cal energy input per 1 food calorie produced (Table II).

Although fruits and vegetables require larger energy inputs per food calorie than grain, neither are as energy-expensive as producing animal protein. From 10 to 90 kcal of fossil energy are required to produce 1 kcal of animal protein (Tables II, III). The major reason that animal-protein products are significantly more energy-expensive than plant-protein foods is that forage and grain crops have to be grown, harvested, and then fed to the animals. Also,the forage and feed that maintain the breeding herd are additional energy costs. For example, about 1.3 head of breeding cattle must be maintained to produce 1 calf per year (Pimentel et al. 1975). Of importance is the fact that many of the grains fed to animals are entirely suitable for human consumption. In industrialized nations, about 90% of the grain produced is cycled through livestock to produce milk, eggs, and meat.

Plant-protein production per hectare, especially legume crops like soybeans, contrasts greatly with animal-protein production. For example, about 20 times more protein is produced raising soybeans than producing pork (Tables II, III). Note also that energy inputs for soybean protein are about one-twentieth that for pork-protein production.

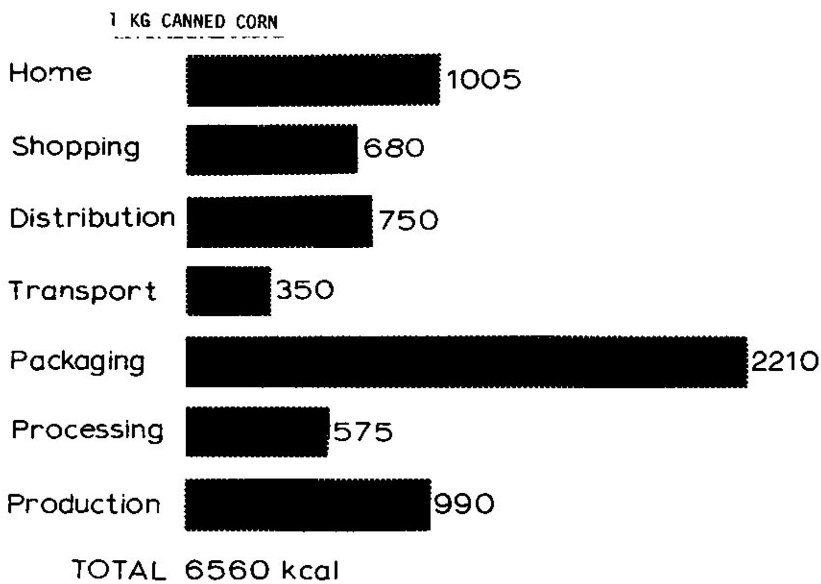


Fig 3. Energy inputs for a 1-kg can of sweet corn. (Note, distribution includes storage and home includes refrigeration, cooking, preparation, and washing. One kg of corn contains 825 kcal of food energy.)

*Food Processing and Packaging*

Once food is produced it is usually packaged to facilitate wide distribution in the marketplace. In addition, yields of large harvests of perishable foods like fruits and vegetables are frequently processed for use in seasons when fresh crops are unavailable. In the industrialized nations, the fossil-energy inputs are substantial for packaging and also for preserving and processing foods and then placing them in suitable storage (Pimentel & Pimentel 1979). For example, producing sweet corn on the farm uses only about 10% of the total energy used to produce, process, market, and cook 1 kg of canned, sweet corn (Fig 3). Most of the approximately 2785 kcal that are expended in processing are used up to make the steel can. Specifically, the heat-processing and canning of the corn requires only 575 kcal, while the production of the steel can itself requires about 2210 kcal.

Foods are also frozen to preserve them for future use. The fossil-energy inputs for processing by freezing are significantly greater than for processing for canning, averaging 1815 kcal/kg for frozen food compared with only 575 kcal/kg for canned (Figs 3, 4). This is because processing by canning requires only heating and packaging, while freezing may require brief heating (blanching), then cooling, packaging, and freezing at –18° C or lower.

Furthermore, once processed, canned foods are stored at room temperature (actually, slightly cooler is recommended), whereas frozen food must be kept in freezers at temperatures of –18° C or lower. Maintaining such a low temperature requires about 265 kcal/kg per month of storage (USBC 1975). As frozen foods are stored about 6 months, this energy cost must be added to the freezing cost, making the total energy input for frozen food much greater than that for canned food (Figs 3, 4). Fortunately, however, the moisture-resistant plastic and paper con-

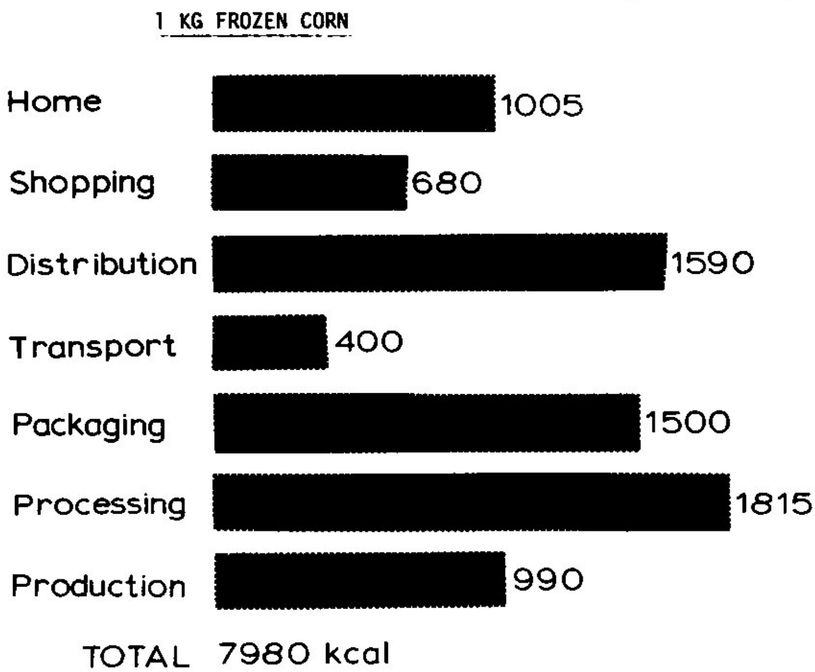


Fig 4. Energy inputs for 1-kg frozen package of sweet corn. (Note, distribution includes storage and home includes refrigeration, cooking, preparation, and washing. One kg of corn contains 825 kcal of food energy.)

tainers for frozen foods require less energy to manufacture than the metal cans or glass jars used for canned food. Another important consideration is that the overall nutritive value and palatability of frozen foods, especially vegetables, are superior to canned foods.

Another way of preserving foods is drying. If done in fossil-fueled ovens, drying is expensive but if done by the sun, the external energy cost is eliminated. In suitable climates, solar drying of food exposed on simple wooden racks is one of the least costly processes for preserving fruits, vegetables, and meats. Salting, another way of processing vegetables and meats for safe storage, was used in the past and is still used today. Salting is also one of the least energy-intensive methods of processing foods requiring only 23 kcal/kg of meat processed (Pimentel & Pimentel 1979). This has some disadvantages, especially related to palatibility and ultimate salt content of the rehydrated food. For some individuals the high residual sodium content of foods may be a health problem.

Two of the most energy-intensive methods of processing foods are freeze-drying and smoking. Freeze-drying, which involves both freezing and drying processes, requires about 3540 kcal/kg of food processed. Smoking uses about 4500 kcal from wood per kilogram of food smoked (Casper 1977; Pimentel & Pimentel 1979).

*Transport of Food*

Movement of food from farm to home is an essential part of the food system. Transport of food products is estimated to be about 60% by truck and about 40% by rail (Pimentel & Pimentel 1979). Based on data for energy requirements of truck and rail transport, the energy required to move 1 kg of food product is calculated to be about 0.5 kcal/km. Assuming 640 km is the average distance that foods are moved, then the energy input per kilogram moved is about 350 kcal.

Although the 350 kcal/kg of food transported is an average figure, frequently much greater energy inputs are required for transporting foods to the marketplace. Consider the journey of a 0.5-kg head of lettuce that has a food energy value of only about 50 kcal. When this lettuce is transported by truck, for example, from California to New York, a distance of 4827 km, the energy expended is about 1800 kcal of fossil energy. This means that just for transport, about 36 kcal of fossil energy are expended per kilocalorie of food energy in the lettuce.

*Cooking and Preparing Foods*

Foods for human consumption are cooked, heated, and/or cooled and all of these operations require the expenditure of energy. In industrialized nations, an estimated 9000 kcal of fossil energy are used per person per day merely for home refrigeration and cooking of foods by gas or electricity (Leach 1976; Pimentel & Pimentel 1979). About 5000 kcal are required, in addition, for washing and for the paper products used in serving. As the per capita consumption of food is 3500 kcal/day, this is 4 cal of energy expended to prepare and serve each calorie of food consumed.

Cooking over an open wood fire requires even more energy than either gas or electricity. Heating food over an open wood fire is only 8 to 10% efficient in transferring heat to food (Stanford 1977) and constitutes an inefficient and costly use of wood fuel. In contrast, the electric stove is 20% efficient in transferring energy to food when the production of electricity itself is taken into account (Pimentel & Pimentel 1979). Of the 3, gas stoves are the best with an efficiency of 33%. Thus, both the kind of fuel available and equipment used will influence the amount of energy needed to heat process a given amount of food.

*Environmental Impacts*

In addition to consuming large amounts of fossil energy, the industrialized agricultural production system is causing serious environmental problems. Vast land areas are devoted to crops and pastures and much of this is exposed to agricultural chemicals like pesticides and fertilizers. While these chemicals are helpful in increasing crop yields, they also find their way into the environment and cause problems there.

For example, each year in the United States, pesticides cause a minimum of $1 billion damage to the environment and public health (Pimentel et al. 1979). From the public health standpoint there is concern about the 45,000 Americans who are poisoned each year with pesticides and the 200 of these who die. Other major problems caused by pesticides include: livestock poisonings; increased control expenses resulting from the destruction of natural enemies and pesticide resistance; crop pollination problems and honeybee losses; crop losses; fish and wildlife losses; and various governmental expenditures used to reduce environmental and social costs resulting from widespread pesticide use (Pimentel et al. 1979).

Nitrogen fertilizer, another major agricultural chemical, often leaches from the land into the ground water and contaminates it. As a result, the contamination of drinking water with nitrates and nitrites can be at high enough levels to be hazardous to humans, especially young children (PSAC 1965). Further, the addition of nitrogen to lakes and streams may result in increased eutrophication (PSAC 1965; Beasley 1972). Thus, the heavy use of nitrogen fertilizers and other agricultural chemicals is causing serious environmental problems.

In addition to agricultural chemicals, soils are eroded from agricultural land in Canada and the United States and are washed into streams, reservoirs, and lakes. The soil sediments have many diverse environmental effects. When sediments deposited into the water bodies impede water flow, they may have to be dredged from these bodies. Each year in the United States dredging costs about $500 million (Nelson 1968) plus large energy inputs needed to power the dredging apparatus for removing the soil.

Extensive sedimentation reduces the depth of light penetration into the water and thereby may reduce or limit the growth of plants and the subsequent productivity of the aquatic system. In addition, soil sediments may also have a detrimental effect upon many kinds of fish (Beasley 1972).

The most far-reaching effect is that an estimated 3 billion ($10^9$) tonnes of soil are washed from United States agricultural lands alone (Pimentel et al. 1976). In fact, agricultural land is the major source of the sediments in Canada and the United States that are washed into aquatic systems.

A recent estimate is that United States agricultural land has lost about a third of its topsoil (NAS 1970). The soil-erosion problem in Canadian agriculture appears to be equally serious. The annual loss of soil from row crops such as corn in the United States is about 45 tonnes/ha (Pimentel et al. 1976). The significant fact is that for each 2.5 cm of soil that is lost from the land, productivity of the land is reduced. In the case of corn with a soil depth of less than 30 cm, each 2.5-cm loss of soil reduces corn yields more than 250 kg/ha (Pimentel et al. 1976). To offset this loss of topsoil and reduced productivity, more fertilizers and other energy-related inputs are needed to maintain yields. Indeed, to compensate for present deterioration, about 47 *l* of gasoline equivalents have to be applied to the crop in the form of fertilizers and other inputs just to maintain current high yields (Pimentel et al. 1976).

The extent of soil erosion is directly related to rapid water runoff from agricultural lands. Water runoff not only carries with it soil, fertilizers, and pesticides, but it also has other far-reaching impacts on agriculture and society. First, the water that runs off the land is no longer available for crop production and thus reduces potential yields for that location (Pimentel et al. 1976). Then, too, rapid water runoff often results in flooding other crops located in lower areas. The estimate is that United States agriculture loses several million dollars in crops annually because of water runoff (USDA 1965). At times, water runoff contributes to serious flooding problems in rural and urban areas in certain regions of the nation.

In addition to all the environmental effects associated with agriculture that have been discussed thus far, other problems exist. Agriculture in the United States consumes more water for irrigation than all other uses of water combined. One study reports that agriculture consumes about 83% of all water withdrawn from streams and lakes in the United States each year, while industry and urban communities consume only 17% (NWC 1973). With this large consumption and increasing demand for water, agriculture will have increasing conflict with other sectors of society for water.

In addition, the clearing of land for crop and livestock production has a detrimental effect on the natural biota. This is because the number and kinds of species that survive in an agricultural system are much fewer than those associated with the natural vegetation.

## Lifestyles and Dietary Regimes

Diets in Canada and the United States are typically high-calorie and high-protein. In the United States, for instance, daily per capita food energy consumed is about 3500 kcal (USDA 1980). The Recommended Daily Allowance is about 2350 kcal or 2700 for males and 2000 for females (NAS 1979). The 3500-kcal intake is 1 factor contributing to obesity, a major health problem in the United States (U.S. Senate 1977).

Not only are the diets typical of Canada and the United States high in calories but they are also high in protein, especially animal protein. In the United States about 70 g of animal protein are consumed per capita per day and in addition, about 32 g of plant protein are eaten. The total daily intake is high, 102 g (USDA 1977). Contrast this with the FAO recommendation that 41 g per day is an adequate level of protein intake (FAO 1973). The average total-protein consumption in the United States and Europe is more than twice this recommendation.

To supply the large quantity of animal protein that is consumed in the United States, over 3 billion livestock are maintained; these animals outweigh the United States human population more than 4-fold (Pimentel et al. 1975). In addition to the large amount of forage that is fed the livestock population, they annually consume 60 to 90% of the total grain used in industrialized nations (UKMAFF 1976; USDA 1977). Although forage is unsuitable for human consumption, the grains are excellent foods for humans.

Providing feed for these animals requires land. In fact, in Canada and the United States several million hectares of land are used merely to grow forage and grains for livestock. At present in the United States about 130 million tonnes of grain, an equivalent of 605 kg grain per person, are fed animals to provide meat and other animal products for the high animal-protein diets consumed.

The total fossil energy expended to maintain the United States livestock population is $413 \times 10^{12}$ kcal and includes the cost of maintaining land needed for pasture and grain production and the husbandry of the livestock (Pimentel et al. 1980a). This is in sharp contrast with all other crops produced in the United States, for which an average of $700 \times 10^{12}$ kcal of energy are expended; this represents a significant quantity of energy only for production. When energy costs of processing, transport, and preparation and cooking are included, the total increases to about 3.3 x $10^{15}$ kcal/yr. This is indeed high and amounts to about 17% of the total energy economy of the United States and, as mentioned, is similar for Canada. A change in eating patterns to consume less meat and other animal products in industrialized nations might improve human health and certainly would significantly reduce the land and energy inputs required in the food system.

With this in mind it is interesting to consider what would happen if the United States moved from a grain/grass-fed livestock system to only a grass-fed system. Analyses show that the total amount of animal protein that could be produced would be reduced by nearly one-half (Pimentel et al. 1980a). As a result, daily per capita protein consumption in the United States under this system would be reduced from 102 g to about 70 g/day (Pimentel et al. 1980a). Even so, the 70 g/day is still significantly higher than the 41-g level recommended by FAO.

A change to a grass-fed livestock system would release 130 million tonnes of grain for direct human consumption and reduce energy input in production by 60% (Pimentel et al. 1980a). This amount of grain could feed about 400 million humans or nearly twice the current population of the United States or 17 times the population of Canada.

Indeed, cycling plant protein through animals is costly in both land and energy, and is an inefficient way to produce protein. In all probability, such a drastic change in production patterns will not be necessary, but if land and energy resources become scarce in the United States and Europe some modification of present protein production will need to be considered.

A comparison of the energy requirements to produce a high plant-protein diet versus a high animal-protein diet provides helpful insight into some of the differences. High plant-protein diets or vegetarian diets are usually of 2 major types: the lacto-ovo diet that includes eggs, milk, and milk products and the complete vegetarian diet that includes only plant proteins.

The following example illustrates some of the differences these dietary regimes have in fossil fuel requirements for production. For these calculations the average daily calorie food intake of 3300 kcal is held constant for the 3 diets. The amount of protein is over 100 g/day in the high animal protein or nonvegetarian diet and is about 80 g in the all-vegetarian diet.

Nearly twice as much fossil energy is expended for food production in a lacto-ovo vegetarian diet than is expended for the complete vegetarian (Fig 5). For the nonvegetarian diet, the fossil energy input is more than 3-fold that of the complete vegetarian diet.

Based on these sample calculations, the complete vegetarian diet is more economical in terms of fossil energy than either of the other 2 types of diets. Energy expenditure is not the only factor to be considered when dietary choices are made. Personal choices are often based on social and cultural attitudes as well as desirable palatability characteristics. Another major consideration is that there can be significant nutritional differences between the pure vegetarian diet and diets that include animal products. This is because vitamin $B_{12}$, an essential nutrient, is lacking in pure vegetarian diets and must be taken as a dietary supplement. Further, the quality of protein consumed may not be adequate because that depends on the combination of plant proteins consumed. When the essential amino acids of plant foods are complemented, then protein quality of a vegetarian diet will be satisfactory. A diet of all plant foods is usually of greater volume and bulk, making it difficult for young children and women to consume

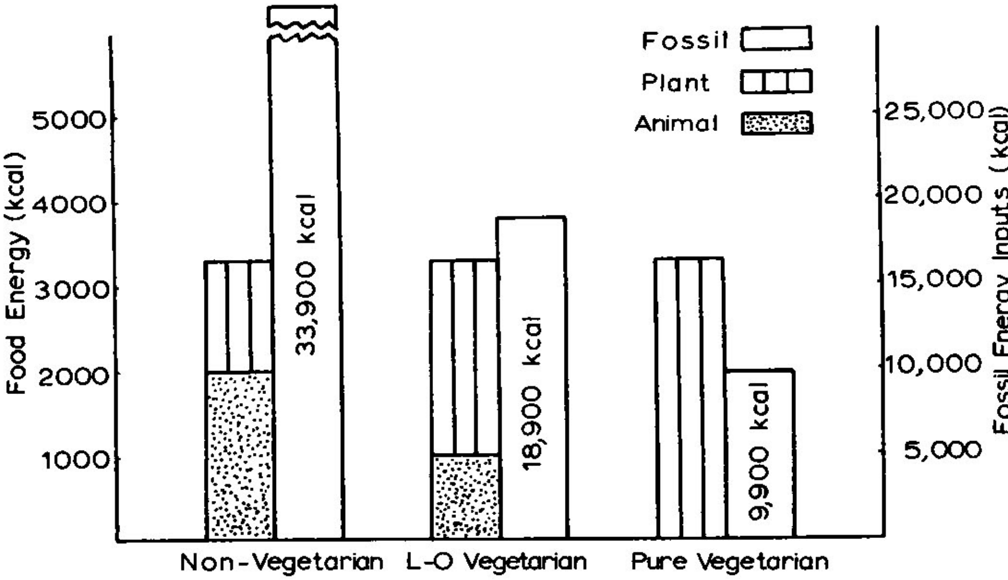


Fig 5. Daily food energy intake of pure vegetarians, l-o (lacto-ovo) vegetarians, and nonvegetarians and the calculated fossil energy inputs to produce these diets under United States conditions.

the quantities necessary to meet all nutritional needs. In addition, infants, rapidly growing adolescents, pregnant and lactating women, and other nutritionally vulnerable groups consuming pure vegetarian diets may need nutritional supplements of vitamins A and D and iodine.

Although these examples are based on limited data, they suggest that significant reductions in energy use as well as land and water resource use are possible by modifying diets and eating patterns. Further reductions in quantity of energy and other resources are possible by reducing the total caloric intake of the population from 3500 kcal to something less than 2500 kcal. Note that optimum calorie intake for an individual is based on his or her basal metabolic rate, physical activity, and the effect of food consumed (Guthrie 1979).

How much fossil energy could be saved in the food systems of industrialized nations like Canada and the United States and have an ecologically and energetically sustainable system? My estimate is that as much as 50% could be saved, while maintaining high crop yields and improved environmental quality.

## Biomass as an Energy Source

In considering all possible energy resources, conversion of biomass energy often has been suggested as a substantial energy source. Today energy from biomass conversion amounts to less than 1% of the United States energy supply, whereas in 1850 about 91% of the energy supply came from biomass in the form of fuel wood (EOP 1977). Of course, in 1850 the United States population was only about 23 million or about one-tenth the current level of 215 million, and per capita energy consumption was about one-fifth current consumption. Today, wood supplies a mere 1% of United States and 4% of Canadian energy needs (USBC 1977; CYB 1977). In certain regions wood is an important fuel resource.

The United States in 1979 consumed more than 19 x $10^{15}$ kcal. This is more than the total sunlight energy fixed by photosynthesis in the United States, about 13.5 x $10^{15}$ kcal (Fig 6).

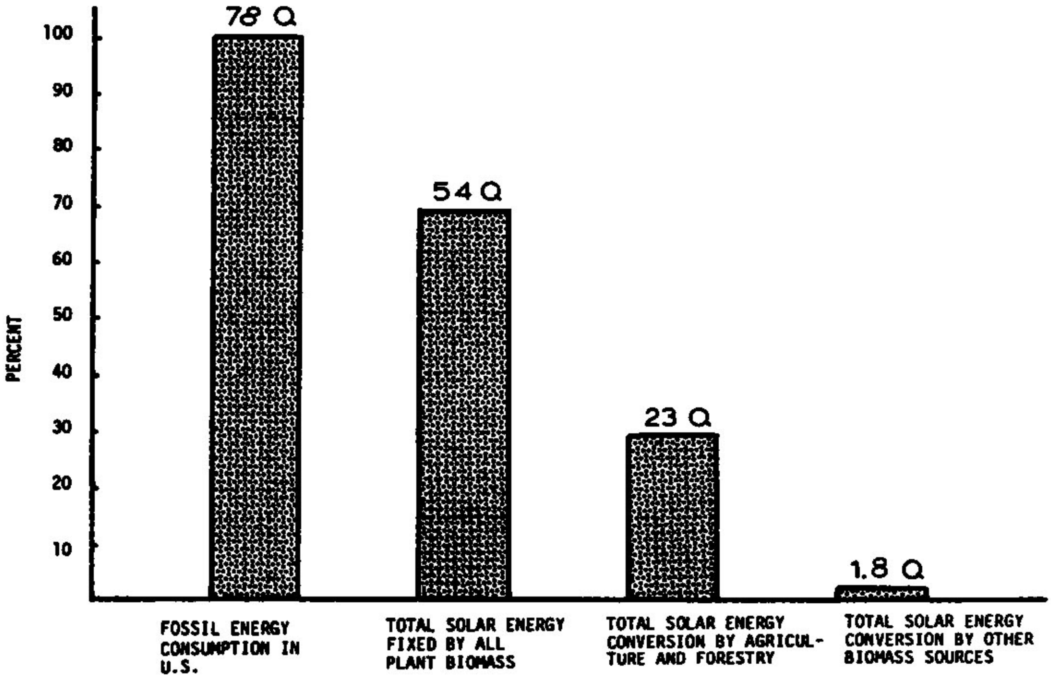


Fig 6. Biological solar energy conversion compared with fossil energy consumption in the United States; all data calculated for 1 yr.

About half of the total solar energy fixed is harvested in the form of agricultural and forestry products. This has several significant implications. First, about half of all the solar energy fixed by plants in the United States already is being harvested in the form of food, fiber, and forest. Thus, this energy source is a vital factor in the United States economy. Further, the value of solar-energy conversion in agricultural and forestry production must be fully recognized, and efforts to utilize the remaining biomass directly for energy conversion must not reduce the effectiveness of agriculture and forestry. This also applies to Canada.

A wide range of proposals exists for the utilization of crop remains for conversion of biomass energy (Alich & Inman 1974; Alich et al. 1976). An analysis of the agricultural, environmental, and energetic aspects of the use of crop remains suggests that little or none of these remains should be used for biomass-energy conversion (Pimentel et al. 1978). In fact, the evidence suggests that crop remains left on the land function to prevent sediment runoff, to conserve soil and water, to maintain soil organic matter and soil structure, and to prevent nutrient (N, P, K, Ca, etc.) loss. Energetically the removal of most crop remains will cost Canada and the United States more in terms of energy in the long run than any short-term gains that are currently possible (Pimentel et al. 1980b). The environmental impact of utilizing forest residues is less than using crop residues but there are still problems in utilizing forest residues (Pimentel et al. 1980b).

Converting forest residues into various fuel sources will deplete nutrients at forest sites and increase soil erosion. Careful forest management practices can reduce the impact on forests if forest residues are utilized.

Canada and the United States are using some grain for producing gasohol (DOE 1980; OTA 1980). If oil or natural gas are employed in the fermentation/distillation process of making ethanol, then the inputs of high-grade energy are 114,000 BTU to produce 1 gal (Ca. 3.79 *l*) of high-grade ethanol with an energy value of 76,000 BTU (DOE 1980). The net energy loss is 38,000 BTU/gal produced. This net loss can be reduced by more than half if credit is given for the by-product animal feed (11,000 BTU) and refinery credit (8,000 BTU). However, there is still a net loss.

If the fermentation/distillation plants are fired with coal, then a process of converting low-grade fuel (coal) into high-grade fuel (ethanol) has advantages. By this process then, for every gallon of low-grade fuel invested, about 2 gal of high-grade fuel are obtained (DOE 1980). The cost of a net gallon (3.79 *l* of ethanol was calculated to be $2.14, which is expensive compared with current gasoline prices. Ethanol is made competitive with gasoline by federal and state subsidies that may run as high as $1.13/gal.

The subsidies are paid by the public (taxes). The public pays a second time in higher meat, milk, and egg prices. As mentioned earlier, 90% of United States grain is fed to livestock. Livestock are fed surplus grain, the same surplus grain that gasohol producers are drawing on (DOE 1980). Increased demand for this surplus grain will raise the price of grains. Clearly, high-priced grain will result in higher prices paid for meat, milk, and eggs.

Biomass resources, including grains, should be utilized to help supply fuel needs of Canada and the United States. Although the contribution from biomass may be only 5 to 10% of these nations' needs, every resource should be carefully used. Utilizing biomass as an energy source has numerous environmental, economic, and social costs associated, hence, great care must be exercised in making use of our valuable biomass resources.

## Conclusion

Sufficient food is being produced in the world today to feed its population adequately if it were effectively distributed. With the resources of land, water, and energy already in short supply in many parts of the world, it may not be possible to feed the world population adequately in the future.

No longer can we afford to make ad hoc decisions affecting isolated sections of the world or even segments of society within a nation. The scope of the problems facing us now is all-encompassing. They require first an understanding of the interdependencies of food production, and supplies of arable land, water, and energy. Decisions about 1 facet will affect the status of another. This means decisions are more difficult to make and require a depth of understanding about the carrying capacity of the earth's resources. We all have a stake in how these vital decisions are to be made for they will affect the quality of our life and even the survival of our progeny.

Research is needed on: (a) how to integrate both crop and livestock production with other components of the ecosystem to reduce energy inputs while becoming more ecologically sound; (b) the nutritional needs of humans as a basis for decisions concerning which crop and livestock systems can best meet these needs with minimum energy inputs while maintaining a sustainable agricultural environment; (c) how to produce agricultural products as close to the consumers as practical to minimize the expenditure of transport energy; (d) developing food processing and packaging systems that are energy efficient; and (e) devising ways and means of conserving energy in home cooking and preparation.

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