

## **Energy Use in the U.S. Food System: a summary of existing research and analysis**

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### ***Introduction***

Energy derived from fossil fuels (oil, coal, and natural gas) has come to play a very central role in the U.S. economy and in American lifestyles, not to mention in the production, processing, and distribution of food. Most of what is currently known about energy use in the U.S. food system is a direct result of the “energy crisis” of the early 1970s. The OPEC oil embargo of 1973 triggered numerous studies and critiques of U.S. energy use and policy. The food system had just undergone several decades of intense industrialization. In the years following the end of World War II, inorganic fertilizers, synthetic pesticides, irrigation, more complex machinery, and larger, more powerful tractors pushed agriculture into the modern era and boosted yields dramatically. All of these technologies required fossil fuels, however. Beyond the farm gate, energy used to process, market, and distribute food increased as well. Consumer behavior helped contribute to this increase as households purchased more “convenience” and snack foods. Another factor was the relatively recent ability of supermarkets to provide fresh fruits and vegetables year-round shipped in from sources around the world.

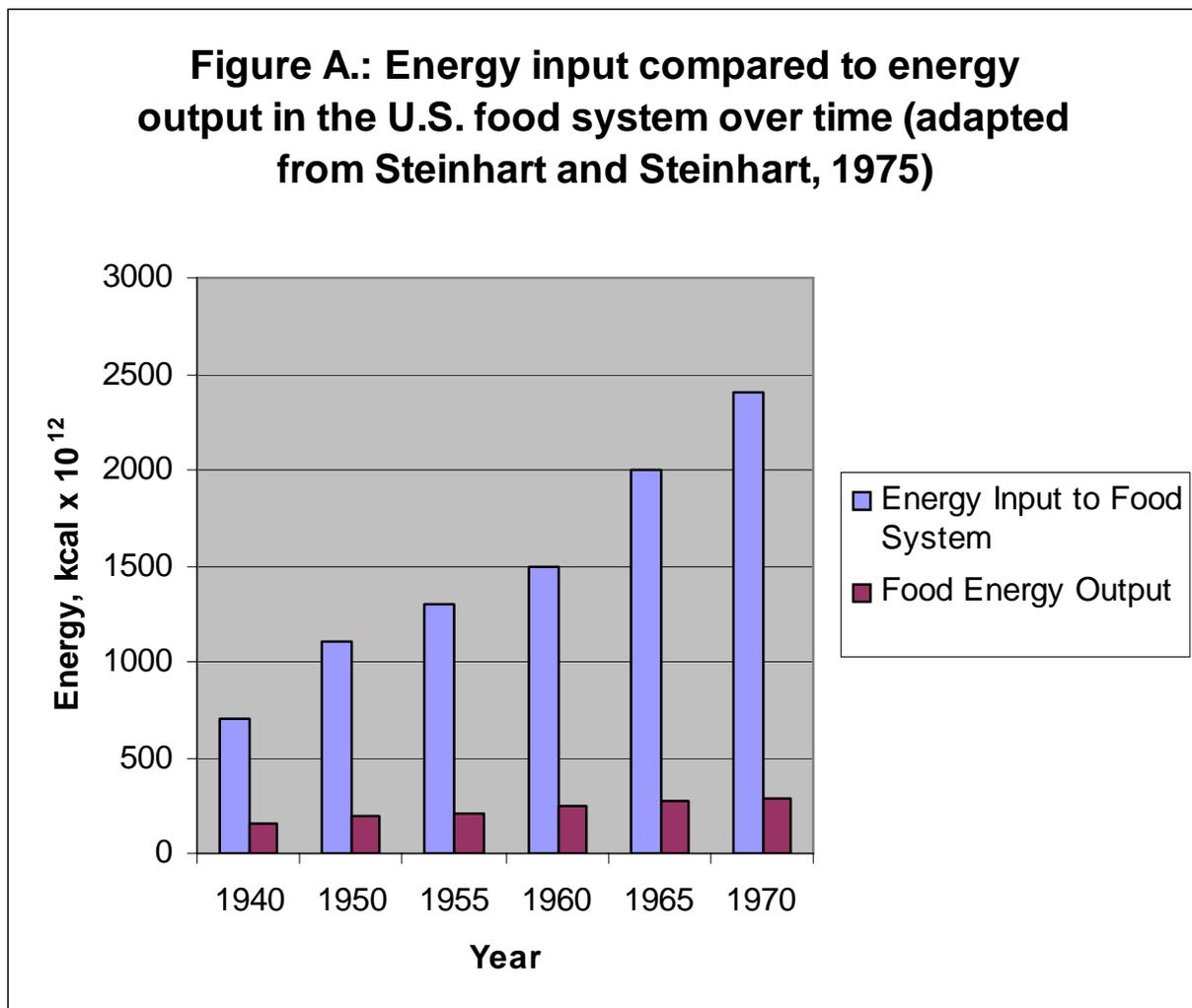
Recently, there has been renewed interest in energy consumption as research on sustainable agriculture has broadened into analyses of food systems. This paper summarizes existing research and analyses of energy use in the food system (with particular attention to the relative amounts of energy used by various sectors of the food system), discusses where the most significant and feasible energy savings might be achieved, and suggests areas for future research. This review was undertaken to provide information to a “Regional Food Systems Seminar” (Hendrickson et al. 1995) at the University of Wisconsin-Madison. This seminar explored some of the environmental, social, and economic issues presented by the modern, global food system with a particular focus on the possibility of more local or regionally based food systems to address these issues. The original objective was to find data on energy use such that local food systems could be compared to the global food system. In particular, the seminar was interested in potential transportation energy savings for local food systems. Given the scarcity of such research, the primary focus became compiling existing research on energy use by sector (production, processing, transportation, etc.).

To provide context for the following discussion of energy use, it is instructive to remember that fossil fuel energy is a finite resource and that its use causes a number of negative impacts on the biosphere and human health. Until recently, analysts had been forecasting that known oil and natural gas reserves would be effectively diminished in 30 to 50 years (Gever et al. 1991; Worldwatch 1992). Within the last several years there have been discoveries suggesting fossil reserves may last somewhat longer but the finiteness of fossil fuels remains a stark reality. The impact of burning fossil fuels on ecosystems is well documented (see for example the *State of the World* series by Worldwatch). In the face of dwindling supplies and the negative impacts of its use, the United States (with less than 5 percent of the world population) consumes about 25 percent of all fossil fuels used in the world annually (DOE 1991).

### ***Energy Use in the U.S. Food System***

Perhaps the most prolific analysts of food system energy use over the past twenty years have been David and Marcia Pimentel. Much of their work compares the energetics of modern, industrial agriculture with farming systems based on human and animal labor. In 1979 the Pimentels reported that the U.S. expends three times as much energy per capita for food as developing countries expend per capita for all energy-consuming activities (Pimentel and Pimentel 1979). In 1989, 1,500 liters (396.3 gallons) of gasoline equivalents were used per capita to produce, process, distribute, and prepare food in the U.S (Pimentel et al. 1989). In addition to comparisons of farming systems in developed and developing nations, the Pimentels have examined energy use throughout the U.S. food system. By their account, the food system uses 17 percent of the total energy supply in the U.S. (Pimentel et al. 1989).

One of the Pimentel's primary analytical tools has been the input-output ratio. This methodology is designed to measure agricultural efficiency by comparing food energy output to energy input. For example, the Pimentels calculate that in 1945 one calorie of energy input into corn production yielded 4 calories of energy output. This return diminished to 2.4 calories output for every 1 calorie input by 1979 (Pimentel 1983). Energy use is higher for fruits and vegetables and highest for animal products. The Pimentels calculate that fruits and vegetables require 2 calories input to yield 1 calorie of output while animal proteins require 20 to 80 calories of energy input for 1 calorie of energy output (Pimentel 1983). While input-output ratios do provide one measure of efficiency, they can be overemphasized. Although energy inputs and outputs can both be expressed in the same units—calories—their value and utility are different. In addition to providing energy, foods contain vitamins, minerals, and protein. Foods also have cultural values that cannot be quantified. Input-output ratios are best used to compare the energetics of different production systems (i.e. industrial vs. human and animal labor based systems or “conventional” vs. “organic”) and to compare the efficiencies of raising different types of foods to meet specific needs (i.e., the production of beans and grains vs. livestock for protein). This methodology can also provide benchmarks against which to measure increasing or declining efficiency in food systems over time. In regard to the later, the U.S. food system as become more and more energy intensive (see Figure A). The modern food production and distribution system expends 10 to 15 calories of energy for every one calorie of energy produced (Gussow, 1991).



One of the first relatively comprehensive investigations of energy use in the food system is that of John and Carol Steinhart in 1974. The Steinharts calculated energy use throughout the food system from 1940 to 1970 (see Table 1).

<b>Table 1. Energy use in the food system, 1940 and 1970</b>			
<b>Sector</b>	<b>1940</b>	<b>1970</b>	
On farm	18%	24%	Includes fuel, electricity, fertilizer, machinery, irrigation.
Processing	31%	24%	Includes processing machinery and packaging.
Transportation	11%	15%	Includes the manufacture of trucks and trailers.
Commercial/Home	40%	37%	Includes commercial and home refrigeration and cooking.
Total Food System		12.8%	

Adapted from Steinhart and Steinhart, 1974

The Steinharts concluded that the food system accounted for 12.8 percent of U.S. energy consumption in 1970. Later studies report estimations between 12 and 20 percent. Table 2 summarizes the findings of nine different studies that document energy use by sector. A second set of studies (Table 3) has examined energy use by sector for specific foods. These figures show how the proportion of energy use by sector can vary widely for different food products. This is an important contribution to the studies that have focused on aggregate values. The variation in relative energy use among types of food becomes increasingly important as one makes suggestions for specific conservation measures.

Comparison of the studies in Table 2 is difficult due to substantial differences in how the food system is defined. Some analysts, for example, do not consider home preparation to be part of the food system. This omission creates significant discrepancies in other parts of the table, especially as a relatively large proportion of energy use (22-27 percent) is attributed to home preparation by other studies. Regrettably, it is often difficult to ascertain exactly how the food system has been defined and what elements and activities are included in the named sectors. Some studies include transportation in the wholesale and retail sector, or even the processing sector, others separate transportation into its own category, while others do not specify if or where transportation is included. None of the studies considers waste disposal and recycling. Perhaps the most significant observation about Table 2 is that studies of energy use in the food system rely primarily on mid-1970s data. Obviously, energy analysis of the food system is in need of update and re-evaluation. The following section highlights findings in the production, processing, transportation, and home preparation sectors.

**Table 2: Percent of total energy use by sector in the U.S. food system**

<b>Author(s)</b>	<b>Hirst<sup>1</sup></b>	<b>Steinhart<sup>2</sup></b>	<b>Buf/Zar<sup>3</sup></b>	<b>Pierotti<sup>4</sup></b>	<b>Arsdall<sup>5</sup></b>	<b>Fluck<sup>6</sup></b>	<b>Singh<sup>7</sup></b>	<b>Poincelot<sup>8</sup></b>	<b>Average<sup>9</sup></b>
Publication year	1974	1974	1977	1977	1978	1980	1986	1986	
Data source year	1963	1970	1975	n.d.	1975	1974/77?	1978	1979/81	
Agricultural production	18	24	49	43.1	12.8	15.5	17.6	17.6	17.5
Processing <sup>a</sup>	33	24	37	34.1	30.8	27.3	29.1	29.1	28.1
Wholesale/Retail	16		10	16.1		8.1	7.9	2.6	9
Marketing/Distribution <sup>b</sup>					11.1				
Transportation	3 <sup>*</sup>	15	3	6.4		13	2.4 <sup>@</sup>	7.9	11
Restaurants <sup>c</sup>		13.5			17.9	13.7	17	17	15.8
Home preparation	30	23.5			27.4	22.4	26	25.9	25.0
Food system <sup>d</sup>	16.5	12.8	6 to 9 <sup>#</sup>	16	15.6	16.1	16.5	17	15.6

1 Hirst, 1974

2 Steinhart and Steinhart, 1974

3 Buffington and Zar adapted from Fritsch et al., 1975

4 Pierotti et al., 1977 (no date given for data)

5 Van Arsdall and Devlin, 1978

6 Fluck and Baird, 1980 (Although not specified, it appears their data is from 1974 and/or 1977)

7 Singh, 1986

8 Poincelot, 1986

9 These averages exclude the two studies (3 and 4) that exclude two sectors (restaurants and home preparation).

a Includes packaging in many studies.

b This category appears to parallel the wholesale/retail sector but includes transportation.

c Sometimes defined as “away-from-home meals at commercial eating establishments.”

d The percentage of total U.S. energy consumption used in the food system.

\* Does not include moving materials to farms or processors, nor transporting food from stores to home. These are included in the wholesale/retail and home preparation sectors. The author indicates that if grouped together his transportation figure would more than triple.

# Does not include transportation, wholesale/retail, and home preparation.

@ Described by the authors only as “trucks”

**Table 3. Percent energy use by sectors for bread, canned corn, and beef.**

	FOOD PRODUCT		
	1 kg. loaf of bread <sup>1</sup>	1 lb. can of corn <sup>2</sup>	140 g beef <sup>1</sup>
Production	45%	10.9%	98.3%
Processing	27%	15.9%	.2%
Packaging	7%	26.9%	.2%
Transportation	14%	11.6%	.2%
Marketing	7%	8.3%	.4%
Shopping	—	15.9%	.3%
Home preparation	—	10.5%	.5%
Total kcal	7,345	4,111	29,497

<sup>1</sup> Pimentel and Pimentel, 1979<sup>2</sup> Brown and Batty, 1976*Agricultural Production*

By most accounts agriculture consumes a relatively small percentage of total U.S. energy and, within the food system, processing and home preparation consume significantly more energy than does farming. At the same time, however, “agriculture consumes more petroleum products than any other single industry” (Buffington and Zar 1977). As will be seen, many of these products are fertilizers and pesticides. In 1974, the Economic Research Service of the USDA in cooperation with the Federal Energy Administration (now the U.S. Department of Energy) began constructing an “agricultural energy data base” (Stout 1984). This study was limited to energy use in agricultural production and concluded that agriculture accounted for 3 percent of total U.S. energy use. This database provides an accounting of energy by type of fuel, commodity, operation (planting, cultivation, harvesting, fertilizer, livestock handling, etc.), state, and month. Table 4 summarizes energy use by farming operation in 1974.

Of particular note here is the large proportion of energy used in the form of fertilizers and pesticides. The use of inorganic fertilizers and pesticides, manufactured from natural gas and petroleum, increased dramatically between 1960 and 1980. Fertilizer use expanded three times and herbicide use increased over four and half times in that time period (NRC 1989). Fertilizers alone accounted for 30 percent of energy use in agriculture in 1974 (Stout, 1984). Fertilizer and pesticide use has declined since the early 1980s but they still represent the largest energy input into agriculture. While beyond the scope of this paper, the impacts of an industrialized, energy-intensive agriculture system on land, water and air are considerable and alarming (see NRC 1989). Soil erosion, salinization, groundwater depletion and excessive reliance on pesticides all jeopardize future agricultural yields.

**Table 4. Energy use by farming operation in 1974**

Operation	% of total energy	% of direct energy
Fertilizers/Pesticides	36	-
Field Machinery	19	30
Transportation	16	25
Irrigation	13	20
Livestock/dairy/poultry	8	12
Crop drying	5	8
Miscellaneous	3	5

Adapted from Stout, 1984.

In the U.S., corn production accounts for approximately a fourth of the total energy consumed in farm production and almost half of the agricultural energy demand is concentrated in seven states—California, Illinois, Iowa, Kansas, Minnesota, Nebraska, and Texas (Van Arsdall and Devlin 1978). As indicated by the input and output studies noted above, animal foods are far more energy intensive than plant foods. One indication of this is the fact that over two-thirds of annual crop production in the U.S. is used for animal production (Pimentel et al 1994). According to one study, the substitution of one pound of bread for one pound of beef monthly throughout a year by U.S. citizens would save energy equal to that contained in over 120 million barrels of oil (Mayer and Rawitscher 1979).

### **Processing**

With more than 75 percent of food grown on farms being processed in some way before it is consumed (Buffington and Zar 1977), it is little wonder that this sector accounts for one-quarter to one-third of energy use in the food system. Consumer preferences (guided by advertising) for fast, convenient foods have pushed energy use in the sector. Food packaging has become increasingly energy intensive with the use of energy-intensive materials, excessive packaging, and the proliferation of smaller, single serving packages. In numerous instances, the energy used to manufacture food packaging exceeds the inputs of energy for the food product (Pimentel 1979). As much as 15 percent of energy use in the food system has been attributed to packaging alone (Pimentel 1990).

Although the proliferation of manufactured, convenience foods has driven energy use in this sector dramatically, these foods do not necessarily take more energy than similar foods prepared at home. More efficient ovens and the use of bulk ingredients can give food processors an energy advantage over the home-cooked meal (Rawitscher and Mayer 1979A). It is important to note, however, that some of the most energy-intensive food processing industries produce products that are the most nutritionally suspect. The processing of sugar, wet corn, and malt beverages use approximately 20 percent of the food processing energy in the U.S. (Rawitscher and Mayer 1979B).

In terms of the energy efficiency of food processing methods, several studies conclude that canning uses less energy than freezing. Although steel or aluminum cans are extremely energy intensive to manufacture, the electricity need to run freezers rather quickly eliminates the advantages of freezing. For example, if corn is kept frozen longer than 22 days it becomes more energy consumptive than canning (Brown and Batty 1976). Unless accomplished by solar-drying, dehydrating foods can require even more energy (Pimentel 1979). Table 5 compares various preservation techniques with both homegrown and purchased fresh produce.

<b>Food</b>	<b>Energy Consumption (BTU/lb.)</b>				
	<b>Home grown</b>	<b>Fresh</b>	<b>Canned</b>	<b>Frozen</b>	<b>Dehydrated</b>
Corn	-	5,250	10,300	12,750	37,100
Carrots	1,300	4,750	9,200	12,750	37,100
Apples	917	5,950	400	9,200	23,200
Potatoes	2,850	6,250	9,000	14,950	26,700

From Buffington and Zar 1977 p. 704. They reference: Federal Energy Administration (1975) *Monthly Energy Review*, August. Accession no. PB-242769-08. National Technical Information Center, Washington, D.C. and Fritsch *et.al.* 1975.

Table 6 lists *processing* energy inputs for various manufactured food products. The figures in this table do not include the energy used for on-farm production, marketing, transportation, or home preparation.

<b>Table 6. Processing energy inputs for manufactured foods</b>	
<b>Product</b>	<b>kcal/kg</b>
Beet sugar	5,660
Cane sugar	3,370
Fruit and vegetables (canned)	575
Fruit and vegetables (frozen)	1,815
Flour	484
Baked goods	1,485
Breakfast cereals	15,675
Meat	1,206
Milk	354
Dehydrated foods	3,542
Fish (frozen)	1,815
Ice cream	880
Chocolate	18,591
Coffee (instant)	18,948
Soft drinks	1,425 (per liter)
Wine and other spirits	830 (per liter)
Pet food	828
Ice	151

Adapted from Pimentel (1979)

### ***Transportation***

According to several studies, transportation consumes a rather small portion (3-6 percent) of energy in the food system. Other analysts report figures of 12 or 13 percent (Vilstrup 1980; Poincelot 1986; Fluck 1992). This discrepancy is at least in part a result of how the transportation sector is defined. Some studies limit their definition to the transportation of food products, while others describe the transportation sector as including:

- The transportation of machinery, fertilizers, pesticides, fuel, and other goods to farms.
- Raw agricultural products shipped to processors.
- Produce and processed goods delivered to wholesale distributors.
- Wholesalers delivering to retail markets, restaurants, and institutions.
- Consumers driving to and from markets and restaurants.

Fluck elaborates further, maintaining that transportation energy costs should include:

- Liquid fuel and associated fuel production energy.
- Energy to construct and maintain vehicles (trucks, trains, boats, and planes).
- Energy to provide roads (construction and maintenance). (Fluck 1992)

This more complete view of transportation energy is reflected in the larger percentage attributed to the transportation sector by Fluck. In his analysis, Fluck makes use of a comprehensive study of food transportation conducted by the USDA (Barton 1980). Barton's research included most of the above categories except energy used by consumers driving to markets and restaurants. He reports that in 1977 the transportation of farm inputs, commodities, and manufactured food products consumed 2,892 million gallons of diesel fuel and 411 million gallons of gasoline. Truck shipments made up 41 percent of the total ton-miles but used 77 percent of the fuel. The transportation of farm inputs used 619 million gallons, with fertilizer distribution being the largest user at 195 million gallons. Commodity shipments used 1,416 million gallons—654 million for grains and soybeans and 525

million for fruits and vegetables. The shipment of commodities and manufactured food products accounted for 76 percent of total ton-miles and 80 percent of total fuel use.

Obviously, a full accounting of the energy requirements to transport food would raise many of the figures for the transportation sector in Table 3 considerably. Poincelot estimates that about 75 percent of the energy used in the marketing and distribution sector of the food system is consumed in the movement of food through wholesalers, retailers, and other commercial users of food. An additional consideration is that most studies restrict their analysis (due to data availability) to the transportation of only domestically produced food. Of course, in today's global food system, many products are imported into the U.S. A comprehensive study of transportation energy needs to include international trade.

One of the arguments for re-localizing food systems is the savings in transportation energy. An often quoted figure is that the average food item in the U.S. travels 1,300 miles. The Cold War era study that generated this figure analyzes the impact of various nuclear attack scenarios on the U.S. food system (DOE 1969). The 1,300 miles figure (actually 1,346.1) is based, the authors admit, on an oversimplified model of commodity flows and a number of assumptions and estimations. The authors conclude that transportation requirements in the food system are "probably considerably greater." More recently, the figure 1,100 miles has been reported for food traveling to consumers in the United Kingdom (Blythman 1993). Between 1979 and 1994 the distance foods traveled in the U.K. increased by 50 percent (Paxton 1996) and one would expect that a similar increase has occurred in the U.S. since the 1969 DOE study. Fresh produce arriving in Austin, Texas has been estimated to have traveled an average 1,129 miles (Robbins 1996). From Barton's 1980 study the mileage figures in Table 7 can be estimated.

<b>Table 7. Estimated transportation distances for different food products</b>	
<b>Product</b>	<b>Mileage</b>
Fresh produce (from California and Florida to major terminal markets)	1,500
Processed fruits and vegetables	800
Meat products	950
Breakfast cereal	1,350
Milk and eggs	50-75

The large mileage numbers reported for fresh vegetables is due to the fact that such a large proportion of the fresh vegetables consumed in the United States are grown in the San Joaquin Valley of California. Within California, Auburn found that decentralized distribution of fresh produce (food produced in a county being consumed in that county) would save one-fourth the fuel and one-third the cost of centralized distribution (shipping food to warehouses and then shipping it back to markets) (Auburn 1988).

Although this one study cannot be generalized to other regions and the food system in general, it does suggest that significant energy and cost saving may be realized by local food systems. It is important to realize however, that short-haul distribution can be more energy intensive due to the type of trucks typically used and the smaller quantities shipped.

Regardless of the actual miles or the relative proportion of energy used in transporting food products, it is important to realize that transportation is an especially vulnerable sector of the food system. In contrast to the other sectors of the food system, transportation is almost exclusively dependent upon liquid fuels derived from oil. International supply disruptions and price fluctuations can have a more marked and immediate impact on this sector (OECD 1982). And this vulnerable sector is, experts agree, the most critical sector of the food system. What the modern food industry hails as the "global supermarket" depends heavily on cheap and efficient

transportation. Without cheap and efficient transportation, there can be no “global supermarket.” Subsidies in this sector (highway maintenance for example) are significant and help keep food affordable for the average American. If fuel were priced so as to reflect its true costs (including environmental impacts) food prices would rise accordingly. Already, 6-12 percent of the consumer dollar spent on food eaten at home represents transportation costs (Rhodes 1993). True-cost pricing for gasoline has been estimated at \$4.50/gallon by the Worldwatch Institute (1989). Another study has suggested an increase of over two dollars (World Resources Institute 1992). These and other considerations have led many analysts of the food system to suggest at least a partial return to a more decentralized system of distribution, in which individual states and/or regions are more self-reliant in food (Tansey and Worsley 1995; Kloppenburg et al. 1996). See Paxton (1996) for a review of the environmental and social consequences of long distance food transport.

### ***Shopping and Preparation in the Home***

Energy used by shoppers and home preparation consumes up to one third of the total energy used in the food system. Brown and Batty's 1976 study of corn indicates that more energy is used to drive to a supermarket to buy a can of corn than is consumed in the (non-irrigated) production of the corn (Brown and Batty 1976). While shoppers usually buy multiple items in a trip to the store, this kind of information is helpful in understanding where substantial energy savings can occur. Obviously, fewer and larger (in terms of the number of items purchased) shopping trips to the store can save considerable amounts of energy.

The energy used in home preparation can vary widely according to the equipment used as well as the techniques and habits of the person cooking. In one study, energy use varied by as much as 50% for five chefs preparing the same meal on seven occasions (Mayer and Rawitscher 1979). Studies comparing commercially processed foods with the energy needed to prepare similar foods in the home have yielded mixed results. Generally, supermarket foods which require large scale equipment and metal packaging can be prepared in the home using less energy. In a study of bread, however, researchers have discovered that even if six loaves are baked at once in the home kitchen, energy use is greater per pound than for the commercial bakery (Mayer and Rawitscher 1979).

### ***Food System Energy Conservation and Savings***

Suggestions as to where and how to decrease energy consumption in the food system can be divided into three categories. The first is largely technical and involves the application of more efficient engines, fuels, and materials. The following list provides examples of this type of potential energy savings.

- Conversion of all farm machinery to diesel engines,
- Improved irrigation pump efficiency,
- Basic efficiency and conservation measures in food processing plants,
- Improved aerodynamics, better tires, use of diesel gasoline, etc. in semi-trucks, and
- Aluminum rail cars and other railroad efficiency measures.

A second set of conservation measures involves the substitution and refinement of techniques and processes. Examples of this type of energy savings include:

- Solar drying of crops (rather than using electricity),
- Increased use of manures (green and animal) and crop rotations rather than inorganic fertilizers,
- More timely and appropriate use of pesticides,
- Conservation tillage, no-till, and reduced tillage,
- Route optimization and capacity loading in freight shipments, and
- Reduction in food waste throughout all sectors of the food system.

Although these first two categories certainly imply social and economic choices and changes, the third category of energy savings is profoundly social. Many of these measures reflect awareness that, as fossil energy resources are depleted, difficult political and structural choices may need to be made. Some examples include:

- Decrease human population (and therefore food demand),
- Decrease consumption of beef, sugar, and highly processed foods,
- Decrease consumption of “luxury” agricultural items (tobacco and pet food), and
- Increased reliance on local food production and limiting consumption of imported foods.

Where the most significant, feasible, and sensible energy savings can be achieved is, of course, extremely political. Few would argue with the energy conserving measures possible through the use of more efficient technologies while the suggestion that people consume less meat creates controversy. For as many analysts that argue for a reduction in the use of inorganic fertilizers there are as many who maintain that such fertilizer use is critical to maintain high yields and feed growing populations. Regardless of one's stance on these issues, it seems clear that energy savings that require no changes in consumer habits are likely to be small. It appears that some of the greatest saving can be realized by:

- reduced use of petroleum-based fertilizers and fuel on farms,
- a decline in the consumption of highly processed foods, meat, and sugar,
- a reduction in excessive and energy intensive packaging,
- more efficient practices by consumers in shopping and cooking at home,
- and a shift toward the production of some foods (such as fruits and vegetables) closer to their point of consumption.

However, for any of these issues and those discussed above to be taken seriously—and for appropriate policy decisions to be made—energy analysis of the food system needs to be revisited and updated.

### ***Research Needs***

There is a profound need to replicate the studies of the 1970s to determine exactly how and where energy is being used in the food system. When such studies are conducted, they should endeavor to include all sectors of the food system from production to consumption to the disposal or recycling of food and packaging wastes, as well as supporting industries. In reporting, researchers need to be clear about what elements of the food system have been included in their calculations and to specify their data sources. This summary of existing research has been made difficult by the lack of such explanation and documentation. In addition to replicating former studies, it would be helpful and instructive to have comparative studies such that various types of foods and food systems could be evaluated. For example, studies comparing the energetics of industrial, global food flows with lower input, local food flows would be extremely helpful. Currently, there is surging interest in “local” and “regional” food systems but in order to make reasonable arguments and decisions about the relative merits of such systems, there needs to be adequate information about their energy use.

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