THE ENERGY BUDGET IN THE US FOOD SYSTEM

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The energy budget

This paper considers the whole food energy chain, extending from farm production to family consumption.

The energy budget takes into consideration the energy used throughout the production process – planting, cultivating, fertilising, irrigating, harvesting, crop drying, and so on. After the crop has passed through the farm gate, it still absorbs energy to transport it to the market and through the processing industry and along the wholesale and retail channels of distribution. Finally, the housewife uses still more energy shopping for the food, storing it in a refrigerator, and finally preparing it for the table.

Energy is also required to grow animal foods; to prepare hay and silage; and to process, mix, and feed foodstuffs to farm animals for meat and milk and egg production.

Energy use in agricultural production also includes certain off-farm inputs. To take just one item, fertiliser requires energy to distribute it on the land; but it had a lot of energy locked into it before it ever got on to the farm. Clearly, energy was needed to deliver it from the factory to the farm; but even before that, it absorbed very considerable amounts of energy in its manufacture. Similarly, the use of farm machinery and implements absorbs energy in the field; but a prorated share of the off-farm energy needed to manufacture and deliver them, and the energy used for repairs and maintenance, must be taken into account. Consideration is therefore given to the many energy inputs which are not generally associated with food production as contrasted with crop production.

The efficiency of energy conversion for crops will be discussed. That is, the energy absorbed in production will be compared with the energy available in the food produced.

The energy used on the farm will be compared with the energy consumption in the various sectors after the crop leaves the farm – in the transport sector, the food processing industry, the distributive trade, and the home. And, with special reference to the farm, consideration is given to the kinds of energy used, and their relative quantities, and what the implications are.

Energy in the food chain: production

The average farmer, asked about how much energy he used on the farm, would simply go through his accounts and pick out the fuel items – diesel and petrol for tractors and trucks, electricity for pumping and crop drying, and so on. He would not normally think of including such items as bags of nitrogen fertiliser or cans of insect spray.

Lately, however, and more especially since the oil crisis of 1973, scientists have been very much concerned with the total energy really consumed in the food chain.

As a convenient classification, energy consumption can be divided into three parts: First, there is the "upstream" part – the energy used off-farm before the farmer actually starts the production process. This is often referred to as "Support" energy, and includes the manufacturing and transport energy-inputs for materials and supplies used on the farm for food production. There is, for example, the energy input for the manufacture of fertiliser; and this may actually be the greatest single energy input in crop production. Similarly, much energy in the form of labour and materials goes into the production and maintenance of tractors and trucks and other machinery and equipment; and a pro rata share of that energy must be debited against the crop. However, once these "upstream" energy inputs have been pinpointed and assessed, it is convenient to merge them with the inputs in the second part, the energy used in actual production on the farm – a process which is completed when the crop passes through the farm gate.

The third part covers energy inputs which are incurred between the farm gate and the dinner table. They are known as the "downstream" energy inputs – transport and processing and distribution and cooking and so on. They include the energy absorbed in cooking the food, because production serves no useful purpose until the food is ready for consumption.

Pimentel *et al* produced one of the first detailed studies of energy consumption in maize crop production – that is, up to the farm gate. The energy input figures published by Pimentel have been regrouped by the authors in Table 1. One group is basically the energy that went into the upstream of off-farm production of the chemicals used in maize production (plus a negligible amount of energy used in seed production). The items starred are those which had not generally been considered as energy inputs.

The other group in Table 1 consists of items which, broadly, may be considered as related to agricultural engineering energy, in that they are concerned more or less with actual fuel consumption on the farm. The data published by Pimentel included those for every fifth year from 1945 to 1975; but for simplicity, only those for the first and last years of that period are given in Table 1. Also, labour has been omitted as relatively insignificant. It amounted to 57 hours per hectare in 1945, and 17 hours in 1975.

Comparing the 1975 figures for energy input and output in US maize production, with those for 1945, the off-farm chemical energy inputs rose from about a quarter of a

TABLE 1 Energy input and output in US maize production

	Kilocalories per hectare 1945	1975	Increase
"Upstream" input: Chemical and seed			
*Nitrogen	121 400	2 429 000	x 20
*Potassium	25 600	288 000	x 11,3
*Phosphorus	13 200	220 000	x 16,7
*Lime	13 200	66 500	x 5,0
*Insecticides	–	101 000	
*Herbicides	–	181 000	
*Seed	76 560	146 160	x 1,9
Totals	249 960	3 431 660	x 13,7
"On-farm" input: Agricultural engineering			
*Machinery	538 000	1 420 250	x 2,6
Fuel	1 400 000	2 100 000	x 2,5
Irrigation	104 000	780 000	x 7,5
Drying	42 000	375 000	x 8,9
Electricity	40 000	380 000	x 9,5
Transport	50 000	180 000	x 3,6
Totals	2 174 000	5 235 250	x 2,4
Grand totals	2 423 960	8 666 910	x 3,6
Output: Food energy in maize yield	7 419 360	18 771 120	x 2,5
Conversion efficiency			
Energy Output	7 419 360	18 771 120	
Energy Input	2 423 960	8 666 910	
Ratio	=3,06	=2,16	x 0,7

(After Pimentel)

million kilocalories to about 3½ million – about 14 times as much. Nitrogen energy actually increased twenty-fold, and became the largest single energy input. Agricultural engineering inputs rose from a little over two million kilocalories per hectare to a little more than five million – only about 2½ times as much.

Considering the grand totals – that is, for upstream and on-farm inputs combined – the figure rose from about 2½ million to nearly nine million kilocalories per hectare . . . 3½ times.

Responding to this greater energy input, the food energy in the maize produced in the US rose from about 7½ to nearly 19 million kilocalories; a factor of only 2½.

This indicates a lower efficiency of energy input, which is made clear in the last line of Table 1. The ratio of food energy output to fuel energy input was about three in 1945, but only two in 1975. Figure 1 illustrates the overall picture. It shows that after 30 years of applying more and more energy, and getting higher and higher yields, the American farmer is now getting a lower maize yield per unit of energy applied. The picture is, of course, an illustration of the Law of Diminishing Returns; but it's only one side of the picture. Looked at from another angle: The energy in the maize produced is still twice as much as the energy applied. For every kilocalorie of energy applied to the maize crop, the return is still two kilocalories of food energy. It's less efficient, but still looks a good trade-off; because in a world with an exploding population to be fed, production from one hectare of maize has risen from about 7½ million kilocalories to nearly 19 million.

However, in a world of depleting oil supplies, and with virtually no substitute energy sources currently in sight, efficient use of energy is highly desirable.

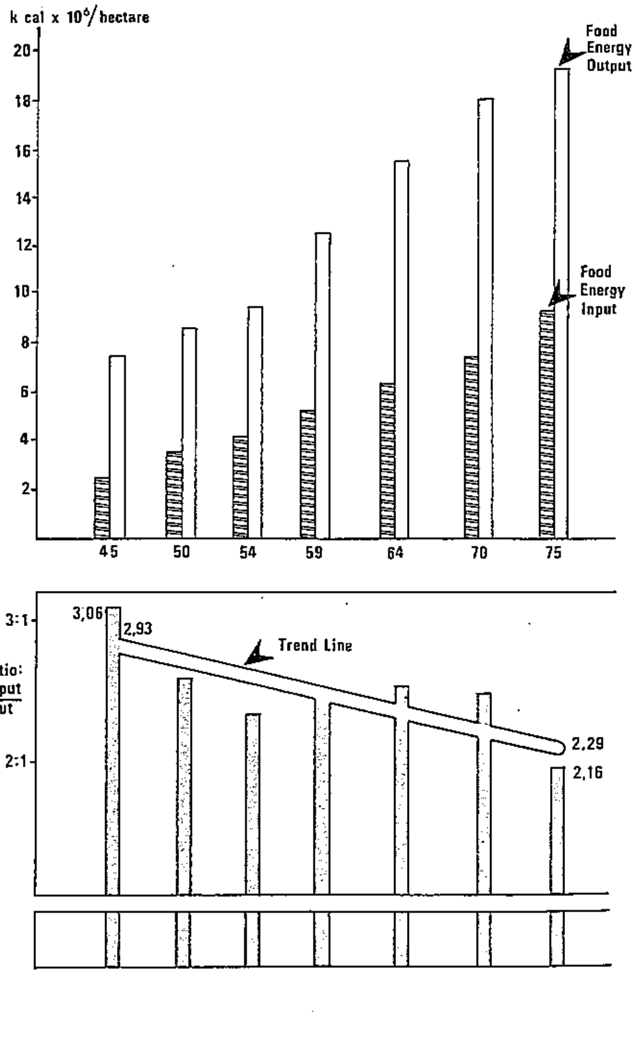

FIG 1 Energy input and output in US maize production 1945 to 1975

If the 1975 amount of energy were applied at the 1945 rate per hectare, the maize yield in the US would be about $26\frac{1}{2}$ million food kilocalories instead of about 19 million. However it would require about $3\frac{1}{2}$ times the crop area, and land is also a limiting factor. Actually, whatever claims are made about modern agriculture, higher yields per hectare are produced primarily through the use of increasing quantities of fossil fuel; and the use of a depleting resource to subsidise production is not efficient. The matter would be entirely different if the additional energy came from a plentiful or inexhaustible source – such as solar energy.

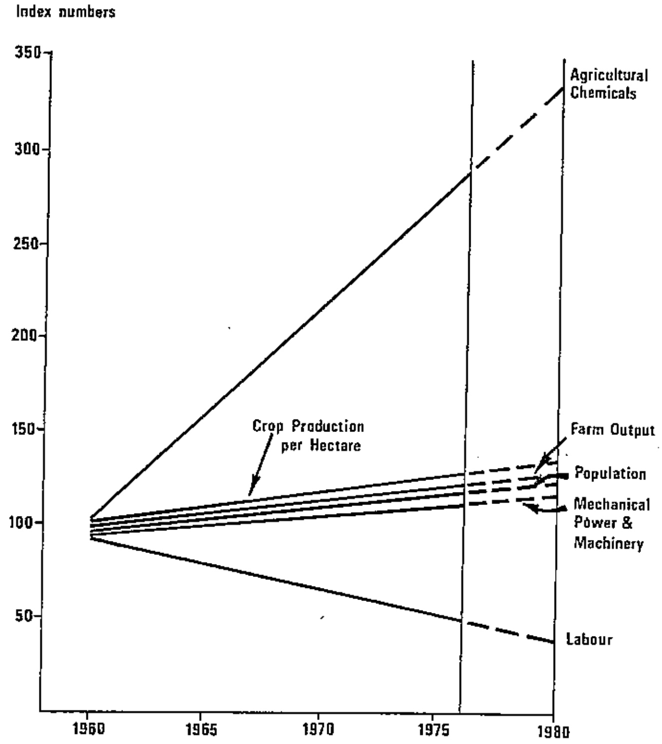

FIG 2 Trend of index numbers for selected farm inputs, farm output, and population, USA 1960 to 1976 (1960 = 100)

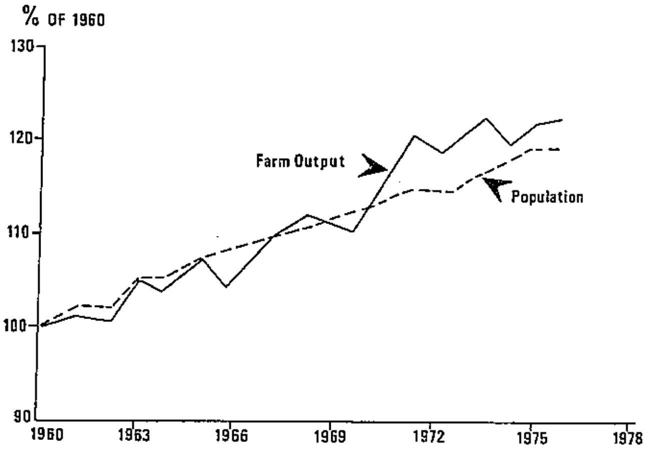

FIG 3 United States farm output and population

TABLE 2 Energy inputs and return in hand-powered maize production in Mexico (per hectare)

Item	Input	k cal
Labour	1 144 hours	
Axe and hoe	0,8 kg	16 570
Seeds	10,4 kg	36 192
TOTAL		.52 762
Yield (1 944 kg)		6 765 120
Output/input ratio		128,2:1

(From: Pimentel)

Figure 2 shows the use of selected farm inputs between 1960 and 1976. Inputs of agricultural chemicals, mainly fertiliser, increased by 172 per cent but power and machinery inputs increased by only six per cent. Over the same period, Figure 3 shows that the farm output did little more than keep pace with population growth (except for the period 1971 to 1974).

Modern agriculture is paradoxically less energy-efficient than some forms of primitive agriculture. As Table 1 shows, the US current return from maize is ± 2 kilocalories in food energy for every one kilocalorie of fuel input; but Pimentel gives quite startling figures (Table 2) for the return from a cut-and-burn technology studied in an area of Mexico, where the only inputs were a man, an axe, a hoe, and some seed. The total energy input (apart from manpower) was for the axe and hoe and seed production. It amounted to less than 53 000 kilocalories. The maize yield of 1944 kg/ha was almost as high as the US average in 1945; but the ratio of food energy produced to energy input was 128:1 . . . compared with America's figures of 3:1 in 1945 and only 2:1 in 1975.

There are many other examples of highly efficient energy conversion in less sophisticated agriculture.

Table 3 (a) gives examples of US energy usage in agriculture for field crops, and vegetable and orchard production, for 1974. Among field crops, flue-cured and burley and shade tobacco top the list of energy input per hectare. Rice is also a high energy consumer, as is sugar cane.

The most common grain crops – maize and sorghum – consume four to five million kilocalories per hectare; and wheat less than two million kilocalories per hectare. Vegetables consume much more energy than cereal crops. Among the horticultural crops, citrus consumes nearly as much energy as tobacco; apples and grapes take more than cereals, and pineapples absorb rather less than maize.

TABLE 3 (a) United States: selected examples of energy consumption in agricultural production 1974 (crops)

Crops	Hectares x 1000		Kilocalories per ha x 1000
Field crops:			
Flue-cured tobacco	250		37 007
Shade tobacco	3		27 657
Burley tobacco	138		13 457
Rice	1 047		10 986
Sugar cane	350		9 664
Cotton	5 557		6 744
Peanuts	616		5 963
Maize	26 383		4 767
Grain sorghum	5 632		4 536
Corn silage	4 328		4 485
Lucerne	10 782		2 839
Winter wheat	21 208		1 884
Soybeans	21 684		1 500
Spring wheat	7 593		1 422
Total field crops	133 740	(Average)	2 950
Vegetables:			
Potatoes	559		12 882
Vegetables, fresh	628		9 271
Vegetables, processing	718		9 265
Orchards:			
Oranges	357		28 613
Apples	185		18 384
Grapes	232		7 719
Pineapples	23		3 769
Total all crops*	137 834	(Average)	3 272

*Including other crops not listed

Source: USDA and FEA

TABLE 3 (b) United States: selected examples of energy consumption in agricultural production 1974 (animals)

Animals	Head x 1000		Kilocalories per head x 1000
Livestock:			
Beef:			
Cows and calves	44 537		374
Feedlots	23 936		369
Pigs	85 933		109
Sheep and lambs	14 525		64
Total meat animals	163 931	(Average)	198
Dairy:			
Dairy animals	11 220		1 167
Poultry:			**(Per 1000 head)**
Layers	286 478		4 959
Pullets	285 622		5 421
Broilers	2 990 938		1 682
Turkeys	131 310		13 763

Source: USDA and FEA

Table 3 (b) gives similar information for animal production.

Table 4 summaries the US fossil fuel consumption for agricultural production in 1974. Virtually the total agricultural production is dependent on petroleum products.

TABLE 4 United States fossil fuel consumption for agricultural production 1974

Commodity	Petrol litres x 1000	Diesel litres x 1000	Fuel Oil litres x 1000	LP Gas litres x 1000	Natural Gas $m^3 \times 10^6$	Electricity kWh x 10^6	Coal tons
Total field crops	9 851 663	7 439 598	289 826	4 161 205	4 060	16 105	
Total all crops	10 906 816	8 655 492	1 117 120	4 348 140	4 517	22 060	
Total meat animals	1 997 603	1 318 024		232 822	0	3 508	
Total dairy animals	826 424			289 607		5 105	
Total poultry	270 036	16 016	33 376	767 678	131	1 415	
Total livestock	3 094 063	1 334 040	33 376	1 260		10 028	32 725
Total agriculture	14 000 879	9 989 531	1 150 496	5 608 247	4 648	32 088	32 725

Source: USDA and FEA

Table 5 gives the fossil fuel requirements for various crops produced in California; the crop energy output; and the conversion ratio of efficiency (output/input).

TABLE 5 Fossil fuel requirements for various crops produced in California: crop energy output; and conversion ratio of efficiency (output/input)

	Fuel and/or electricity inputs (1000 k cal/ton)	Crop calorie content output (1000 k cal/ton)	Ratio
Field crops:			
Barley	479,0	3 166,1	6,6
Wheat flour	563,3	3 020,9	5,4
Maize	1 027,3	3 338,4	3,3
Rice	1 289,3	3 293,1	2,6
Grain sorghum	1 188,8	3 011,8	2,6
			Average 4,1
Raw vegetables and fruits:			
Potatoes	325,4	689,5	2,1
Apples	401,1	508,0	1,3
Grapes	576,9	607,8	1,1
Carrots	359,8	381,0	1,1
Tomatoes	262,2	199,6	0,8
Pears	964,2	553,3	0,6
Beans, green	2 058,0	1 115,8	0,5
Grapefruit	1 165,5	371,9	0,3
Lettuce	484,3	163,3	0,3
Broccoli	1 178,6	290,3	0,2
Cauliflower	986,4	244,9	0,2
			Average 0,8
Canned vegetables and fruits:			
Grapes	1 115,3	462,7	0,4
Beans, green	3 021,5	870,9	0,3
Apples	1 397,8	371,9	0,3
Pears	1 734,1	417,3	0,2
Grapefruit	1 797,7	272,2	0,2
Tomatoes	1 138,9	190,5	0,2
Frozen vegetables and fruits:			
Beans, green	2 856,1	925,3	0,3
Broccoli	1 911,2	254,0	0,1
Cauliflower	1 619,8	199,6	0,1
			Average 0,2
Dried fruits and nuts:			
Prunes	4 447,1	3 120,7	0,7
Walnuts	10 745,6	5 697,1	0,5

From: Cervinka et al *(1974)*

Certain cereals — such as barley, wheat, maize, rice and grain sorghum — show a high ratio (2,6 to 6,6) of food energy production compared with fossil fuel energy input. Raw vegetables and fruit in general produced a lower average ratio (0,2 to 2,1). In many cases they require a much greater energy input than the food energy they produce. Canned vegetables and fruits, frozen vegetables and fruits, and dried fruits and nuts, all have a low efficiency, producing far less food energy than the input energy.

Downstream energy — the food processing industry

Steinhart has produced figures for the energy consumption in the US food processing industry. Food processing converts the raw agricultural product into a form more acceptable, convenient, or sophisticated; or sometimes it just adds frills.

Annually in the US, 125 million animals — cattle and sheep and pigs — are slaughtered and cleaned and skinned. Three thousand million broilers are defeathered and dressed. The food processing industry mills grain. It bakes bread and biscuits and cake and breakfast cereals; it crushes sugar cane and refines the juice and makes sweets; it converts fresh tea leaves and coffee beans into "instant" beverages; it cures ham. It produces wine and brandy from grapes, changes milk into cheese, makes jam from strawberries, crisps from potatoes, margarine from vegetable oils.

Tomatoes emerge from the processor as tomato sauce or soup; raw meat becomes a can of curried stew or a ready-cooked steak-and-kidney pie. Apricots are crystallised, nuts are shelled, dills are pickled, oranges are squeezed, apples may become a cooked apple pie or cider.

Altogether, the US has something like 30 000 manufacturing establishments handling food and kindred products. With a population of about 210 million, there is one processing plant for every 7 000 people; with three in the average family, one plant for about 2 300 families.

The 1974 production was about 12 thousand million cans of fruit and fruit-juice and vegetables alone; plus vast quantities of canned meat and fish, plus bottled jams and other food preparations; plus over 1 000 million kilograms of fruit and vegetables and poultry processed as frozen food packs.

The foods had to be cleaned, prepared, sterilized, cooked and/or frozen — all absorbing energy; as did the manufacture of billions of cans and bottles and cardboard cartons.

Apart from the energy directly consumed in processing and packing, very large energy inputs are used in the production of all the machinery needed and the production of all the trucks and trailers required to take the produce to the processing plant, and from there to the wholesalers and retailers; and this tranportation eats up fuel. In 1974, railways and inter-city motor transport moved over 150 thousand million tons of farm products.

Steinhart shows (Table 6:2) that total energy consumption in the processing industry, plus transport, more than trebled between 1940 and 1970. The greatest increases were in the processing itself and in the fuel used for transport. The food processing industry accounted for about 39 per cent of the total energy use in the system; on-farm energy use amounted to about 24 per cent; and commercial and home requirements amounted to about 37 per cent.

Between 1940 and 1970, "on-farm" energy use rose from 124,5 x 10^{12} k cal to 526 x 10^{12} k cal, a factor of over four. The processing industry rose from 285,8 x 10^{12} k cal to 841,9 x 10^{12} k cal – three times as much.

Commercial and home consumption increased from 275,2 x 10^{12} k cal in 1940 to 804,0 x 10^{12} k cal in 1970 – also three times as much.

TABLE 6 Energy use in the United States food system

Components	Kilocalories x 10^{12}	
	1940	1970
1. On-farm		
Fuel (direct use)	70,0	232,0
Electricity	0,7	63,8
Fertiliser	12,4	94,0
Agricultural steel	1,6	2,0
Tractors	12,8	19,3
Irrigation	18,0	35,0
Sub-total	124,5	526,1
Sub-total as percentage of total	18,2%	24,2%
2. Processing industry		
Food processing industry	147,0	308,0
Food processing machinery	0,7	6,0
Paper packaging	8,5	38,0
Glass containers	14,0	47,0
Steel/aluminium cans	38,0	122,0
Transport (fuel)	49,6	246,9
Truck/trailer manufacture	28,0	74,0
Sub-total	285,8	841,9
Sub-total as percentage of total	41,7%	38,8%
3. Commercial and home		
Commercial refrigeration and cooking	121,0	263,0
Refrigeration machinery (home and commercial)	10,0	61,0
Home refrigeration and cooking	144,2	480,0
Sub-total as percentage of total	40,1%	37,0%
4. Total	685,5	2 172,0

After Steinhart and Steinhart, from various sources

TABLE 7 Fossil fuel requirements for various fresh and processed fruit and vegetable crops produced in California; crop energy output; and conversion ratio or efficiency (output/input)

Crops	Fuel and electricity inputs (1000 k cal/ton)	Crop calorie content output (1000 k cal/ton)	Ratio
Green beans:			
Fresh	2 048	1 116	0,5
Canned	3 021	871	0,3
Apples:			
Fresh	401	508	1,3
Canned	1 398	372	0,3
Tomatoes:			
Fresh	262	200	0,8
Canned	1 139	190	0,2
Cauliflower:			
Fresh	986	245	0,2
Frozen	1 620	200	0,1

Source: Cervinka et al

Downstream energy – commercial and home

The last links in the food energy chain have been combined by Steinhart and Steinhart into the Commercial and Home Sector (Table 6:3). The figures cover the expenditures of energy in commercial refrigeration and cooking; the energy cost of manufacturing the refrigeration machinery, both home and commercial; and the energy absorbed in the home, in keeping the food refrigerated and in cooking and otherwise preparing it for the dinner table.

Here again, the energy has more than tripled between 1940 and 1970; with the greatest use, and the greatest increase, taking place in the home.

Figure 4 illustrates the energy distribution between the three sectors as studied by Steinhart for the year 1970.

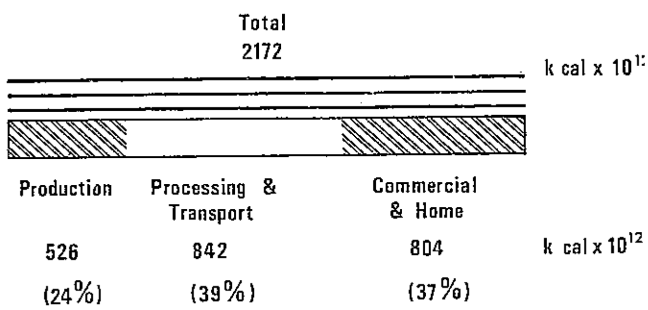

FIG 4 Energy use in the United States food system (1970) (Steinhart)

TABLE 8 Energy inputs for canned sweet corn and beef

Energy used for	Energy input (k cal) to produce 1 k cal of food energy: Canned sweet corn	Energy input (k cal) to produce 1 k cal of food energy: Canned beef
Production on-farm	1,20	77,333
Processing	4,69	1,07
Transporting	0,67	0,21
Distribution	0,91	0,28
Shopping	2,13	0,67
Home	1,33	0,41
Total	10,93	79,97

Source: Pimentel

Table 8 brings out two important points about energy consumption in the food chain, using canned sweet corn and canned beef as examples.

In the case of sweet corn, it takes nearly 11 kilocalories to produce one kilocalorie of food energy. Processing absorbs far more energy than production; and consumer energy use, for shopping and home preparation, is also much greater than that used to grow the crop.

Canned beef absorbs about 80 kilocalories to produce one kilocalorie of food energy — seven times as much as for the sweet corn. However, the downstream costs are relatively low. Production on the farm takes 92 per cent of the total energy input. This is accounted for by the facts that grain is grown for animal feed, and that animal conversion of grain into meat is a very inefficient process. In other words, energywise, meat is a luxury food.

Synoptic view of energy in the United States food system

Figure 5 (Steinhart) shows that despite an increasing energy input into the US food system during the 50-year period 1920 to 1970, rising from about 0,2 x 10^{15} k cal to about eleven times that figure, the index of farm output rose only from about 60 to 120. (The average output over the period 1957 to 1959 was taken as a base of 100). Steinhart pointed out the chart displays features of the US food system not easily seen from economic data. The curve shown had no theoretical basis but was suggested by the data as a smoothed portrayal of America's increasing food production. It was, however, similar to most growth curves and suggested that, to the extent that increasing energy subsidies to the food system had increased food production, the US is nearing the end of an era. Like the logistic growth curve, there is an exponential phase which lasted from 1920 or earlier until 1950 or 1955. Since then, the increments in production have been smaller, despite the continuing growth in energy use. It is likely that further

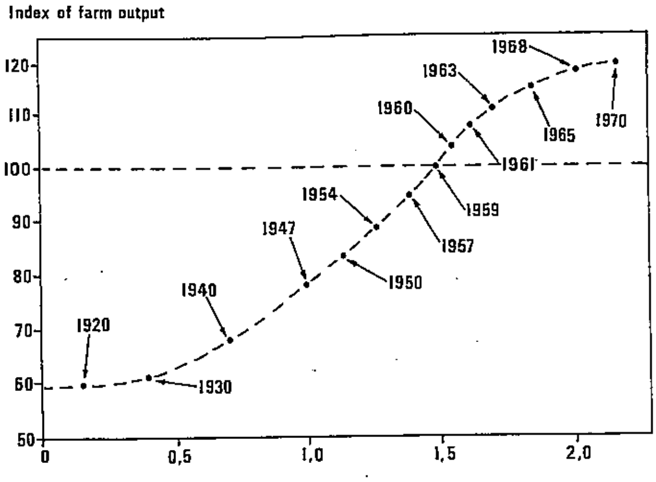

FIG 5 Energy input to United States food system (k cal x 10^{15}) (Steinhart)

increases in food production from increasing energy inputs will be harder and harder to come by. Of course, a major change in the food system could change things, but the argument advanced by the technological optimist is that one can always get more if one has enough energy, and that no other major changes are required. The historical facts of the US does not support that view (Steinhart).

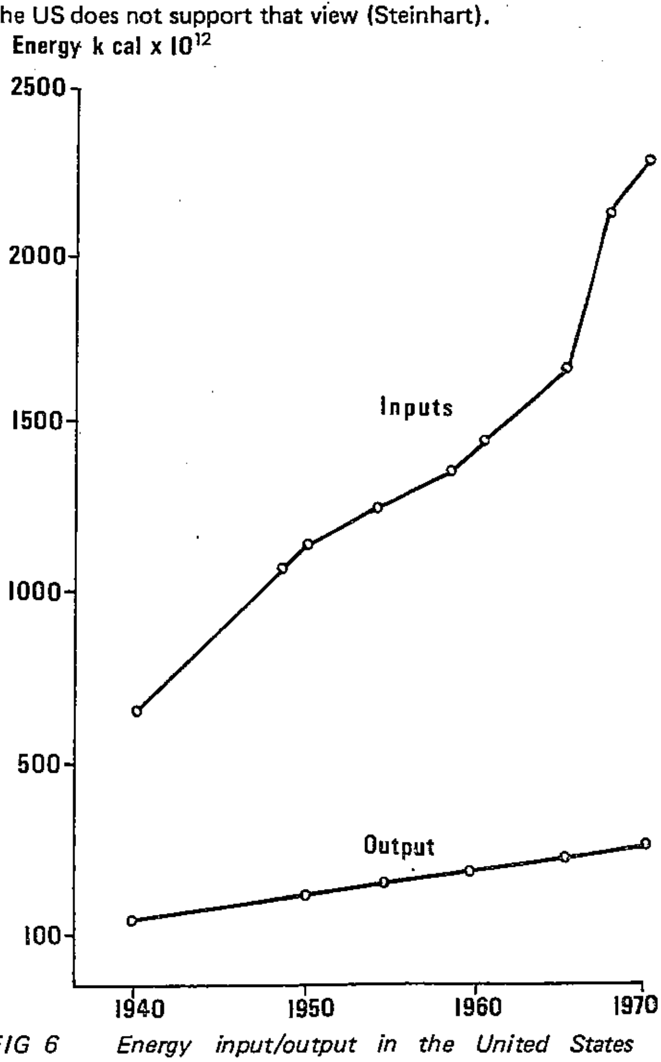

FIG 6 Energy input/output in the United States food system (Steinhart)

So, as agriculture prepares to inject more energy into the food system, the system is being operated with an ever-decreasing efficiency.

Figure 6 shows clearly that it is not only in farm production that energy consumption is growing fast. The lower line shows the energy value of the food consumed – obtained by multiplying the daily calorie intake by the population. As the daily calorie intake per person has remained fairly constant, the rise in the curve primarily reflects the population increase over 30 years. The upper line shows the much faster rate of energy consumption in the food chain.

Cost of energy in the United States food system

Figure 7 emphasises the cost of downstream energy of the US food system. In 1973, farmers in the USA received $50 billion for the food they produced; but consumers paid $133 billion. The difference of $83 billion was the marketing slice of consumer cost.

Food processers added $29 billion for milling and baking, cooking and canning and freezing and so on. Wholesalers' services came to $11 billion. The retail trade smacked another $24 billion on top of that. Finally, eating houses (restaurants and cafes and snack bars) cost the consumer a further $19 billion.

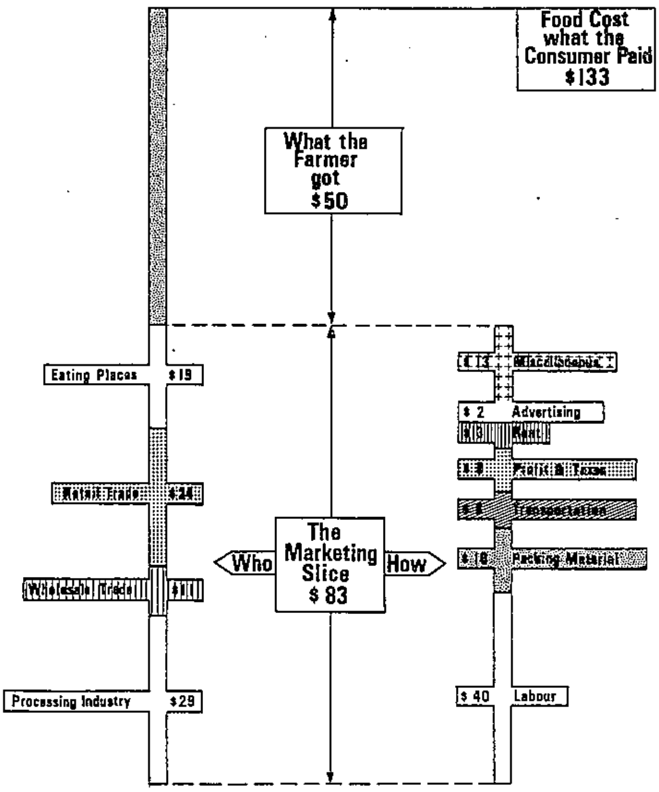

FIG 7 The United States food chain, and downstream costs, 1973 ($ x 10^9)

Looking at the marketing slice from another angle, labour received $40 billion in wages; packaging material (cartons and cans and bottles) cost $10 billion. Transportation absorbed $6 billion. Profits and taxes, together, $3 billion; and advertising processed food, $2 billion.

The remaining $13 billion went for miscellaneous items – depreciation, repairs, bad debts, interest, and other charges.

Figure 8 compares the US marketing costs of farm foods for the years 1959 and 1975.

In 1959, US farmers received about 33 per cent of the total paid by the consumer, and 35 per cent in 1975; but in terms of cash, they received $21 billion in 1959 and $55 billion in 1975. Downstream costs – the marketing slice – rose from $43 to $104 billion.

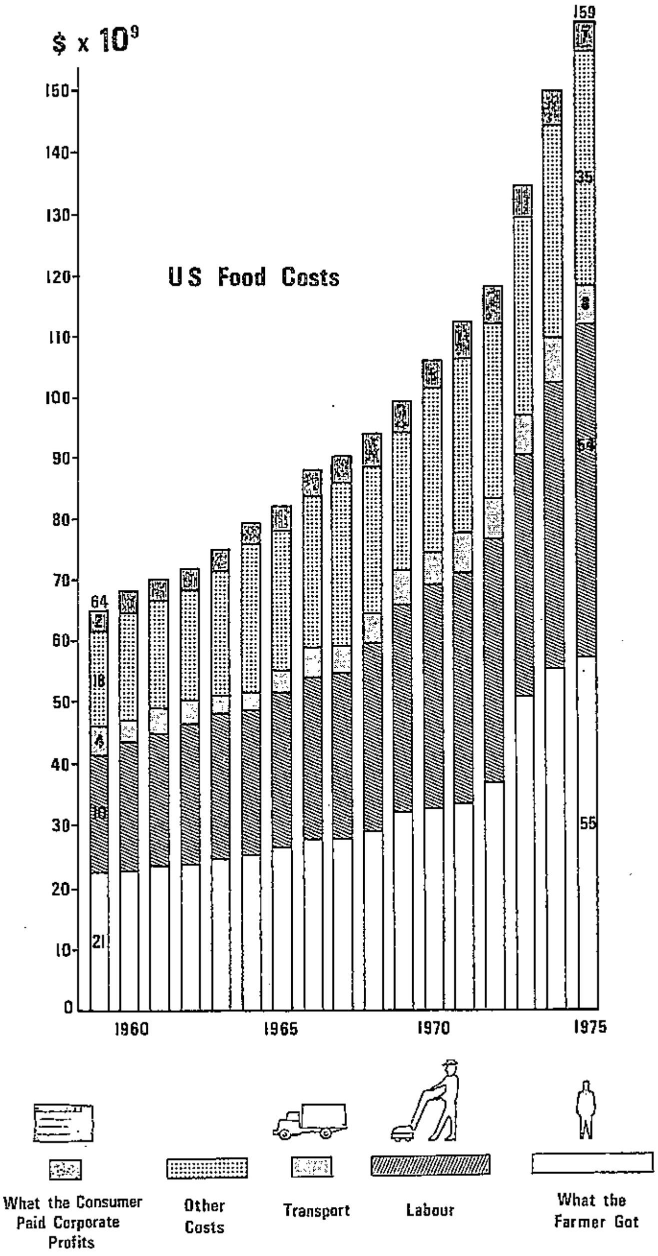

FIG 8 US Food costs

Summary

All in all, the total energy input into food production on the farm — including all the upstream energy used for the manufacture of chemicals and so on — is only about one-quarter of the total energy used in the food chain. The other three-quarters are shared about equally between the processing industry, and the commercial and home sector.

This three-to-one distribution of energy in the food chain applies also to employment in the food chain. The US has about four million farmers; but 12 million other people work in some phase of agriculture. Their livelihood depends on supplying inputs, and transporting and processing and merchandising the end-product — food.

The proportions are likely to be much about the same in South Africa. For every farmer producing food, three other workers are links in the food chain. They are job-dependent upon agriculture.

Conclusion

In this paper it has been demonstrated how vulnerable the food chain is to an interruption in oil supplies, and how extravagant total energy inputs have become.

However, massive food production is impossible without massive energy use; and therefore society — the government, industry, trade, farmer — EVERYONE — must view the situation with very considerable concern.

It is absolutely imperative to generate and implement a well-conceived and co-ordinated plan of action, directed on the one hand toward the conservation of energy, and on the other toward the development and utilisation of alternative sources of energy.

There is no other way. Our existence as a thriving society is at stake.

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