Beef Production Options and Requirements for Fossil Fuel

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Summary. A large percentage of the feed resources used in beef production cannot be used by man or most other animals. These noncompetitive feeds could be used in different ways to increase beef production, but fossil fuel consumption by the beef industry would not be greatly reduced.

Agricultural production in the United States directly uses between 2 and 3 percent of the national energy, with beef production accounting for approximately one-fourth of this total (*1*). In this article we discuss the energy and resource uses by the beef industry and examine the alternative production strategies that might be implemented. We also apply to the national situation the methodology tested in a study of energy use for beef production in Colorado (*2*). Key questions that need to be answered are: What geographical areas would be favored by alternative strategies? How much beef could be produced with reduced use of fossil fuel? and What effects would these alternative methods have on the quality and acceptance of the beef produced?

Beef Production Systems

The beef industry consists of two rather distinct and seldom integrated components: breeding herds for calf production (cow-calf operations) and cattle undergoing the feeding or finishing phase. Besides or between these operations are stocking systems for rearing animals from weaning to the time they are put in the feedlot. Cattle also go to slaughter at various weights without being finished in a feedlot. The typical pattern of beef production and feed use is shown in Fig. 1.

Cow-calf operations. The national supply of beef is primarily determined by owners of brood cows. Many of these animals are in small herds (87 percent of them are in herds of less than 100 cows) belonging to part-time farmers who keep brood cows for a variety of reasons, of which monetary return is not dominant. The supply of calves is thus maintained to a large extent by operators who do not require that their product pay all the normal costs of production (*3*). Milk cows represent about 20 percent of the nation's cows and probably about an equal percentage of the beef produced. The larger commercial brood cow herds are usually located on land unsuited for other agricultural purposes, and are found mostly west of the Mississippi. Rather than the cow herd, the major and often dominant financial asset of such operations is the land, which continues to appreciate in value. The options for handling calves after weaning are varied, but generally calves consume feed resources similar to brood cows.

Feedlots. The feedlot developed as part of a system to market feed grains. The feed grains (for livestock) usually refer to corn, sorghum, and barley, whereas the food grains (for man) usually refer to wheat, rye, and rice. In times when the major grain market was livestock feed, it became profitable to use large amounts of grain to speed up the growth and fattening process which resulted in beef that was uniformly tender, juicy, and generally very acceptable to consumers. In marked contrast to the cow-calf operations where only minimal purchased inputs are economically justified, feedlots are highly mechanized, capital-intensive operations. Feeding periods run from 60 to 150 days, so that decisions on cattle feeding can be made very rapidly compared to cow-calf operations where decisions about size of operation are usually made only once a year and high fixed costs make it difficult to change methods. Feedlots and other systems for inducing the rapid growth of cattle first developed in the Corn Belt, but more recently they have expanded in the western states in response to increased feed grain production brought about by irrigation. The rapid changes that have occurred in cattle feeding are illustrated by the fact that total grain use for finishing cattle was 47 million metric tons in 1971, 46 in 1972, 38 in 1973, and 24 in 1974 (*4*). The percentage of forage (grass, hay, crop residues) in the average feed ration changed from 26 percent in 1971 to 39 percent in 1974. Cattle feeding thus adjusts rapidly to changes in the supply and cost of grain. Cattle feeders tend to manage the U.S. grain reserves (*5*), in fact, if not by design. As an example, at present (autumn 1977) wheat is the cheapest feed grain in many inland feeding locations and is being used extensively.

Heavy grain feeding is characteristic of the finishing or fattening phase carried out in the feedlot, and it is commonly believed, even by producers, that grain feeding produces fat cattle whereas forage-fed cattle are lean. Actually, the differences are primarily a matter of time and feed quality. As cattle get heavier, they lay down a higher percentage of fat. The percentage of fat is essentially the same at any given body weight regardless of the type of feed or the length of time taken to reach that weight (Fig. 2).

Growth occurs when an animal consumes more feed energy than it needs for maintenance. Cattle can consume more energy and thus gain weight more rapidly, if they eat grain rather than forage. To produce beef that will be marbled (intramuscular fat produces marbling) and will be graded as "choice" by the U.S. Department of Agriculture, it is usually necessary to feed the cattle on grain. Grass-fed cattle gain weight more slowly, do not attain sufficient weights, and are too old at slaughter to be graded as choice. Because of the more favorable price, the choice grade is the predominant goal of feeders, and thus it is apparent that the existing grading system has imposed a structure on the industry which in turn has institutionalized consumer tastes and a demand for grain-fed cattle.

Feed supplies for beef production. Feed use for beef cattle can be divided into four broad categories on the basis of competition for feeds and land by man and other farm animals. Feeds include forage, grains, and supplements in the form of vitamins, minerals, and various

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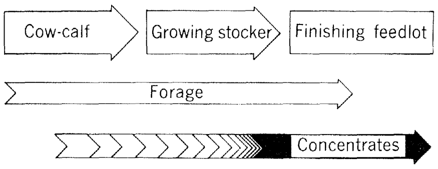

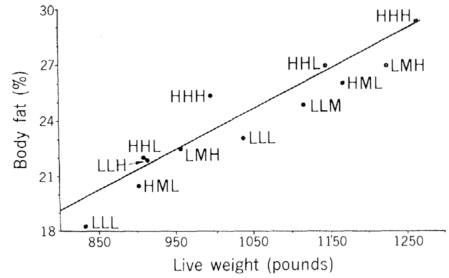

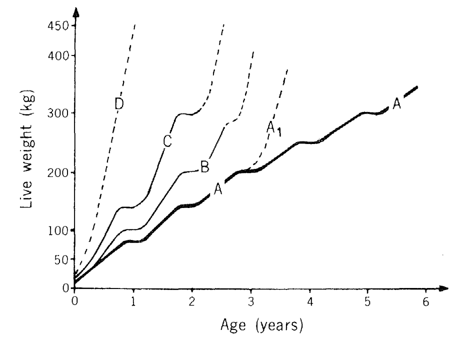

Fig. 1 (left). Beef production systems. Characteristic phases of the beef production system illustrating the relation between forage and concentrate feeding. Fig. 2 (center). The relation between live weight and carcass fat in cattle fed various levels of feed energy (*30*). Abbreviations: *LLL*, low energy (20 percent concentrates) for 273 days; *LLH*, low energy 182 days, high energy (90 percent concentrate) 91 days; *LMH*, low 91 days, medium (55 percent concentrates) 91 days, high 91 days; *HML*, high 91 days, medium 91 days, low 91 days; *HHL*, high 182 days, low 91 days; and *HHH*, high 273 days. Fig. 3 (right). Effect of different production systems on the growth pattern of beef cattle (*19*). Curve A, traditional extensive beef production on natural pasture; curve A_1, as for curve A but with intensive finishing; curves B and C, different types of semi-intensive production systems; and curve D, intensive feeding of fast-growing beef breeds.

additives. Feeds represent about 75 percent of the total cost of beef production, and the production of feeds represents the major energy use in beef production (*6*). Feed use for beef production has been summarized in detail by Byerly (*7*), and the implications for land use by crops and forage have been discussed by Wedin *et al.* (*8*). Feeding systems vary in energy requirements, and adjustments in production offer the potential for conserving nonrenewable resources. Feeding intensity is, in general, closely related to fossil fuel use and inversely related to the number of cattle that have to be maintained to supply a given amount of beef (Fig. 3).

1) The first category of feed use includes feeds, crop residues, and wastes which cannot be used as feed for other animals. Much of the rangeland areas of the West, for example, are marginal land that cannot be used for crops.

2) The second category includes forage from pastures and haylands on areas subject to erosion by wind or water, such as the drier areas of the Great Plains and the West. As a conservation measure, this is an effective use of such areas, but in many instances this type of land has been used for crop production. Competition for this land depends upon the price of grain.

3) The third category includes forage produced on good cropland in direct competition with other row crops such as corn silage, alfalfa, and clover. Corn silage and alfalfa are not consumed by man, but the land on which they are produced could provide food for man.

4) The fourth category includes grain that is to be used as feed but is produced in direct competition with grain to be used for other domestic animals and man.

Pasture is the dominant feed resource consumed by beef cattle (Table 1). Harvested forages represented a larger component than concentrates which accounted for only 12 percent of the total feed units in 1974. A substantial difference in feed use exists between cattle in feedlots and other beef cattle (including both the cow-calf operations and

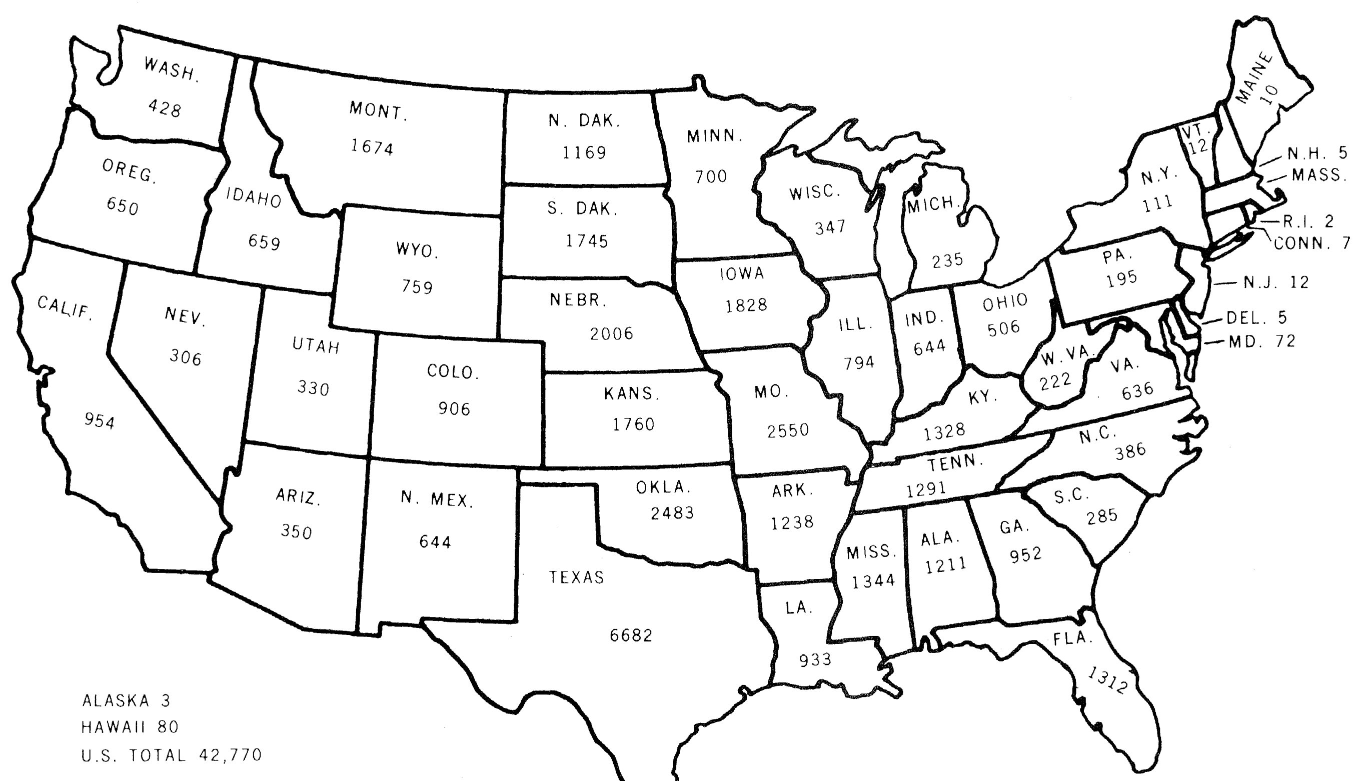

Fig. 4. Distribution of beef cows by states, 1 July 1976 (*31*). The data indicate beef cows that have calved (×1000).

stocking systems). The feed of other beef cattle consists of 83 percent pasture and only 4 percent concentrates, which are mostly protein supplements. Cattle in feedlots consume no pasture and almost 70 percent of their feed is concentrate. Forage resources that have supported the increased numbers of beef cattle in recent decades (a twofold increase since 1950) have to a large extent been made available by large decreases in numbers of sheep and dairy cattle. Dairy production has become energy- and capital-intensive while sheep production has declined for a number of reasons, including predator problems (*9*).

Geographical distribution. The location of cattle operations is dictated by the availability of feed. Cow-calf operations are found largely in the West, Great Plains, and Southeast, where grazing is available. Cattle on feed are located in grain-surplus regions including the Great Plains and the Corn Belt. Specific locations by region are shown in Table 2, while total cow numbers by states are shown in Fig. 4. Western states have vast areas of rangeland, but total cattle numbers are not great because carrying capacity is low. The Northeast has much abandoned cropland of low fertility, but the winter feeding period is too long to allow profitable cattle operations. The Southeast has had the most rapid growth of beef cattle in recent decades. However, the feed supply of this area is heavily dependent on fertilizer for pasture.

The feedlot sector is much more concentrated than the cow-calf sector. The Northern Plains, Corn Belt, and Southwest control 70 percent of feeding. Feeding in the Corn Belt has actually declined 22 percent in the last 10 years, whereas it has expanded 38 percent in the Northern Plains and 87 percent in the Southwest (Table 2).

Energy Use for Beef Production

Energy use in beef production can be divided into two general categories: fuel used directly for the operation of ranches and transportation of cattle and feed, and the energy required to produce feed for the cattle. The major energy use by cow-calf operations on the extensive ranges of the West are for pickup trucks and producing hay for winter feed. Table 3 reviews some estimates of fuel use on Colorado ranches as well as requirements for ranches in some other western states. Fuel use by motor vehicles per pound of gain taken from Colorado farm-management records indicates that 2.0 to 4.0 megacalories (Mcal) of fuel was required per pound of gain per head (*10*). Range production of beef is no longer a low-energy operation since the cow pony has been replaced by the pickup truck and the cattle are driven by transport trucks. Cow-calf enterprises in the more humid regions of the country (that is, the Southeast), by contrast, require less land per cow and require less transportation but are generally heavily dependent on nitrogen fertilizer, which represents the major energy input in this region. As indicated above, the majority of brood cows are in small herds and it has been difficult to obtain reliable estimates of energy use for these operations.

Energy requirements for feedlot operations are about 1.0 Mcal per head per day (Table 3). The fossil fuel energy represented by feed is dependent upon the type of ration fed; high concentrate rations produced under Colorado conditions, consisting mostly of ground corn and resulting in 3.0 pounds per day of gain, require 21.0 Mcal for feed and only 1.0 Mcal for feedlot operation (*3*). A corn silage ration producing 2.0 pounds of gain per day requires 12 Mcal for feed and 1.0 Mcal for feedlot operation. The high corn grain ration therefore requires

Table 1. Total feed consumption in corn feed unit equivalents for 1974 to 1975 in millions of tons (*24*).

Feed source	Cattle on feed	Other beef cattle	All beef cattle
Concentrates			
Feed grains	21.4	7.9	29.2
Food grains	1.2	0.1	1.3
By-product feeds	3.9	3.0	6.9
Total concentrates	26.5	11.0	37.4
Harvested roughages	12.2	37.6	49.8
Pasture		230.3	230.3
Total all feed	38.7	278.9	317.5

Table 2. Regional distribution of cattle in the United States with percentage change, 1967 to 1977 (*25*).

Region	Percentage of totals, January 1977				Percentage change in numbers, 1967 to 1977		
	States (No.)	Cows	Other cattle	Cattle on feed	Cows	Other cattle	Cattle on feed
Pacific	3	5.8	6.1	8.4	−3.0	0.2	−12.7
Mountain	6	9.1	8.3	10.9	6.0	4.9	31.6
Northern Plains	4	12.9	15.0	26.3	0.9	−9.0	38.4
Southwest	4	19.5	19.4	20.2	19.9	46.8	86.8
Lake states	3	8.1	8.6	5.5	−6.4	−32.8	−23.1
Corn Belt	5	15.2	18.4	24.0	20.5	15.4	−22.1
Southeast	12	24.1	20.0	3.6	22.3	29.7	11.0
Northeast	11	5.1	4.1	1.0	−9.7	18.4	10.2
U.S. total		100	100	100	10.3	16.2	11.4

Table 3. Energy requirements for components of beef production system.

Management system	Gain	Reference
*Energy required by cow-calf systems to produce 1 pound of gain by a weaner calf**		
Yearlings, mountain pasture	2.35	(*6*)
Range, 1 pound of winter supplement	2.48	(*26*)
Range, 2 pounds of winter supplement	2.61	(*26*)
Summer range, winter feeding	4.00	(*26*)
Average ranch, California	5.64	(*13*)
Average ranch, New Mexico	14.4	(*27*)
Sprinkler-irrigated pasture (northeast Colorado)	6.1	(*6*)
Energy use for feedlot operations†		
Average for Colorado	1.00	(*6*)
Average for California	0.36	(*13*)
New York estimate	0.52	(*33*)
U.S. survey	0.46	(*12*)
Survey 14 Kansas feedlots	1.20	(*28*)

*Gain expressed as megacalories per pound. †Gain expressed as megacalories per head per day.

Table 4. Energy components for Colorado feed crops.

Irrigated*	Megacalorie per pound of dry weight	Metabolizable energy (Mcal/Mcal)†	Percent of total energy					
			Tillage	Irrigation	Transport on farm	Total direct	Ancillary	Embodied
Corn grain	0.92	0.62	4	46	2	53	3	13
Corn silage	0.44	0.38	7	42	5	53	34	13
Alfalfa	0.40	0.43	3	78	1	82		19
Sugar beets	0.48		9	42	7	58	27	14
Irrigated pasture	0.35	0.34	1	54	1	56	32	12
Dry land				62	2	71	12	17
Wheat	0.33	0.23	51	0	13			
Milo	0.54	0.41	38	0	9	47	38	15
Sorghum pasture	0.09	0.08	46	0	17	63	23	14

*Center-pivot sprinkler, electric power, pumping depth of 240 feet. †Megacalories of fuel energy used per megacalorie of metabolizable energy in feed.

7.3 Mcal of cultural energy per pound of gain compared to 6.5 for the corn silage ration.

Under some conditions the energy requirements for range production of beef are as high as those for the feedlot (Table 3). However, the range estimates include the energy used to maintain cows throughout the year, whereas for other systems, only the weight gain of the calf or feeder is considered.

Figure 5 presents some of the possible combinations of management systems for which we have derived energy estimates. The fossil fuel energy required to produce important feed crops is detailed in Table 4 together with fossil fuel energy required to produce feed energy for beef cattle. In discussing different livestock operations, it is important to distinguish fuel from feed energy. Any combination of the three phases (Fig. 5) of beef production can be or are used to produce beef, and cattle may be slaughtered at younger ages or lighter weights. Table 5 summarizes some of the energy and protein efficiencies calculated from the data in Fig. 5. The least energy-intensive combination will produce a 1100-pound steer with the use of 3379 Mcal, whereas the most energy-intensive combination shown in Table 5 requires 7641 Mcal. If the same carcass composition is assumed, the former uses 3.0 Mcal per megacalorie of carcass beef and the latter 7.0, while approximately two times this energy expenditure is required to produce the energy of retail beef.

These energy efficiencies are low compared to energy conversion by cereals or potatoes, although many fruits and vegetables show an even lower efficiency of energy conversion (*11*). The total energy inputs for the diverse Colorado management systems range from 3379 to 7641 Mcal per head. By way of comparison, the data of Lockeretz (*12*) for all the beef-producing regions of the United States, when calculated on a similar basis, ranges from 1100 to 8000 Mcal per head depending upon the feeding system. The data presented as an average for the state of California on the same basis is 3350 Mcal per head slaughtered (*13*). Our estimates of the energy used by packing plants indicated 100 to 600 Mcal per animal for slaughter and dressing as wholesale beef.

The calculations presented here include only limited transportation of feed or animals because of the difficulty in deciding upon the appropriate distances of transport for the various management systems. Table 6 shows the basis for calculating the energy used for cattle and feed transportation. By way of comparison, a 100-mile trip by a 600-pound steer would require about the same energy as one day's feed in a feedlot.

Energy for Beef Protein

It is difficult to describe the efficiency of protein production by ruminants in a single meaningful expression. This is because ruminants, through the agency of their rumen microbial population, have the ability to convert low-quality protein of nonprotein nitrogen into tissue protein of the highest quality. No good means is available to account for the improvement in protein quality or to treat the efficiency of use by ruminants of low-quality protein that is completely unutilizable by humans. Protein efficiency is usually calculated as total nitrogen times the factor 6.25 (the average amount of nitrogen in protein), but this method provides no indication of protein quality. Estimates of this type are given in Table 7, which indicate that protein production efficiency by beef cattle is lower than other species except sheep. But typically, this analysis ignores the fact that protein consumed by cattle is only partially competitive with man's protein supplies or even that of nonruminant farm animals. A measure of protein quality improvement based on the protein efficiency ratio of cattle feeds compared to the value of beef (*14*) shows an average value for conversion efficiency three times greater than that calculated (as in Table 7) on the usual crude protein basis.

Pimentel *et al.* (*15*) calculated the energy use for protein production by various plant and animal species. These estimates are mostly 2 to 4 Mcal of cultural energy per megacalorie of protein from plants, while beef protein estimates range from 10 Mcal for range to 78 Mcal for feedlot beef. When our data (*6*) were calculated in the same manner, we obtained lower estimates for feedlot beef (Table 5) whether they were based on the protein in carcass beef or the protein in retail beef. The least energy-intensive of the management systems that we studied required 16.0 Mcal of energy to produce 1 Mcal of carcass beef protein with a 1100-pound steer, while the most energy-intensive system required 36.0 Mcal. For comparison, the same data are presented for a 700-pound steer which, if fed the least energy-intensive diet, would require 6.6 Mcal per megacalorie of protein, or one-half the requirement for the 1100-pound steer. However, this approach to efficiency is misleading because, unlike broilers, an average beef cow produces only 0.8 calf per year and, because the offspring are slaughtered at lighter weights, beef production per cow is reduced.

The data of Lockeretz *et al.* (*12*), recalculated in the same terms, indicates the use of 1100 to 8000 Mcal of cultural energy to produce a 1000-pound slaughter animal, which means that the range of their protein efficiencies falls almost exactly within the limits shown for our data in Table 4. A California survey (*13*) of energy use for beef production indicates a mean value for that state of about 18 Mcal per megacalorie of beef protein in the carcass.

Reducing Energy Use for Beef Production

Possibilities for reducing energy use in beef production can be divided into three groups: first, energy conservation within the current production system; second, a reduction in beef production; and third, alternative production strategies.

Energy conservation. Wasteful uses of energy were not found in our study of the beef industry. However, several marginal energy uses could be eliminated without adverse effects, and several new techniques would, if more completely adopted, reduce energy use.

One of the major energy uses in cow-calf production is transportation fuels for pickup trucks. Because of the large distances over which production occurs, great use is made of pickup trucks. Use of more economical vehicles would aid in this respect. Much of the grazing by cow-calf operations occurs year-round. For greater efficiency of pasture and range use, a trend toward semiconfinement in cow-calf operations might be considered. Greater numbers of cows could be supported by grazing only during the summer season when forage quality is good. Harvested roughages or residues could be fed during the winter season.

Feed processing is not a major energy use (*11*) compared to feed production, but energy use and benefits, such as weight gain response to energy inputs, need to be documented more carefully. Dehydrated alfalfa has been a widely recommended winter supplement for cattle in the West because it provides protein, as well as energy, phosphorus, and carotene. However, dehydrated alfalfa is one of the most energy demanding of feed-processing methods because of the need to dry immature plants. The use of 2 pounds of this feed per day for 6 months in winter can double the energy required to produce weaner calves.

Energy requirements for beef production are primarily associated with feed production. In the West, most feed production requires irrigation; and irrigation, if pumping is required, is energy-intensive (*3*). Energy has not been efficiently used for irrigation pumps in the past, and potential energy savings of 25 to 40 percent are suggested (*16*). After irrigation, nitrogen fertilizer is the major energy requirement for feed production in the West as well as in other parts of the country, except where legumes are grown. Some fertilizer-based energy could be saved by better conservation of the plant nutrients in animal manure.

The prospects for improving the efficiency of protein utilization appear to be minimal. The only wasteful use of protein, if it can be called that, for example, is the grazing of cattle on young, high-protein grass, which contains more than the necessary protein. Otherwise, the amount of protein consumed by cattle, unlike the amount consumed by many people in the United States, is generally close to the minimum required for economic reasons. Many grazing cows in the winter, in fact, are fed less protein than desirable. Beef cattle on feed in 1974 consumed 1 million tons of protein supplements, and 0.7 million tons was fed to other beef cattle. This is a small fraction of the total of 19 million tons consumed by all livestock; poultry consumed 8.9 and hogs 5.9 million tons (*4*).

Urea is an important substitute for protein in cattle feeds, mostly in feedlots. However, urea production, like the nitrogen fertilizers, requires large energy inputs. Furthermore, urea has not proved to be an effective substitute for protein in diets composed of poorly digestible forage such as found in winter ranges and pastures.

Reduction in beef consumption. One suggestion, often voiced, to reduce energy use in beef production is to reduce the amount of beef produced. Although imports are not mentioned in relation to this solution, it is assumed that this 7 percent of the supply would not be increased. The nutritional consequences of a substantial reduction in the beef supply have not been analyzed, but two diverse conclusions can be drawn. One, a protein deficiency is a possibility because beef is a major source of high quality protein for some populations (*17*). The opposite conclusion, that a reduction in beef consumption would be desirable, can be drawn from a recent Senate committee report which recommends that

Table 5. Fuel energy use per unit of beef energy and energy of beef protein.

Range	Total	Energy input (Mcal)			
		Per carcass energy	Per retail beef energy	Per energy from carcass protein	Per energy from retail protein
			1100-pound steer		
Lowest	3379	3.0	6.7	16.0	19.7
Highest	7641	7.0	15.1	36.0	44.4
			700-pound steer		
Lowest	1262	2.0	4.4	6.6	8.1

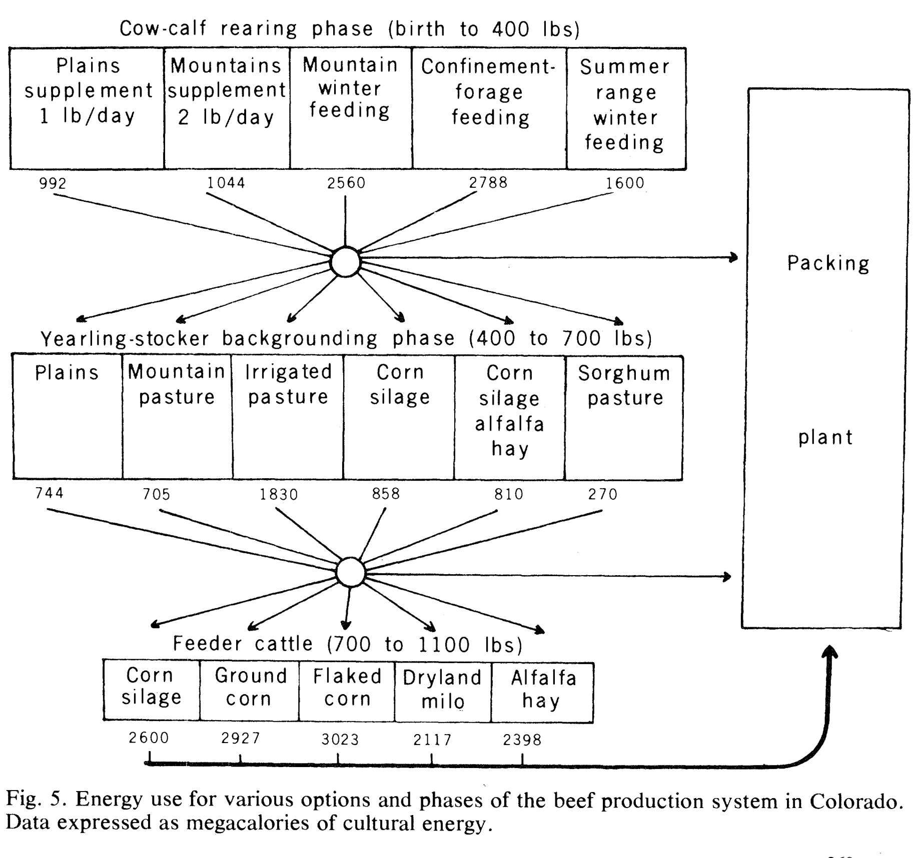

Fig. 5. Energy use for various options and phases of the beef production system in Colorado. Data expressed as megacalories of cultural energy.

the intake of fat, especially saturated fat, should be reduced (*18*).

Factors affecting supply have dominated this discussion, but demand has to be considered. Changes in income have had a great influence on the demand for beef. Also, a remarkably constant 2.5 percent of disposable income has been spent for beef since 1948. However, in the last quarter of 1976 this percentage decreased to 2.27, which raises a question about future spending for beef. Demand for beef is dependent not only on consumer income, but also on population and the price of other products. Demand has been expanding because of the higher incomes and populations. Per capita consumption of beef in the United States has increased from 85 pounds in 1960 to 114 pounds in 1970 and 129 pounds in 1976.

Most projections of future beef consumption consider an average or static situation, when in reality the 9- to 12-year cattle cycle superimposes waves of instability on the market as illustrated in Fig. 6. Unfortunately, price signals are not reflected in the number of cattle ready for slaughter until 4 to 5 years later. In analyzing any trends or projections of the cattle business, it is absolutely essential to establish what phase of the cycle is included in the data. Differences of 20 to 25 percent between high and low beef supplies often mean that short-term trends that are detected are reflections of changing cattle inventories rather than economic changes in the country or in the beef industry. For example, the beef being produced from grass-fed cattle, and the increasing consumption of ground beef in 1975 and 1976 may be only a reflection of a reduction in the numbers of brood cows.

Alternative systems of production. The most frequently suggested alternative to the current system is greater dependence upon forage resources to produce a leaner beef product. However, a complete return to traditional grazing will not succeed because production per animal will decrease drastically. As an example, on the international scene, the average amount of beef produced per head of cattle ranges from 13.9 kilograms in the developing countries, where little or no fossil fuel or competitive feeds are used, to 74.3 for the developed countries (*19*). A change of U.S. production methods to less energy use would reduce the beef produced per head but would require more cows with less beef.

If it is assumed that grazing land cannot be used for other purposes, then the feed used for about 60 percent of the present population of beef cattle feed is

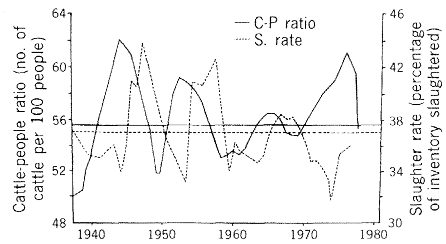

Fig. 6. Ratio of the total number of cattle to the U.S. population, and slaughter rates by year (*32*).

noncompetitive (*7*). Actually, the reduction in beef production would be greater than 60 percent because cattle produced entirely on grass have almost always been slaughtered at lighter weights: at about 800 pounds, compared to the common 1100 pounds for grain-fed steers. A change from a slaughter weight of 1100 to 800 pounds requires an increase from 2.2 to 3.0 cows to produce 1000 pounds of carcass beef.

Beef production requires the use of large amounts of land. With a diminishing agricultural land base and traditional production techniques, the carrying capacity of rangeland is fixed. Nevertheless, cattle producers do not perceive forage limitation as a major constraint upon the expansion of beef production (*20*). Production techniques that can raise the limits are known, such as fencing, water supplies, fertilization, irrigation, mechanization, and the use of herbicides and pesticides, all of which

Table 6. Estimated energy requirements for transportation of cattle and feed expressed as megacalories per ton-mile.

Load	Truck size	
	2-ton	Tractor/trailer
400-pound cattle	1.08	0.53
600-pound cattle	0.96	0.46
1100-pound cattle	0.86	0.40
Grain	0.52	0.25
Hay	1.15	0.39

Table 7. Efficiency of production of animal protein and energy by farm animals (*29*). All calculations include nutrients for entire production systems, that is, nutrients for cow to produce calf.

Protein source	Protein efficiency (g/Mcal)*
Milk	12.8
Broiler	11.9
Eggs	10.1
Pork	6.1
Beef	2.9

*Edible protein (in grams) divided by total digestible energy consumed (in megacalories).

are energy-intensive. Associated with greater energy-intensiveness are also higher production costs. A recent regional analysis of beef cow-calf production costs illustrates the above point (*3*). In the slowly expanding beef cow regions of the Great Plains, variable annual costs per cow range from $65 to $81. However, in the more rapidly growing areas, costs were more than twice as great; $164 per cow in the Corn Belt and $201 in the Southeast. The costs of fertilization and of harvesting forage for winter feed raise the costs in these areas. Beef cattle expansion to date has not been based on the low-energy grazing system but upon low-cost systems requiring fertilization and mechanical harvesting. Two examples of potential expansion are available. A national study indicated that pasture and range production could be doubled in 10 years by improving management and using more fertilizers, herbicides, and tillage for reseeding (*21*). Our results indicate that further expansion of the beef industry in Colorado is possible with corn silage feeding (*6*).

Crop residues, especially cornstalks and straw, are receiving greater attention. However, at present, the largest sources of these materials are in areas where there are few cattle and few fences. The cost of harvesting and processing such products is, at present, only marginally economical. If feed prices increase more rapidly than processing costs, these feed resources may become important to the beef business. Another source of largely unexploited feed is manure. By feeding manure, the available feed supply can be considerably expanded. Experiments indicate that manure recycling can be an efficient alternative, but most of the processes are in the developmental stage and must be adjusted to greater energy costs. Manure recovery is possible only in confinement or feedlot situations. A national inventory of wastes and residues has been completed which indicates the magnitude of this potential resource for feed or for other purposes such as bioconversion (*22*).

An interesting alternative frequently suggested for reducing energy use is the replacement of domestic breeds of cattle with bison. This would eliminate the need for supplemental feeding because bison have the ability to forage in deep snow and their nutrient needs are more closely matched by native grassland production. But the bison's undomesticated nature would require far greater inputs for fencing, restraint, and handling. In addition, its reproductive efficiency and growth is inferior to cattle (*23*).

Conclusions

Fossil fuel energy use for beef production was estimated to vary from 5.1 to 11.6 Mcal per pound. Per capita consumption in 1976 was 129 pounds of beef or 658 to 1493 Mcal per capita. The equivalent in gasoline would be 19.7 to 49.8 gallons per capita, which might be compared to the use of 50 gallons of gasoline for driving 1000 miles in an automobile with a gasoline consumption of 20 miles per gallon.

Energy in the national beef production system is used primarily for the production of feed, and any proposal for major reductions in energy use will have to be directed toward alternative feeding systems. There are no low energy options for producing beef in the quantities approaching those currently consumed in this country.

Differences in fossil fuel use by alternative production systems are not as large as commonly supposed, but changes in the use of scarce fuel resources could release feed resources for other uses by directing beef production toward greater use of noncompetitive feed resources. Much criticism has been directed toward grain feeding of beef cattle and a reduction in grain use would reduce, to some extent, energy use per pound of beef. A reduction in grain feeding and earlier slaughter is also often proposed as a method for reducing the fat content of beef. Such a change would have appeal, but it would require dramatic changes in the institutional framework in such areas as beef grading, storage, marketing, advertising, and consumer acceptance. The members of the livestock industry, particularly cattlefeeders, have been in a sense the managers of the U.S. grain reserve, and no other mechanism such as large-scale storage, is now operating that could adequately handle a fluctuating grain supply. Grain for export has been readily available at the expense of livestock feeding whenever the demand was adequate.

National energy policy might place emphasis on the use of energy resources for alternative feeding systems. The broad choices are to use energy for (i) improvement of pastures and ranges, (ii) harvesting and processing unused wastes and crop residues, (iii) production of higher yielding forages from cropland, and (iv) production of cereal grains as an integral part of a planned grain reserve program. Certainly some combination of the alternatives will continue to be used. A cost-benefit analysis of these options could be made in terms of energy conservation and other socially desirable objectives. Policy decisions to favor one or more options would then require some mechanism that would direct beef production toward that option.

A reduction in per capita beef production would reduce energy use, and an anticipated price increase in the near future will almost certainly result in a decline in consumption. But if trends of the past continue, this will trigger an increase in cattle numbers and some 10 years from now, a return to the current phase of the cattle cycle.

From this analysis it is clear that beef protein production requires more energy than most other protein sources and that major reductions do not appear feasible without substantial reductions in beef supply. With our market economy, certain federal policies could change the situation, the most obvious being some form of energy rationing or control. Otherwise, beef consumption is a response to supply and demand, and exhortations for energy conservation through reducing beef consumption are not likely to be very effective.

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