Summary

Analyses of the economics of solar collection in the firm- and shifting-peak cases (that is, with off-peak electricity indefinitely available or with a flat load curve) indicate that, for many important applications, solar energy systems that interface with electric utilities can be justified only in terms of the value of the off-peak utility fuels that they displace. In regions where off-peak electricity costs are low, the most economically efficient solar energy systems will be those that use electricity as the auxiliary energy source. This implies extremely low break-even costs for a number of important solar energy applications. In regions where the cost of off-peak electricity is higher than that of competing energy forms, the most economical solar energy systems will utilize auxiliary fuels other than electricity.

The general conclusion is that conventional electric utility systems and most solar energy systems represent a poor technological match. The basic problem is that both technologies are very capital intensive. The electric utility, because of the high fixed costs of generation, transmission, and distribution capacity, represents a poor backup for solar energy systems. On the other hand, the solar collection system, because it represents pure, high-cost capital and because of its outage problems, cannot be considered as a part-load source of auxiliary energy for the electric utility system.

References and Notes

1. See, for example, P. J. Hughes, W. A. Beckman, J. A. Duffie, paper presented at the Sharing the Sun Conference, Winnipeg, Canada, August 1976. See also *Solar Engineering Magazine* (August 1976), p. 24.
2. Basing the break-even cost for the solar collection system on the current price of base-load fuel is equivalent to assuming that the real rate of increase of the price of base-load fuel less the real time rate of discount of money is zero. This appears to be a reasonable assumption. See, for example; Staff Report, Executive Office of the President, Council on Wage and Price Stability, *A Study of Coal Prices* (Washington, D.C., March 1976); J. G. Asbury and K. Costello, *ASME Publ. No. 76-IPC-PWR-7* (May 1976).
3. J. G. Asbury and A. Kouvalis, *Argonne Natl. Lab. Publ. No. ANL/ES-50* (April 1976). Although the storage components on either side in Fig. 1b are drawn the same, the storage devices used in electric storage heating systems are generally of higher quality or lower cost than the storage devices used in solar systems. Under worst practice, the same storage device used in the solar system can be incorporated in the storage heating system. The principal advantage of storage in electric storage heating is the high temperature, up to 1200°F, that can be achieved in magnesite bricks or other materials.
4. J. Asbury, R. Giese, S. Nelson, L. Akridge, P. Graf, K. Heitner, "Assessment of Energy Storage Technologies and Systems (Phase I): Electric Storage Heating, Storage Air Conditioning and Storage Hot Water Heaters," *Argonne Natl. Lab. Publ. No. ANL/ES-54* (October 1976).
5. See, for example, C. Cicchetti, W. Gillen, P. Smolensky, "The Marginal Cost and Pricing of Electricity: An Applied Approach," *Natl. Sci. Found. Rep. STA 74-24370* (June 1976); L. T. Mahoney, Jr., National Economic Research Associates, Inc., testimony at a hearing before the Public Service Commission of New York, Case No. 26806, January 1976; testimony at a hearing before Public Service Commission of Wisconsin, Docket No. 6630-ER-2, December 1975; J. G. Miller, Wisconsin Power and Light Company, testimony and exhibits at a hearing before the Public Service Commission of Wisconsin, Docket No. 2-U-8085, April 1976.
6. S. F. Gilman, Ed., *Solar Energy Heat Pump Systems for Heating and Cooling Buildings–Workshop Proceedings* (Pennsylvania State Univ. Press, University Park, and ERDA Technical Information Center, Oak Ridge, Tenn., 1975).
7. See, for example, V. D. Karman, T. L. Freeman, J. W. Mitchell, "Simulation study of solar heat systems," paper presented at the Sharing the Sun Conference, Winnipeg, Canada, August 1976.
8. Gordian Associates Incorporated, "Evaluation of the air-to-air heat pump for residential space conditioning," report prepared for the Federal Energy Agency under contract FEA-CO-04-50171-00, April 1976.
9. As shown in (*8*), the cost of a heat pump sized to meet the cooling load is approximately $1000 greater than the cost of an air conditioner. This cost difference holds approximately for most regions of the country. Although the heat pump is less efficient in the air-conditioning mode than the standard air conditioner, this charge against the heat pump is ignored here. None of the solar-assisted heat pump concepts considered here use solar energy when the heat pump is operating as an air conditioner.
10. We ignore the resistance component of the heat pump's design-day power demand. For the system design concept examined here, energy can in principle be input to the storage reservoirs during nighttime hours to eliminate the following day's on-peak resistance power requirement.
11. For a detailed analysis see J. G. Asbury and R. O. Mueller, *Argonne Natl. Lab. Publ. No. ANL/ES-52* (August 1976).
12. Public Service Electric & Gas Co., "An assessment of energy storage systems suitable for use by electric utilities," report prepared for the Energy Research and Development Administration under contract E(11-1)-2501 and the Electric Power Research Institute under research project 225, July 1976.
13. These break-even storage costs correspond to PSE&G's "typical values" for generating plant capital and fuel costs. The PSE&G also calculated break-even cost ranges corresponding to variations in input costs. The PSE&G typical value conventional-plant generating costs are similar to those used in the Aerospace study cited below.
14. Aerospace Corp., "Solar thermal conversion mission analysis—Southwestern United States," report prepared for the National Science Foundation under contract NSF-C797, January 1975.
15. For the efficient-price solution, see O. Williamson, *Am. Econ. Rev.* **56**, 810 (1966); M. Crew and P. Kleindorfer, *J. Polit. Econ.* **79**, 1369 (1971).
16. We thank E. Croke for a very helpful suggestion and R. Giese, S. Nelson, and V. Rabl for a number of useful comments. Supported by the Chemical and Thermal Energy Storage Branch, Division of Energy Storage Systems, Office of the Assistant Administrator for Conservation, Energy Research and Development Administration.

Ruminant Livestock Research and Development

Six vital areas of ruminant R & D need increased support to help meet year 2000 productivity needs.

T. C. Byerly

Ruminant livestock (cattle, sheep, goats, water buffalo, camels) represent one of man's most valuable renewable resources. They provide edible protein of exceptional value, fiber, leather, and a wide variety of useful by-products and even, in some countries, motive power and fuel. How to maintain an adequate supply of ruminant products—in the face of rising human population—is one of the more serious research problems facing agricultural scientists today. An obvious solution would be to increase the ruminant inventory by increasing the rates of calving and weaning. But to do this would require a corresponding increase in the quantity and quality of the feed base. Instead, by placing more research emphasis on increasing the efficiency of ruminant production, we could boost world production of ruminant meat and milk protein by 50 percent without adding to the current land area used to support ruminant livestock, and without increasing the present world inventory of ruminant livestock. In reality, an intermediate course is most likely to develop, with a moderate increase in numbers occurring along with an increased efficiency of production.

A brief survey of pertinent data shows the need for this projected 50 percent increase in production and the extent of the resources required to attain the goal.

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If the current rate of increase in human population continues, in the year 2000 the world will have a population of 6.4 billion people, up from 3.92 billion in 1974. Total edible ruminant protein produced in 1974 was 25 million metric tons, which gave an average world per capita consumption of 6.4 kilograms of edible protein. To maintain that average for the year 2000 would require a total world production of 37.7 million metric tons, that is, an increase of approximately 50 percent (Table 1).

Actually, the average world per capita consumption might decrease from the current 6.4 kg to about 5.9 kg, because in the developing countries where the per capita figure is low (3.3 kg), population would increase most rapidly. When one considers that the present and projected per capita supply of milk and meat protein for the developed countries is 15.5 kg, and that of countries with centrally planned economies is 5.8 kg, the projected increase in world total edible protein from ruminants becomes more of a necessity rather than just another desirable goal (*1*).

Data in Table 1 indicate a one-to-one relation between scientist-man years (SMY's) and productivity. If we assume that the 1974 relation continues, an increase of about 45 percent in SMY's would be necessary to maintain per capita levels of ruminant edible protein production to the year 2000. However, since the rate of response of production to new technology increments may be falling, the estimate of needed SMY's may be somewhat low.

The other resource required to meet the year 2000 per capita protein requirement is, of course, a monetary one, and here the increase in R & D funds required is about the same as that for SMY's, that is, 45 percent. Whatever the sources for these added funds—the countries themselves, foreign assistance, or public foundation support or industry—world governments will have to establish the policies necessary to implement the resulting technology for production, product marketing, and consumer use. Particularly in developing countries, development programs cannot succeed without adequate government commitments and supportive policies.

R & D Funding

The United States continues to provide the most support among all countries for all types of R & D; that support was more than $28 billion in 1972 and is now more than $30 billion annually. However, U.S. support in terms of gross national product (GNP) has declined steadily since 1964. During the same period, West Germany, Japan, and the Soviet Union have increased that part of their GNP allotted to R & D.

Funds provided by central governments for agricultural R & D in relation to total R & D appropriations vary widely, from 1 percent in Italy to 19 percent in Canada during 1972. Only Italy devoted a smaller proportion of its centrally appropriated funds to agriculture than did the United States. Expressed in constant dollar terms, appropriations for agricultural R & D in the United States, the United Kingdom, and France continued to decline from 1972 to 1975 (*2*). All three country groups (developed, developing, and centrally planned economies), however, spent approximately the same proportion of their total R & D funds on agricultural research, that is, from 4 to 5.5 percent (Table 2). Both the developed and the developing countries spent about the same proportion, 17 percent, of their agricultural R & D funds on ruminant research. Countries with centrally planned economies assigned 11 percent to ruminant R & D.

Funds for R & D in the U.S. Department of Agriculture (USDA) and cooperating institutions are estimated to be about 60 percent of all funds used for agricultural R & D in the United States. Over a 7-year span, from 1967 to 1974, the relative R & D emphasis in some product categories has varied markedly (Table 3). For example, SMY's, and funds for range, pasture, and forage research declined from 1967 to 1974. During the same period, however, R & D emphasis on corn, sorghum, other grains, and soybeans increased substan-

Table 1. Population of countries by groups, ruminant inventory, R & D funds expended, scientist-man years (SMY's), and edible protein produced in the world in 1974 and projected for 2000.

Year	Human population (millions)	Ruminant inventory (millions)*	Ruminant R & D funds (million dollars)	SMY's (thousands)	Edible protein: Total produced (million metric tons)†	Edible protein: Amount per animal unit (kg)†	Edible protein: Amount per capita (kg)†
			Developed countries				
1974	730	275	390	11.3	11.3	41	15.5
2000	1,000	278	534	15.5	15.5	56	15.5
			Centrally planned economies				
1974	1,290	235	105	6.9	7.5	32	5.8
2000	1,800	235	147	9.0	10.5	45	5.8
			Developing countries				
1974	1,900	700	80	5.5	6.2	9	3.3
2000	3,600	700	152	10.0	11.7	17	3.3
			Total				
1974	3,920	1,210	575	23.7	25.0	21‡	6.4‡
2000	6,400	1,213	833	34.5	37.7	31‡	5.9‡

*Animal units. †Edible protein is the composite of 16 percent of carcass weight, 3.5 percent of cow and goat milk weight, and 5.2 percent of buffalo and sheep milk weight. Carcass and milk weight values were taken from (*33*). ‡Average for all countries.

Table 2. A comparison of GNP, funds, and SMY's for all R & D with funds, SMY's, and publication output for agricultural R & D.

GNP (billion dollars)	All R & D for 1974: Funds (million dollars)	All R & D for 1974: SMY's (thousands)	Agricultural R & D in 1974: Funds (million dollars)	Agricultural R & D in 1974: SMY's (thousands)	R & D articles (thousands)*
		Developed countries			
2,492	53,707	1,439	2,240	62	60.6
		Centrally planned economies			
704	21,146	1,436	957	67	32.4
		Developing countries			
459	8,442	627	465	36	25.0
		Total			
3,655	83,295	3,502	3,662	165	118.0

*These are estimated numbers of articles in primary and review research journals, based on a worldwide abstract survey.

tially. Funds and SMY's for livestock, including ruminant animals, remained about the same.

Some foreign agricultural research is conducted in countries that have accrued funds to the credit of the United States from sales of farm products. These funds, which they receive under authority of Public Law 480, are appropriated by the Congress from year to year and are administered by the USDA. From 1961 to 1975, 170 projects related to ruminants or forage were completed in 20 countries under the PL 480 program.

Foreign research is also conducted through contracts between the U.S. Agency for International Development and U.S. universities and other research agencies.

About $465 million is spent annually for all types of agricultural R & D and technical assistance in the developing countries, and half of that is of external origin. About half of the external funds comes through United Nations agencies and half through other regional and bilateral intergovernmental programs and nongovernment sources (*3*). Foreign assistance for ruminant-related R & D is about $33 million annually.

Basis for Estimates

My estimates of trends in agricultural and ruminant R & D are based on published projects, programs, research reports, abstracts, and reviews on a worldwide basis. Both primary and review publications were scanned and those deemed relevant were read and their substance recorded and collated as quantitative and qualitative confirmation or negation of apparent trends. The reviews focused primarily on material published during 2 years a decade apart, 1965 and 1975, to provide a basis for estimating substantive trends.

In addition to the above sources, files of the National Agricultural Library were searched for material in journals from all countries and regions of the world.

Of the 3000 abstracts read for the 1965 estimates, about 2000 were related to ruminants; of the 5400 read for 1975, about 4000 were ruminant related. The numbers of ruminant-related abstracts in the sample were then expanded in proportion to their incidence in the journals of origin and their distribution among countries of origin to provide an estimate of total ruminant R & D articles (Table 2).

The total number of estimated ruminant-related R & D articles increased about 50 percent during the period under study. As might be expected, the developed countries and those with centrally planned economies have a larger average proportion of their agricultural R & D articles in the ruminant-related field than have the developing countries. Priority in most of the developing countries appears to be R & D on crops produced for human consumption.

My assumption of ruminant production capability in year 2000 is based on specific analyses of trends in six different areas of ruminant livestock R & D: forage and nutrition, diseases and parasites, reproduction and genetics, systems, product technology, and ruminant productivity.

Forage and Nutrition

Forage quality is the first limiting factor in ruminant production in many areas, particularly those with tropical climates. In the developing countries, most ruminants subsist wholly on forage (grass, hay, crop residues). In other countries, forage (or its equivalent in hay or silage) provides about three-fourths of the feed used by ruminants. Therefore, factors that affect the quality of forage in turn affect the quality and quantity of ruminant products. For this reason, much of the R & D on ruminant nutrition is directed toward forage improvement (*4*). Forage quantity can also be a critical factor, because where feed grains or other supplementary feed supplies are limited, forage provides an alternative for maintaining meat and milk protein.

The nutritive quality of pasture and range forage varies seasonally. In periods of rapid growth (spring or wet seasons), protein content may be more than 20 percent and the total digestible nutrients may exceed 70 percent. In other seasons, however, these values may be as low as 2 percent and 35 percent, respectively. Some grasses, especially in the tropics, are adequate during only brief periods of the year, or never.

Because of this natural variability in forage quality, supplementary feeding may be necessary during nongrowing seasons in some regions to avoid ruminant mortality. Supplementary feeding is often necessary to maintain reproductive level and is generally necessary to maintain milk production. However, supplementary feeding is not always profitable. Hence, research to improve technology for ruminant feeding continues in the use of hay, silage, feed grains, cassava, and other crops. Supplementation of grazing with molasses, urea, crop residues, millings, and industrial by-products and wastes is especially important (*5*).

Trends in R & D include the development of economically efficient forage production and incorporation of its use into ruminant production systems; the management of site, seasonal, and annu-

Table 3. Comparison of selected groups of agricultural R & D expenditures and number of SMY's in the USDA and cooperating institutions, 1967 and 1974. Data for 1967 from (*34*) and for 1974 from (*35*).

Product or research area	SMY's (number)		R & D funds (thousand dollars)		R & D funds (thousand dollars)*	
	1967	1974	1967	1974	1967	1974
Range	146	128	5,189	8,466	5,189	5,842
Pasture	65	59	2,870	3,763	2,870	2,644
Forage	322	296	13,076	17,833	13,076	12,305
Subtotal	533	483	21,133	30,062	21,135	20,791
Corn	277	327	11,567	19,307	11,567	13,322
Sorghum	65	86	2,329	4,819	2,329	3,325
Other grains	117	119	5,240	7,381	5,240	5,093
Subtotal	459	532	19,136	31,507	19,136	21,740
Soybeans	147	236	5,967	13,828	5,967	9,541
Poultry	409	375	21,570	28,263	21,570	19,501
Swine	195	221	13,906	21,400	13,906	14,766
Other livestock	73	95	4,386	7,175	4,386	4,951
Subtotal	677	691	39,862	56,838	39,862	39,218
Beef	457	529	29,514	50,184	29,514	34,627
Dairy	508	467	30,191	39,728	30,191	27,412
Sheep and wool	173	135	8,812	11,477	8,812	7,919
Subtotal	1,138	1,131	68,517	101,389	68,517	69,958
Total	10,171	10,613	472,913	729,227	472,913	503,167

*Constant dollars.

al variation in supply and quality of forage; supplemental feeding; and pasture and range improvement. Published abstracts in forage-related research increased from about 2100 in 1965 to about 4000 in 1974. A further increase of 1400 occurred in 1975, coincident with increases in feed and fertilizer costs and decreases in cattle prices. Increases in 1975 were sharp in North America, Australia, and the Soviet Union.

Production of ruminant carcass meat in 1974 was about 90 kg per animal unit in the developed countries, 30 kg in countries with centrally planned economies, and 20 kg in developing countries. Development and application of improved technology could double the current output of ruminant products in developing countries. In India, any increase would, of course, be mostly in milk and milk products.

Under the technology now being used, the complete elimination of grain in the feed of cattle raised for beef production would probably reduce the amount of beef produced in the United States. But by use of conserved forage, urea, molasses, and other non-whole cereal supplements, improved pastures, pasture and animal management, including disease and parasite control, it should be feasible to increase ruminant carcass meat output in the world by half.

By means of forage R & D it should be possible to develop the technology for producing 1 metric ton of beef, sheep, or goat liveweight per hectare, or 10 metric tons of milk, under optimal conditions. Input costs with present or prospective technology would have to be very high in order to approach this level in many regions of the world.

A more immediate R & D objective is to determine the conditions and systems under which forage production for ruminants on arable land can compete biologically, environmentally, and socially with cereal and other food crop production.

Efficiency of conversion of the energy and protein in feed to meat and milk is limited by reproductive rate. When reproductive rate is improved, feed efficiency will be improved.

Management of the energy flow from sunlight through forage plants and ruminant consumers to meat, milk, wool, leather, and recycled by-products as feed, fuel, or manure can contribute to increased energetic efficiency of the total system. The competitive position of ruminant products with synthetic materials and vegetable foods can be improved by R & D and the application of resulting technology (*6*).

Diseases and Parasites

Annual world mortality losses from diseases and parasites exceed 50 million cattle and buffalo and 100 million sheep and goats. Morbidity and its accompanying depressing effect on the quality of ruminant products accounts for an equivalent reduction in product realized.

The history of livestock disease research has already recorded significant gains in eliminating or reducing losses from diseases such as foot-and-mouth disease, tuberculosis, brucellosis, rinderpest, and bovine pleuropneumonia. These achievements give assurance that current losses from other diseases and parasites may be reduced by further R & D and technology application.

Vector elimination by the use of sterile males of the tsetse fly is the subject of extensive current research sponsored by the Agency for International Development in Tanzania. Gruvel (*7*), in extensive ecological studies in central Africa, has found that tsetse flies rest in specific habitats and that identification of these places facilitates selective use of insecticides. Wilson *et al.* (*8*) reported that in tsetse-infested areas in Uganda, herds treated with the chemical Suramin developed an immunity to trypanosomiasis. Herd productivity was low during the first year of treatment but returned to the level of similar herds in noninfested areas during the second year (*9–12*).

The N'Dama cattle of Nigeria are trypanosome-resistant or tolerant, and research with these small cattle to make them more productive is in progress.

Research on the control of helminth parasites is conducted in every region of the world. These parasites cause serious economic losses among sheep and goats generally and among cattle and buffalo in many areas. Some helminths infest man and his companion animals as well as his livestock. Control of these parasites in the environment offers R & D opportunities as do biological and chemical control of worm parasites (*7*).

New and exciting research on immunization against viral diseases shows much promise (*13*). Bachrach *et al.* (*14*) have produced a foot-and-mouth disease vaccine from the noninfective protein coat of the virus rather than from the whole infective virus.

New information based on nucleic acid hybridization indicates that bovine leukemia is an infective viral disease acquired by cattle through horizontal transmission from some as yet unidentified species. Callahan *et al.* (*12*) believe that the eradication of virus-spreading vectors should eliminate the disease.

A 1975 review of worldwide R & D articles on ruminant parasitic infections, diseases, and other disorders reflects a wide divergence in the amount of research effort given to the various categories. In general, the degree of emphasis in a given country relates closely with the severity of the problem. For example, in the developed countries, reproduction problems have first priority. Articles on nontransmissible disorders are proportionally less numerous in the developing countries and countries with centrally planned economies than articles on transmissible diseases. Parasites account for only 10 percent of the articles in the developed countries, 20 percent in the centrally planned, and 30 percent in the developing countries.

Reproduction and Genetics

World ruminant reproduction rates are less than two-thirds of potential. Feed deficiency is the first limiting factor in the developing countries and in substantial areas of developed countries and those with centrally planned economies. In such areas, first calves are born when cows are 3 to 4 years of age. Cows then calve in alternate years. Ewes and does first reproduce as 2-year olds or older. Long periods of severe undernutrition may increase embryo (*15*), neonatal, and maternal mortality.

Regardless of how the goal is reached, any improvement of reproduction rate will mean that a smaller breeding herd of more efficient animals can produce the same or even larger turnoff (animal products for sale) than a larger, less efficient herd. This is the reason that R & D in improving ruminant reproduction rate has been approached in so many different ways. The payoffs are cumulative.

Estrus, fertilization, implantation, and gestation comprise a complex sequence. They are subject to the action and interaction of an even more complex set of factors—environmental, psychological, neural, chemical, and hormonal actions and interactions—which prepare and maintain or fail to maintain pregnancy, and embryonic and fetal development (*16*). Parturition terminates one set of interactions, is determined by another set, and is followed by a third set initiating and supporting lactation and the concomitant doubling of voluntary food intake and its metabolism. Failure may occur at any point.

Sheep and goats in temperate regions usually breed during fall and winter when daylight hours are short. Their 5-month gestation period could permit three successive pregnancies and lactations in 2 years. This objective is sought by: (i) genetic research to breed sheep insensitive to photoperiod and thus produce young uniformly throughout the year; (ii) research in which ewes are subjected to short days by confinement in darkened shelters for a few weeks during the summer to induce estrus and ovulation; and (iii) research on hormones and prostaglandins that might induce estrus and ovulation during anestrous periods (*17*). The potential for complete success, that is, a 50 percent increase in meat and milk production above current levels, would be equivalent to about 3.5 million (metric) tons of sheep and goat milk and 3.5 million tons of sheep and goat carcass meat annually in the world.

In 1975, about 1000 abstracts worldwide dealt with reproduction and genetics of ruminants. About half of these were published in the developed countries, 35 percent in countries with centrally planned economies, and 15 percent in developing countries. About 72 percent of the abstracts on ruminant genetics and breeding were concerned with cattle, 25 percent with sheep, 2 percent with buffalo, and 1 percent with goats.

Among the most challenging opportunities for future ruminant livestock R & D are breeding for a great degree of fecundity and for resistance to diseases that can be attacked through a genetic approach. The N'Dama cattle of West Africa, because of their genetic resistance to trypanosomiasis, and Finnsheep, because they produce larger litters than other domestic breeds (*18*), provide examples of the animals that can be used in such research.

Research and development in ruminant reproduction could be a determining factor in whether or not meat and milk supplies are sustained or increased. It is an area replete with brilliant, innovative, and sophisticated research. It is fraught with complexity, of great potential, promise—and perplexity. Past progress has often been more apparent than real (*19*).

Systems

Because the systems that farmers use to organize and manage their resources affect the supply and cost of food to consumers, production systems research focuses on the organization and structure of farming, including such aspects as efficiency of resource use, costs and returns, and economies of scale. Thus, the socioeconomic sciences are essential components of systems research needed to guide R & D resource allocation. Payoffs from this kind of activity continue to accrue.

Controlled environments, already widely used in poultry and swine production, are under test for lamb and beef production. For lambs, this research shows that programmed lighting in the dam environment can control the season of reproduction and possibly prevent the transmission of parasites from dam to lamb. Under conditions of a Texas cattle systems study, a pasture regime gave larger returns on investment than that of drylot feeding. If competition for land to grow food crops increases, quality and location of land available for pasture may be restricted (*20*). A 1976 systems study of vertical integration in the cattle industry (a type of business enterprise in which one company controls all aspects of the production, processing, and marketing of the cattle) concluded that an enterprise producing about 222 tons liveweight was likely to be of optimal size (*21*). A recent CIAT study (*3, 22*) in Colombia found that people in low-income strata spend 10 to 20 percent of their total income for beef. The researchers concluded that, although an increase in food crops such as rice and cassava was the most effective route to sufficient caloric intake, good nutrition and adequate protein would require more maize, beans, and beef in the diet—and, of course, increased income to buy these foods, particularly beef (*22*).

As might be expected, developed countries lead all others in the number of projects devoted to ruminant-related socioeconomic research, including many types of systems research. In 1975, 75 percent of such R & D abstracts in the world literature originated in developed countries, 20 percent in countries with centrally planned economies, and only 5 percent in developing countries. Trends show that research areas having high priority are efficiency of resource use and the development of management strategies to increase margins of profit.

The devising of more effective and more efficient ruminant production systems will require an even higher degree of coordination among particular research disciplines. Existing mechanisms and procedures provide a multitude of opportunities for doing this. Recommendations of an ad hoc working group of the Agricultural Research Policy Advisory Committee (ARPAC) cited need for greater coordination in research on herd management, disease control, and forage intake (*23*).

Products Technology

A survey based on data from *Food Science and Technology Abstracts* for 1975 indicates that about 79 percent of the ruminant-related meat and milk technology articles published in the world literature originated in the developed countries. Only 17 percent originated in countries with centrally planned economies and 6 percent in the developing countries. Among the developed and centrally planned countries, the degree of research emphasis for both meat and milk technology is quite similar in the three main categories: (i) composition and quality; (ii) products, preservation, and processing; and (iii) engineering and sanitation. Among the developing countries, however, very few meat technology abstracts were reported in the latter two categories; heaviest emphasis in milk technology was in engineering and sanitation.

The greatest potential for increased productivity in this area would seem to be in stepped-up technology use in the developing countries. But in the absence of ready transfer of new technology from developed countries, the best route would seem to be R & D by the developing countries themselves. For example, domestic production of fat in many countries is insufficient to meet demand; for them, continued or expanded R & D on butter, and on tallow production and modification may be the preferred option (*24*).

A process for hydrolysis of lactose in milk by lactase from *Saccharomyces* species may extend milk use among populations with a high frequency of lactose intolerance. Such lactose-hydrolyzed milk was reported by Paige *et al.* (*25*) to be consumed without discomfort by lactose-intolerant black youths.

Whey continues to require further R & D on economical utilization. World production of liquid whey in 1974 was about 90 million tons. Some was fed to pigs, some was used in calf and poultry feeds, and a limited amount was used in human food products. About half of it became a waste disposal problem. Recent work on feed use for cattle may extend its economic use. Whey may have potential use as an energy source for nonprotein nitrogen metabolism in the rumen (*26*).

Recent advances in meat R & D among the developed countries include mechanical deboning, meat protein concentrates and food products from blood and visceral tissues, and meat homogenates extrusion and texturization of the resulting fibers. The potential volume of such products is large. Fields (*27*) estimated a potential of about 7 million tons of bones which could be mechanically deboned with a 30 percent yield of food grade meat and marrow. Doty *et al.* (*28*) described technology now or potentially available for production of protein concentrates and food products from blood, viscera, and other soft tissues. Products can be made from blood with excellent protein efficiency ratios.

Wool and leather are very important ruminant products. Recent research has developed processes for shrink-proofing woolens; innovations in tanning procedures may lead to replacement of leather made from horsehides, now in diminishing supply. The PL 480 program supports productive wool and leather research in Pakistan and India.

Ruminant Productivity

Production of meat and milk protein from ruminant livestock in 1974 averaged about 21 kg per animal unit (Table 1). Productivity within regions varies widely. In developing countries in 1974, edible protein ranged from 6 kg per animal unit to 17; among the centrally planned economies, from 8 kg to 54; and among developed countries, from 14 kg to 73—the latter figure applying to Japan.

Of the published dairy science abstracts in 1975, about 63 percent originated in developed countries, 30 percent in centrally planned economies, and 7 percent in developing countries. Both the distribution of publications and milk production per cow reflect the level of technology applied in milk production in countries of the three categories.

Among the main trend areas in R & D related to milk production are (i) nutrient intake, and the sources and metabolism of the nutrients; (ii) reproduction; (iii) metabolic diseases; (iv) genetic capacity for milk production; (v) mastitis; and (vi) milk substitutes for calf, lamb, and kid feeding.

Low feed intake is a primary factor limiting milk production of cows grazing on forage of low digestibility (*29*). Although indigenous cattle may have a capacity to produce more milk, there are three common limiting factors to achieving high yields: disease, low-quality feed, and inefficient management. Even when genetic production potential is low, introduction of exotic breeds is not the full answer. They may not be well adapted to the environment; for example, they may be more susceptible to certain parasites or other disorders.

In the United States, 2.4 million cows in the Dairy Herd Improvement Association in 1974 produced an average of almost 6000 kg of milk per cow, compared to the national average of 4600 kg. Average production in Africa, however, was 509 kg; in Asia, 610 kg; and in South America, 980 kg.

Awassi milk sheep of the Near East produce 250 kg per lactation—the equivalent in protein to 392 kg of cow or goat milk. France, Greece, Turkey, and Iran each produced more than 500,000 tons of sheep milk in 1974. Both buffalo and goat milk make sizable contributions to the world's protein production, Asian countries being the chief producers.

Replacement of suckled milk by formulated feeds for very young calves, lambs, and kids is an area of increasing importance and broadening interest. After a few days of being fed on colostrum to assure them the benefits of the immunoglobulins it contains, the young animals may be shifted to other foods. The advantages of this shift are: (i) it allows the maximum amount of milk to be used for direct human consumption or for cheese, butter, ghee, yogurt, and other products; (ii) it allows earlier rebreeding; (iii) it helps to prevent neonatal mortality from infectious disease and parasites, including salmonellosis and viral diarrhea (*30*).

There is a current and growing R & D interest in feeding procedures to increase the proportion of polyunsaturated fat in milk. Polyunsaturates are usually hydrogenated by microbial enzymes in the rumen. Such action can be avoided by feeding the cow treated supplements which will pass through the rumen undigested, but instead are digested by the cow's own enzymes in the gut. The resulting milk, high in polyunsaturated lipids, represents a potential market for people with high blood cholesterol. Such milk must be protected against oxidation to prevent off-flavor (*31*).

As stated earlier, the 1974 world average of edible protein produced per animal unit was 21 kg. Projected productivity for the year 2000, to maintain a per capita production level reasonably near the present one, would be 31 kg per animal unit, without any sizable increase in ruminant inventory. Even though this represents about a 47 percent increase over current worldwide production, it is still slightly lower than the amount currently being produced in countries with centrally planned economies and considerably lower than current production in the developed countries (Table 1).

Conclusions

In 1974, ruminant livestock products had an estimated producer value of $150 billion, representing a contribution of about 2 percent of the world GNP. Ruminant products most useful to man are, of course, those consumed as food—meat, milk, and milk products. Some segments of the world population receive an ample supply; others, unfortunately, do not. About two-thirds of the milk cows are in the developing countries, but because of low yield per cow, they produce only 20 percent of the world supply of milk. A somewhat similar disparate relationship exists in the consumption of beef, although in India, low per capita consumption is due to religious beliefs. Most people of the world, however, like and demand ruminant meat and milk as food; furthermore, these products contain protein of exceptional value (*32*).

In order to maintain or increase per capita supplies of ruminant meat and milk, the world as a whole will probably have to increase support for ruminant R & D by at least 45 percent over the next 25 years. Fortunately, there is evidence that R & D will increase ruminant efficiency and productivity to the degree that it will be possible to maintain per capita supply without adding to current land area used to support ruminants and without increasing ruminant inventories.

Trends observed in the decade from 1965 to 1975 show that there is a direct relation between ruminant R & D production, as measured by R & D articles published, and the production of meat and milk per animal unit. The most logical way to achieve the goal of a 50 percent increase in productivity is to invest proportionate resources in the six areas of R & D in which the trends have been observed. These areas should have high priority: (i) pasture and range improvement, particularly in tropical regions; (ii) genetic resistance and vector management, especially for arthropod-borne hematoprotozoal diseases and helminth parasites; (iii) increased animal unit production through improved conception rate and decreased fetal and perinatal mortality; (iv) development and evaluation of systems—biological, ecological, engineering, economic, and social—for resource use, ruminant production, and product utilization; (v) development of new products such as meat protein concentrates and texturized products from trimmings and edible offals, lactose-hydrolyzed milk acceptable for lactose-intolerant people; and (vi) improvement of milk and meat production through genetic selection and feeding programs designed to satisfy energy, protein, mineral, and other nutrient requirements of pregnant and lactating animals.

References and Notes

1. The terms "developed countries," "centrally planned economies," and "developing countries" refer, with a few exceptions, to the economic-geographic regions listed in the *FAO Production Yearbook 1974* (Food and Agriculture Organization of the United Nations, Rome, 1975). Specifically, developed countries refer to those in North America, Western Europe, Southern Africa, and Oceania (Australia and New Zealand); centrally planned economies include those countries in Eastern Europe, also the Soviet Union, China, North Korea, North Vietnam, Cuba, and Mongolia; developing countries refer to those in Middle America, South America, North Africa, Middle East, Central Africa, East Africa, India, and South and Southeast Asia.
2. Data were obtained from: National Science Board, *Science Indicators 1974* (National Science Foundation, Washington, D.C., 1975); Organization for Economic Cooperation and Development, *Patterns of Resources Devoted to Research and Economic Development in the OECD AREA 1963–71* (OECD, Paris, 1975); *Changing Priorities for Government R & D* (OECD, Paris, 1975); J. K. Boyce and R. E. Evenson, *Agricultural Research and Extension Programs* (Agricultural Development Council, New York, 1975); World Bank Atlas, *Population per Capita, Product and Growth Rates* (World Bank, Washington, D.C., 1974); and W. H. Shapley, *Research and Development in the Federal Budget FY 1977* (Report No. 76-R-4, American Association for the Advancement of Science, Washington, D.C., 1976).
3. Of the 11 international agricultural research institutions supported by the Consultative Group for International Agricultural Research (CGIAR), three conduct significant livestock research programs. These are: CIAT, International Center of Tropical Agriculture, Palmira, Colombia; ILRAD, International Center for Research on Animal Diseases, Nairobi, Kenya; and ILCA, International Livestock Center for Africa, Addis Ababa, Ethopia.
4. The nutritive value of tropical forages, in both semiarid and in humid areas, was reported by E. A. S. Serao and M. Simao Neto, *in Tropical Forages in Livestock Production* (American Society of Agronomy, Madison, 1975), pp. 31–52; C. M. Karue, *East Afr. Agr. For. J.* **40**, 95 (1974); R. O. Whyte, in *Natural Resources of Humid Tropical Asia* (Unesco, Paris, 1974), pp. 239–262; T. G. Graham and B. G. Mayer, *Queensl. J. Agric. Anim. Sci.* **29**, 289 (1972); H. B. Sprague, Ed., *Grasslands of the United States* (Iowa State Univ. Press, Ames, 1974); W. G. Rolian-Jones, F. Ball, R. M. Murray, B. W. Norton, R. A. Leng, *Proc. Austr. Soc. Anim. Prod.* **9**, 341 (1972); T. H. Stobbs, *Trop. Grassl.* **9**, 141 (1975); A. Velez, L. G. Escobar, C. H. Ayala, *Acta Agron. (Palmira)* **22**, 71 (1972).
5. Supplementary feeding experiments with beef cattle were reported by R. L. Mitchell and C. P. Whiteman, *J. Austr. Inst. Agric. Sci.* **38**, 100 (1973); L. S. Pope, *J. Anim. Sci.* **42**, 785 (1976); M. J. Creek, *World Anim. Rev.* (No. 3), 23 (1972); S. Bacvanski, T. Cobis, S. Vucetic, *ibid.* (No. 8), (1973); L. R. Gurah, S. A. Jackson, A. A. Bishop, I. L. McCullough, L. A. Siervert, *Agric. North. Ireland* **50**, 120 (1975); T. R. Preston, *World Anim. Rev.* (No. 1), 24 (1972); K. J. Topps, *ibid.* (No. 3), 14 (1972); T. R. Utley, *J. Anim. Sci.* **40**, 1034 (1975); M. Koger, *ibid.* **42**, 787 (1976); O. Liebenberg, G. Sperling, H. G. Buckert, *Arch. Tierz.* **16**, 501 (1973).
6. Among the articles dealing with ruminant nutrition and metabolism that are useful in giving an overview are three 19th-century reports by M. Rubner [*Z. Biol. (Munich)* **19**, 337 (1883); *ibid.* p. 535; *ibid.* **21**, 250 (1885)]; see also F. C. Waugh, *J. Farm Econ.* **33**, 290 (1951); S. Brody, *Bioenergetics and Growth* (Reinhold, New York, 1945). More recent studies include the following (on nutrients for sheep): A. N. Bhattacharaya and M. Alielu, *J. Anim. Sci.* **41**, 225 (1975); W. Burroughs, *Nutrient Requirements of Beef Cattle* (National Academy of Sciences, Washington, D.C., rev. ed. 4, 1970); ______, D. K. Nelson, D. R. Mertons, *J. Anim. Sci.* **41**, 933 (1975); (on feed use in beef production): T. C. Byerly, *J. Anim. Sci.* **41**, 921 (1975); K. G. Hibbitt, in *Production Disease in Farm Animals*, J. M. Payne, Ed. (Williams & Wilkins, Baltimore, 1973), pp. 149–164; D. B. Lindsay, in *ibid.*, pp. 107–114; G. P. Lofgreen and W. N. Garrett, *J. Anim. Sci.* **27**, 793 (1968); P. W. Moe and W. P. Flatt, *J. Dairy Sci.* **52**, 928 (1967); J. K. Loosli, *Nutrient Requirements of Dairy Cattle* (National Academy of Sciences, Washington, D.C., rev. ed. 4, 1975).
7. J. Gruvel, *Rev. Elev. Med. Vet. Pays Trop.* **28**, 173 (1975).
8. A. J. Wilson, J. Paris, F. G. Luckius, F. K. Dar, A. R. Gray, *Trop. Anim. Health Prod.* **8**, 1 (1976).
9. Diseases and parasites are a widespread problem in ruminant livestock industries. Much of the literature is concerned with African ruminants: see McKelvey (*10*); Janssen (*11*); R. A. Braun, *World Anim. Rev.* (No. 16), 1 (1975); D. Daine, in *Summary of Ongoing Research and Technical Assistance Projects in Agriculture* (U.S. Agency for International Development, Washington, D.C., 1975), pp. 64–65; Gruvel (*7*); Wilson *et al.* (*8*); Helminth parasites are subjects of research in every region: P. K. Bitakaramire, *Bull. Epizoot. Dis. Afr.* **21**, 145 (1973); J. M. Blancou, A. Bouchet, P. Dayne, *Rev. Elev. Med. Vet. Pays Trop.* **28**, 133 (1975); J. G. Ross, *J. Helminthol.* **4**, 393 (1967); I. Manin, in *XIX Congreso Mundio de Medico Veterinario y Zootechnica* (Congreso, Mexico City, 1971), vol. 3, pp. 901–904; J. R. Mitchell, *Bull. Epizoot. Dis. Afr.* **21**, 134 (1973); E. G. Morini and B. de Gullo Toreacho, *Rev. Med. Vet.* **55**, 229 (1974); H. J. Bramble, *J. Agric.* **46**, 231 (1975); Callahan *et al.* (*12*).
10. J. J. McKelvey, Jr., *African Agricultural Research Capabilities* (National Academy of Sciences, Washington, D.C., 1974), pp. 1–221.
11. P. G. Janssen, *African Trypanosomiasis*, report of the Joint FAO/WHO Expert Commission (Food and Agriculture Organization of the United Nations, report No. 84, Rome, 1969).
12. N. Callahan, M. M. Lieber, G. J. Tadoro, D. C. Graves, J. F. Fermer, *Science* **192**, 1005 (1976).
13. Bacterial and viral diseases were discussed by J. A. Kamara, *Trop. Ag. Tanzania* **52**, 183 (1975); S. Kamo, *Bull. Epizoot. Dis. Afr.* **21**, 179 (1973); Bachrach *et al.* (*14*); L. L. Martel, *Rev. Elev. Med. Vet. Pays Trop.* **28**, 275 (1975); A. Provost, C. Borredon, R. Queval, *ibid.*, p. 385.
14. M. L. Bachrach, D. M. Moore, P. D. McKercher, J. Polatnick, *J. Immunol.* **115**, 1636 (1975).
15. J. M. Van Dem Westhuiper, *Agroanimalia* **3**, 91 (1971); J. Knaack, H. Nehring, G. Lorenz, *Tierzucht* **27**, 156 (1973), R. G. Durn and R. M. Doney, *J. Reprod. Fertil. Suppl.* **19**, 253 (1973); R. H. Dutt, *J. Anim. Sci.* **22**, 713 (1963); L. C. Ulberg and L. A. Sheean, *J. Reprod. Fertil. Suppl.* **19**, 155 (1973); R. F. Keeler, *Clin. Toxicol.* **5**, 529 (1972); S. Fernandez-Baca, *World Anim. Rev.* No. 14, 1 (1975).
16. For data on hormone research, see H. Boyd, *Vet. Bull. (London)* **35**, 251 (1965); L. L. Bellinger and V. E. Mendel, *Anim. Prod.* **19**, 123 (1974); G. C. Liggins, R. J. Fairclough, S. A. Grieves, J. Kendall, B. S. Knox, *Recent Prog. Horm. Res.* **29**, 111 (1973).
17. Reproduction R & D of sheep and goats is discussed by: M. J. Dieker, *Vet. Rec.* **95**, 96 (1974); K. H. Korub, *Arch. Tierz.* **29**, 252 (1975); J. Matlek, A. Pavlok, J. Fulka, *J. Reprod. Fertil.* **47**, 84 (1976).
18. Among the most challenging R & D with regard to ruminants is breeding for disease resistance: see F. B. Hutt, *Genetic Resistance of Disease in Domestic Animals*, (Comstock, Ithaca, N.Y., 1958); G. Bradford, *J. Reprod. Fertil. Suppl.* **15**, 23 (1974); G. E. Dickerson, H. A. Glimp, K. H. Gregory, *J. Anim. Sci.* **41**, 43 (1975). See also McKelvey, (*10*) and Janssen, (*11*). Bradford and Dickerson *et al.*, also discuss breeding control of litter size.
19. Research and development in ruminant reproduction could determine whether meat and milk supplies are sustained; see M. M. Hayes, B. K. Knight, R. B. Sumington, *S. Afr. J. Anim. Sci.* **4**, 55 (1974); B. Benson, M. J. Matthews, V. J. Hruby, *Am. Zool.* **16**, 25 (1976); E. W. Horton, *Prostaglandins* (Springer-Verlag, New York, 1972); D. B. Laster and K. E. Gregory, *J. Anim. Sci.* **37**, 1092 (1975); U. S. von Euler, *Arch. Exp. Pathol. Pharmakol.* **175**, 78 (1934); M. Legendre, *Prod. Agric. Francaise* **98**, 20 (1971).
20. C. H. Long, T. C. Cartwright, H. A. Fitzhugh, *J. Anim. Sci.* **40**, 409 (1975); W. T. Tseng and B. R. Mears, *Trans. Am. Soc. Agric. Eng.* **8**, 206 (1975); Grasslands Research Institute, *Assessment of Continuous Lamb Production in the U.K.* (Grasslands Research Institute, Reading Univ., England, 1973), and *World Agric. Econ. Rural Sociol. Abstr.* **17**, 479 (1975); H. W. Cook, *Colo. State Univ. Exp. St. Bull.* No. 109 (1973).
21. A. A. Araji, *Am. J. Agric. Econ.* **58**, 101 (1976).
22. P. Pinstrup-Andersen, N. Ruiz de Londono, E. Hoover, *Am. J. Agric. Econ.* **58**, 131 (1976); W. Haessel, *ibid.*, p. 341.
23. U.S. Department of Agriculture *U.S. Food Research: Report of Ad Hoc Work Group on Most Important Problems* (USDA, Washington, D.C., May 1976).
24. Animal fats have been researched by L. S. Herbert and K. J. Kearney, *J. Food Technol.* **10**, 55 (1975); R. R. Oltjen and R. A. Dinius, *J. Anim. Sci.* **41**, 703 (1975); L. Quinn, G. O. Mott, W. V. A. Bisschoff, G. Lerne de Rocha, *Pesqui. Agropecu. Bras.* **1**, 303 (1966).
25. D. M. Paige, T. M. Bayless, S. S. Yuang, R. Wexler, *Am. J. Clin. Nutr.* **28**, 818 (1975).
26. G. P. Lynch, F. E. McDonough, D. K. Rough, D. F. Smith, C. H. Gordon, *J. Dairy Sci.* **58**, 1688 (1975).
27. Recent advances in product technology are described by R. A. Fields, *World Rev. Anim. Prod.* **12**, 61 (1976); Doty (*28*).
28. D. M. Doty, in *Alternate Sources of Protein for Animal Production* (National Academy of Sciences, Washington, D.C., 1973), pp. 61; L. D. Saterlee, *J. Anim. Sci.* **41**, 687 (1975); C. Bourgeois, *Rev. Conserve Aliment. Moderne* **35**, 29 (1975).
29. For the feed intake of pregnant and lactating cows, see J. M. Forbes, *Br. Vet. J.* **126**, 1 (1970); H. R. Conrad, A. D. Pratt, J. W. Hibbs, *J. Dairy Sci.* **47**, 54 (1964) reported the feed intake in dairy cows.
30. Feeding of calves engaged the attention of P. Vanderwal, J. E. Sprietsma, J. Huisman, *J. Anim. Sci.* **41**, 486 (1975); Yu Yu, J. S. Stone, M. R. Wilson, *J. Dairy Sci.* **59**, 935 (1976); L. C. Muller, F. C. Ludens, J. A. Rook, *ibid.*, p. 930.
31. Polyunsaturates are discussed by T. W. Scott, L. J. Cook, S. C. Mills, *J. Am. Oil Chem. Soc.* **48**, 358 (1971); R. E. Hodges *et. al.*, *Am. J. Clin. Nutr.* **28**, 1126 (1975); Commonwealth Scientific and Industrial Research Organization, *Rural Research CSIRO* **79**, 13 (1973); T. R. Wrenn, J. H. Weyant, D. L. Wood, J. Bitman, *J. Dairy Sci.* **59**, 627 (1976).
32. Agricultural Research Policy Advisory Committee, *Research to Meet U.S. and World Food Needs: Report of a Working Conference* (U.S. Department of Agriculture, Washington, D.C., 1975), vol. 1.
33. Food and Agriculture Organization of the United Nations, *1974 Production Yearbook* (FAO, Rome, 1975).
34. Current Research Information System, U.S. Department of Agriculture, courtesy of J. Myers.
35. Current Research Information System, *Inventory of Agricultural Research 1974, Research Program Summary* (USDA, Washington, D.C., 1975), vol. 2.

36. I thank W. W. Konkle for editorial assistance in the final draft of this article. Winrock International Livestock Research and Training Center is supported in part by funds from the estate of the late Winthrop Rockefeller and by contributions from public and private sources.