Master

WIND POWER APPLICATIONS IN RURAL AND REMOTE AREAS

by

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Historically, agriculture was a major user of wind generated power before inexpensive power from other sources became available. In 1850, it is estimated the use of windmills in American represented about 1.4 billion horsepower hours of work--25% of all U.S. power needs at that time. By 1903, American windmill technology--including windmills, pumps, and towers--were exported all over the world. Today, as a result of petroleum fuels, rural power cooperatives, and the use of energy wasteful technologies, wind power makes an insignificant contribution to national energy production.

It is reasonable to expect that agriculture, rural and remote areas applications can again play an important role in the development of a future viable wind energy industry in the United States as fossil fuels become more scarce and expensive. An examination of the rural area energy budget identifies numerous areas where wind machines may contribute. Examples of such applications are (1) production of hot water for rural sanitation uses; (2) heating of rural structures and products; (3) refrigeration of rural structures and products; (4) drying of agricultural products; and (5) irrigation or aquaculture.

A great deal of development needs to be done on the design of small to medium scale machines for rural use; the design of simple yet reliable towers; and the matching of wind machine performance to the requirements of specific applications. Programs have been developed by government agencies to exploit wind machines in rural and remote areas. These programs will hopefully guide and accelerate the re-use of the ancient art of manufacturing power from the wind.

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Robert N. Meroney
Professor, Fluid Mechanics
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1. INTRODUCTION

Contrary to popular belief, U.S. food production costs are high. In addition, the oft-quoted statistic that one farm worker feeds 48 persons is misleading because the farmer depends on a complex of support industries (i.e., 20% of total population is in agriculturally related professions). Pimentel, et al., (1973) estimate due to extensive energy consuming practices and plant crops used in the U.S. it costs four times as much to produce a given amount of food energy as in India. The contribution of fuel costs to the price of raw agricultural products varies by type of commodity and method of production but average at 4 to 6% of the current total cost. Since this country's energy use for agricultural production has increased from two to three fold in the last twenty years, and it is anticipated fuel costs may easily double or triple in the decade and increase by five fold by the end of the century, it is conceivable that food costs may increase from the present 16.6 percent of a typical U.S. citizen's disposable mean income to as much as 20 to 25 percent.

Although production of raw agricultural commodities currently represents only 2.6% of the U.S. energy budget (Heichel, 1976) it does rank third in energy consumption after the steel and petroleum refining industries. About equal amounts of fuel energy are used on and off the farm. Fuel is used off the farm to manufacture goods used for farming; petroleum for herbicides, fungicides, plastics, and the manufacture of machinery, natural gas for nitrogen fertilizers, coal for steel production. Fuel is used on the farm to apply manufactured products to assist the growth of crops, i.e., by tractors during planting, cultivation, pest control, herbicide application, to run frost protection equipment, and to move water through irrigation pumps. The bar chart in Figure 1 divides energy consumption among the various classifications.

We also know rather precisely how much energy it requires to produce many of the principal U.S. food crops (Heichel, 1976). As noted in Figure 2, field crops such as oats, corn, soybeans, and wheat consume the least amount of energy for food energy produced. The annual vegetables and fruits for human diets generally provide less food energy than the cultural energy they consume. These crops require more intensive irrigation and application of fertilizers and pesticides than field crops destined for animal consumption. One must recall that although wheat and rice say are staple human foods, the nutritional constraints of most feed grains preclude their direct use for human consumption. Thus even though the efficiency of feed energy conversion to animal meat is only 5 percent for cattle and 12 percent for hogs and broilers, the net energy balance is no worse than the majority of fruit and vegetable crops.

As a result of extensive use of human labor, the net consumption of fuel energy resource per food energy produced is actually less in developing countries than in the U.S. Unfortunately, it is these same countries whose population pressures may require the energy intensive results of the "green revolution." With fuel shortages and high prices to come, innovative use of alternative energy technology will be required if these same developing nations will be able to afford the technology of U.S. agriculture. As the people in these developing countries move into the technological era, past history suggests more than a doubling in consumption of energy to meet food needs (see Figure 4).

While no one can say for certain what changes will occur in agricultural energy usage as a result of increased energy cost, we can be sure that when conventional energy resources become scarce and expensive, alternative energy technologies such as the wind energy conversion systems (WECS) must be re-examined. Historically, agriculture was a major user of wind generated power before inexpensive power from other sources became available. It is thus reasonable to expect that small to medium scale WECS will be acceptable to the agricultural user who is already accustomed to having his resources available at the whim of "mother nature."

2. CHARACTERISTICS OF LOCAL WIND POWER RESOURCES

Recent wind power climatological surveys suggest wind energy densities over the Continental United States are high enough to exploit along the northeast Atlantic seaboard, along the Great Lakes, and over the great plains rising to an inland maximum near Amarillo, Texas (Reed and Blackwell, 1975). These areas where wind speed and wind duration are exploitable are concurrent with a large portion of the nation's grain, forage, and dairy production. Regions of usable wind energy may also exist among the mountainous portions of the west and northwest. Unfortunately, climatological data in these areas cannot currently characterize local wind regimes as dictated by topography (Meroney, 1976a, 1976b).

An examination of annual wind records over the great plains reveals a fortuitous maximum in wind energy availability in most areas in the spring and early summer. This fits well with irrigation pumping needs for many field crops. Questions concerning wind duration, frequency of lulls, etc., have yet to be determined. These must be matched with the need of different cash crops.

Such availability of the wind at the time of maximum need is not always the case. A series of studies in India discussed by Ramiah (1956) reveals that favorable wind velocities do not coincide with the seasons of high water demand for crop irrigation in Poona, Meerut, Coimbatare, Modias, and Bangalore. In Figure 5 a number of possible loads, in a rural community, are placed in classes according to their timing requirements (Golding and Thatcher, 1956).

3. CHARACTERISTICS OF AVAILABLE SMALL WECS

The agricultural industry ~~as one finds it~~ in rural and remote areas has energy requirements and power demands which are, predominantly, of smaller scale than those of other industries. As a consequence, the WECS for these applications will often use individual units sub-optional from a more general point of view (say large scale electric energy production). One may divide the WECS systems into three groups by power delivered: 1-5 kW machines available as "off the shelf" items engineered for general usage; 5-25 kW machines suitable for larger scale applications but requiring greater sophistication in design and installation; 25-75 kW devices provided on an "on order" basis for specific applications.* One may also divide these WECS into two

*At some future time the larger machines may also be available on a routine basis.

further classifications based on application that is, a) high starting torque, low r.p.m. devices, or b) low starting torque, high r.p.m. devices. WECS designed for mechanical coupling to machines to pump, grind, or crush fall into the first classification; devices to generate electrical energy fall into the latter group.*

There are four American manufactured windmills which are sold today which lift water by direct mechanical connection--the Aermotor, Baker, Dempster, and American Wind Turbine. Such devices are typically rated in terms of their mechanical stroke per time, or the delivery rate of water for a given size and depth well. Since the characteristic of the load varies so widely, they are normally not rated in kW or h.p. Most mills are multibladed, rugged, require minimal maintenance, and are designed to operate between 10-30 m.p.h. At higher wind speeds a spring controlled vane moves to turn the axis out of the wind and spill the air. These water pumping mills have a long history of satisfactory performance ranging back to the 1880's.

There are over ten manufacturers which are currently prepared to deliver wind machine-generation packages ranging from 0.025 to 15 kW. Larger machines have been considered and at least some manufacturers will discuss delivery on a special order basis. In addition, plans and kits can be purchased, but these will not be discussed further here.

Very small units less than 0.25 kW are available to produce 6, 12, and 24 volt DC power. These devices are suitable for navigation beacons, cathodic protection, or small amounts of power in remote locations.

*Engineers in the USSR believe, however, high speed WECS can often profitably be used for pumping (Shefter, 1972).

Between 0.25 and 8.0 kW there are a number of U.S. and foreign manufactured devices. Most of these machines are two or three bladed high speed propellers with most effective tip speed to wind speed velocity ratio operation at 5 to 6. Power is frequently generated by means of 3 phase AC semiconductor alternators. In some cases the current is converted to DC by diodes immediately. If an AC current is desired, either mechanical rotary inverters or electronic solid state inverters are manufactured up to 10,000 watts. Synchronous solid state inverters are available which use incoming line voltages to match the phase of the voltage signals produced to that provided over conventional utility lines.

Most of these machines are still too small to meet the monthly electrical needs of a typical rural household or to be a significant replacement for an energy consuming farm application. For example, a household utilizing some 1000 kW hrs/month, in an area with an annual average wind velocity of 15 m.p.h. assuming a 70% windmill generation efficiency and a 30% load factor, would require a 30 ft diameter mill. This mill if its rated speed was 25 m.p.h. would require a 20 kW generator! Since typical systems appear to cost over $1,000/kW, one would require a capital investment of some $20,000! If annual wind is only 10 m.p.h., this increases by a factor of three.

In 1956 Golding and Thatcher estimated some one-third of the power needs of a remote agricultural community of 40 to 50 families might be met by a 25 kW windmill with 10-12 m.p.h. average winds. Since in some types of agricultural production the rate of energy use has increased more than three-fold in twenty years, it can be expected that machines in the 50-100 kW range would be useful for such communities. Except for the NOAH twin-fan machine from Switzerland, no commercial source for such sizes is known.

In the USSR more than thirteen different water lifting and electrical machines have been designed in sizes from 0.7 to 15.2 kW with blade diameters ranging from 6.5 to 40 ft. (Simons, 1975; Shefter, 1972; Stein, 1941). Grouped wind-electrical stations made up of 10-15 machines of 25-30 kW each, working for a common consumer have been utilized instead of one single machine of large diameter.

4. APPLICATIONS OF SMALL WECS SYSTEMS

Historically the use of WECS have only been limited by the creativity of the user. It would be hard to find an area some entrepeneur has not used or tried to use the wind-machine as a prime mover. The generation of electricity and its subsequent use for light, radios, refrigerators, and freezers, milking machines and cream separators, washing machines, sewing machines, vacuum cleaners, inversion heating, cathodic protection of pipelines, etc., is obvious. In many cases it is not absolutely necessary to accumulate the required energy as electrical energy. The development of systems for direct use or non-intensive storage of energy may be divided into five classes such as:

a) water movement--raising to storage in tanks, sprinkling, trickle irrigation, aquaculture, desalination, etc.

b) production of heat--heating of rural structures and products, grain drying, hot water for sanitation, heating of stock water tanks, etc.

c) refrigeration--storage of dairy or fruit produce, domestic cooling, poultry ventilation, etc.

d) processing of mass products--chopping of straw, grinding grain, sawing of lumber, conveying feed, production of fertilizer, etc., ~~and~~

e) movement of air--frost protection, greenhouse ventilation, aeration of farm ponds, prevention of winterkill on mountain lakes, shelterbelt protection, etc.

Because of the high cost of an energy unit accumulator as electrical energy, it is worthwhile to regard the accumulating problem not merely from the generating angle but from that of the consumer (Hutter, 1956). Energy may be stored as sensible heat, latent heat in ice builders or other devices which cause a phase change, potential energy as say water stored at elevation or air under pressure, or kinetic energy as in flywheels. Biederman (1975) reports research on hydrogen fuel and fuel cells in the 5 to 50 kW size range for use on grain crop, dairy, and poultry farms. Chemical storage of energy is also possible by the generation of fertilizer through electrochemical means.

The costs attached to the production of usable energy from the free source of the wind are probably fixed for any particular power plant. Apart from maintenance, they are simply the annual charges for interest and depreciation. The economic feasibility of WECS for a particular application, however, are dependent on a) planning the loads so the fullest use is made of wind energy as available, and b) dovetailing the power from different sources so supply is continuing or at least adequate. The need to provide storage or alternate conventional capacity often means WECS systems can only be justified on fuel savings not by replacement of energy-machine capital (Fatyeev, 1959; Nelson and Gilmore, 1974).

5. TECHNOLOGY DEVELOPMENT

The responsibility to encourage WECS application to rural and remote areas has been assigned by the Wind Energy Conversion Branch, E.R.D.A., to the Rural and Remote Areas Wind Energy Research Program, Agricultural Research Service, U.S. Dept. of Agriculture (Beltsville, Maryland). The responsibility to evaluate and monitor development of small to medium size WECS now resides with the E.R.D.A. Regional Office at Rocky Flats, Colorado.

As an initial phase in the effort to identify those areas in the agricultural community where WECS can make a significant energy saving, a study will be contracted (July 1976) by ARS to separate such information from the 1976 data compiled by the Economic Research Service, USDA, on annual energy use in agriculture. It is expected that the study will require a case-by-case study of all major agricultural enterprises.

Although the above study has not been completed, it is planned to proceed with seed-money funding of investigations to ascertain techinal feasibility of direct wind energy use in agriculture not involving intensive energy storage. As a result of a proposal solicitation in spring, 1976, awards may be expected in the areas of dairy heating and cooling, house and domestic water heating, well irrigation, poultry ventilation, and fertilizer production.

A small subprogram has been suggested to assess the development of electrical energy generation for sale of power to utilities. Feasibility studies would examine the potential for generation of electricity by small rural units, typically 10-50 kW, that could be tied into the networks of commercial electric power distribritors.

Finally the requirements for intensive energy storage in agricultural WECS will be examined. The possibilities of electric chemical conversion to liquid fuels, fertilizers, or long term storage for subsequent intensive usage would be considered.

6. SUMMARY

A great deal of development needs to be done on the design of small to medium scale machines for rural use; the design of simple yet reliable towers; and the matching of wind machine performance to the requirements of specific applications. Programs have been developed by government agencies to exploit wind machines in rural and remote areas. These programs will hopefully guide and accelerate the re-use of the ancient art of manufacturing power from the wind.

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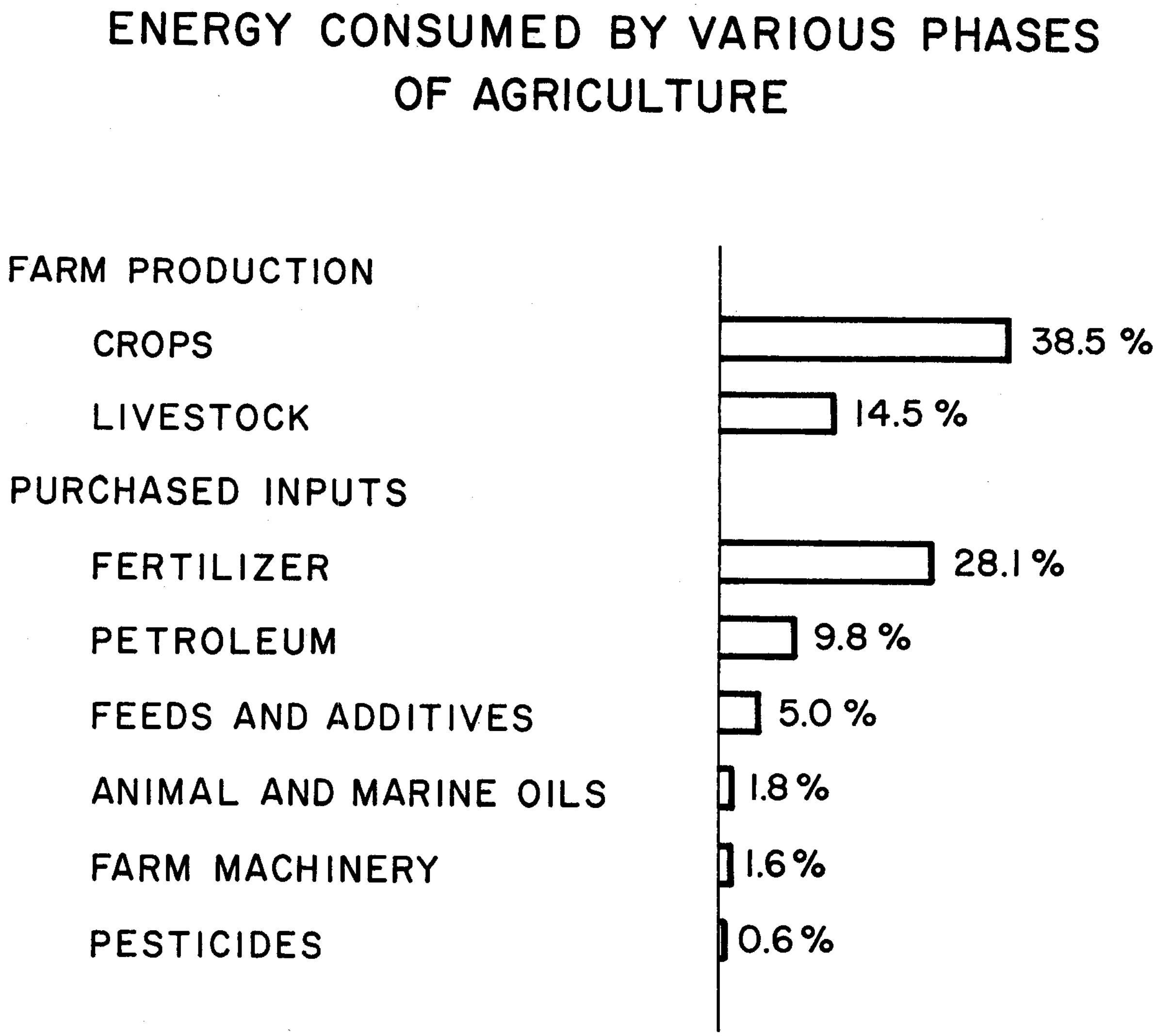

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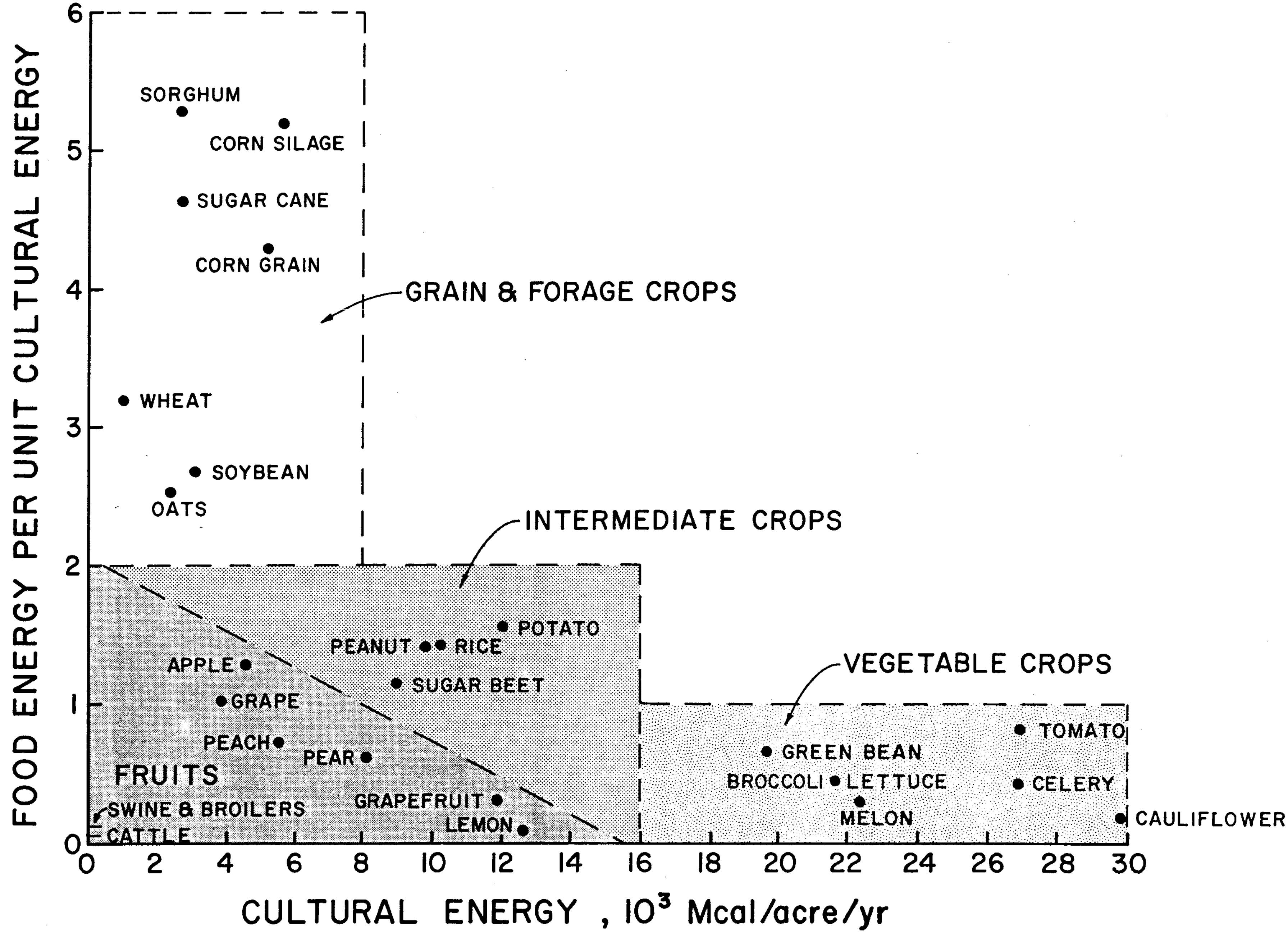

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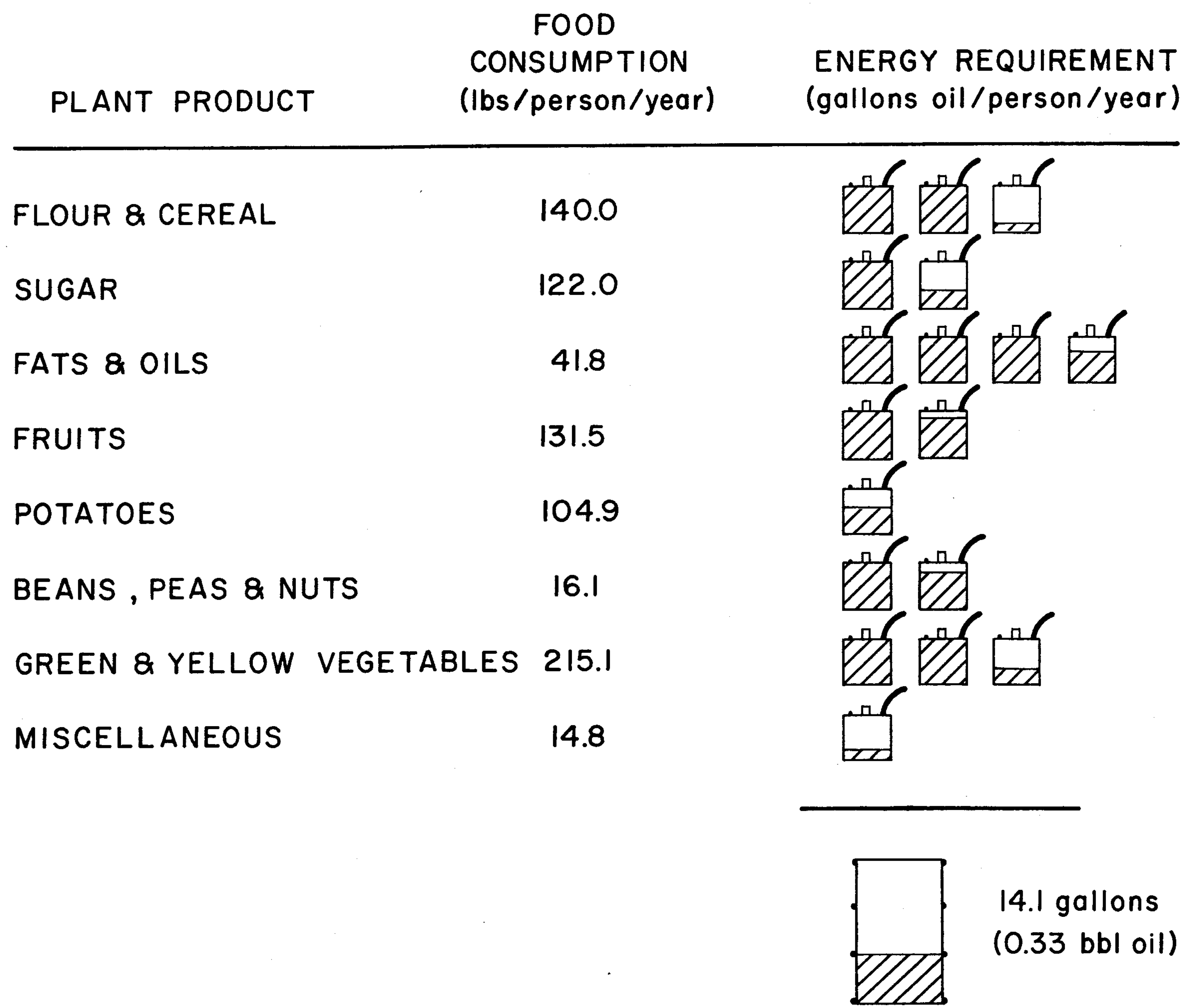


Figure 2b. Energy Consumption by Plant Crop.

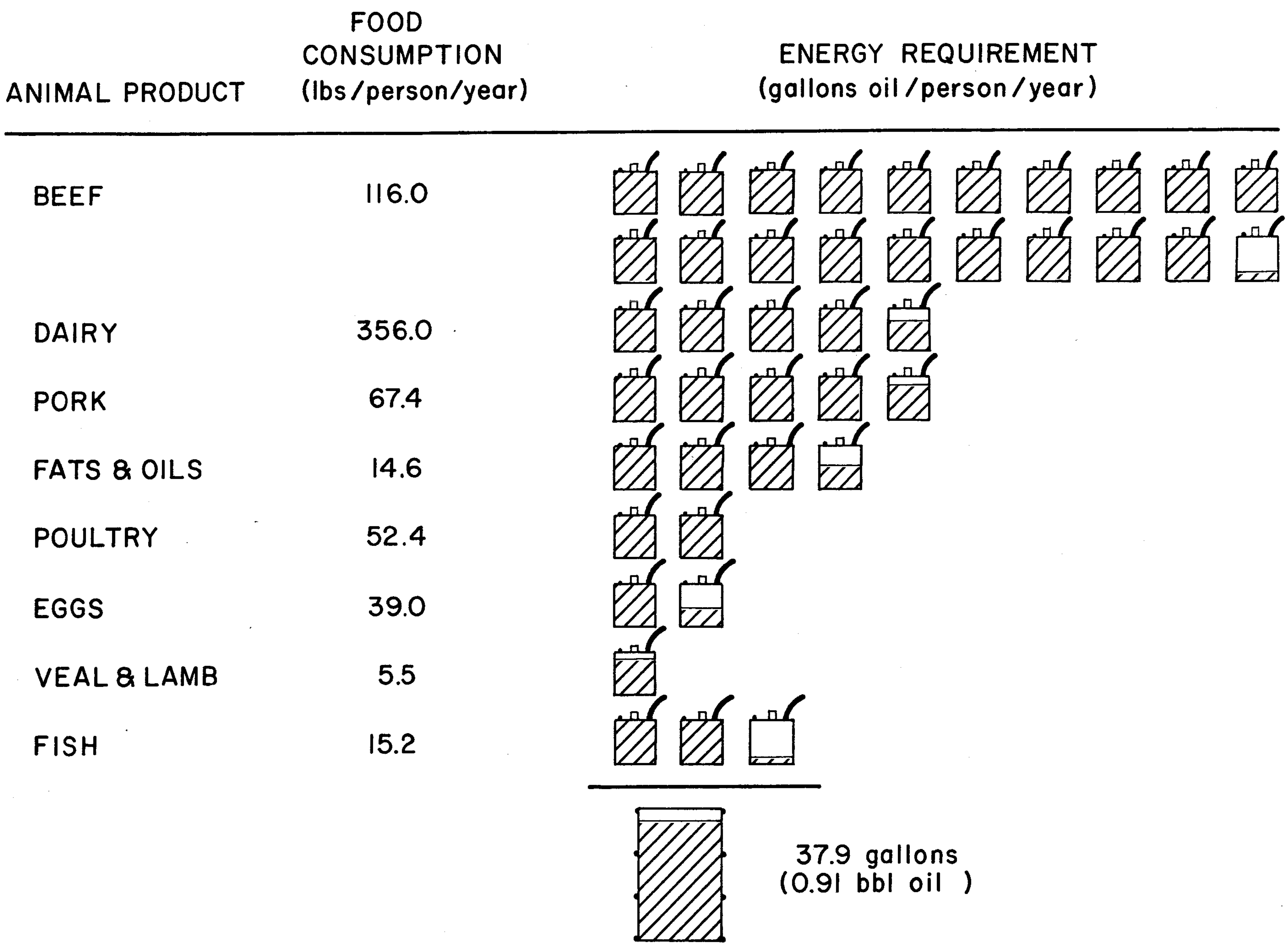


Figure 2c. Energy Consumption by Livestock Product.

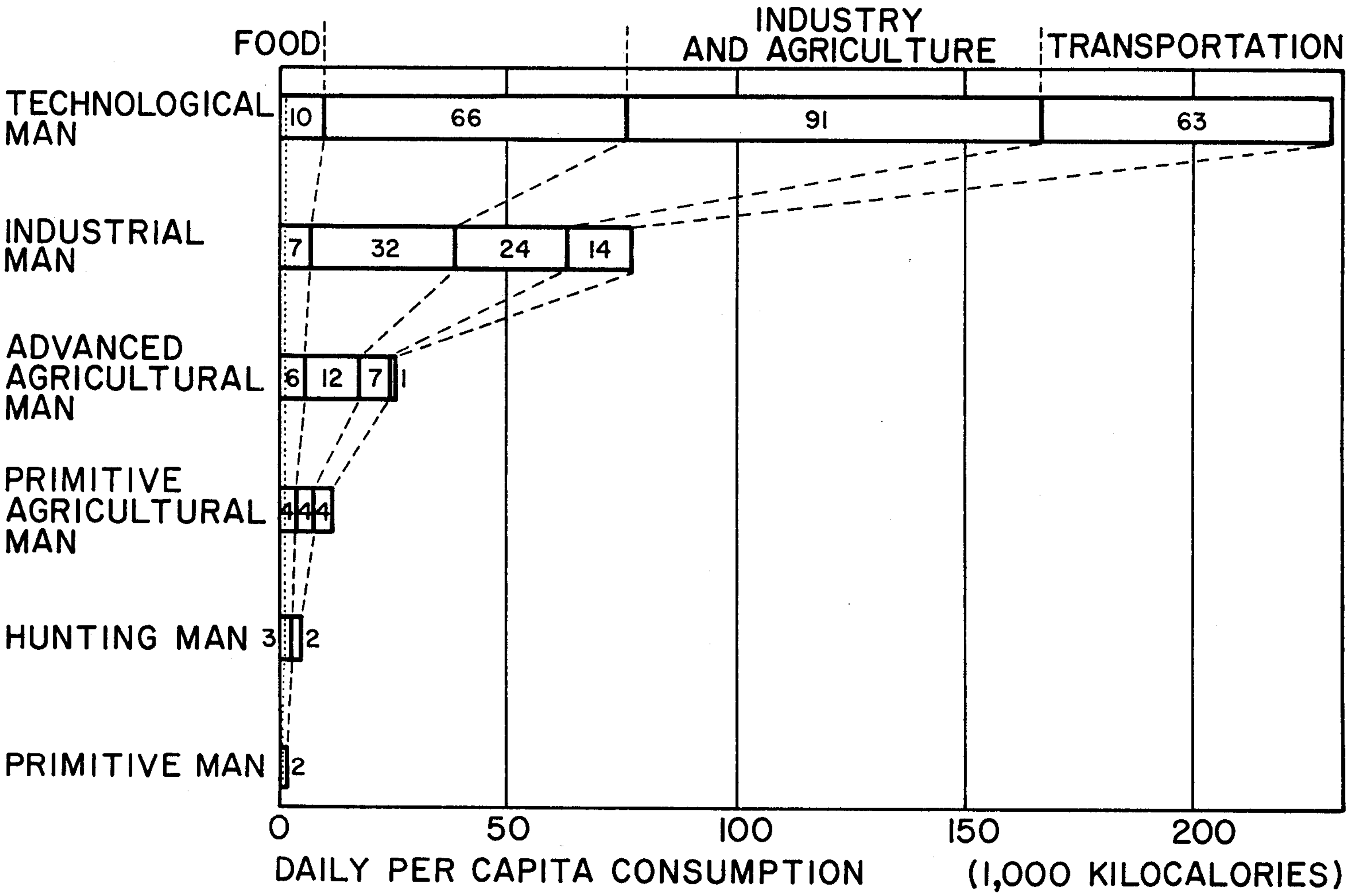


Figure 3. Daily Consumption of Energy Per Capita During Stages of Human Development (From Rappaport, 1971).

RANDOM (DAY OR NIGHT)	DAY (NO PRECISE TIME)	DAY (PRECISE TIME)	NIGHT (PRECISE TIME)	WIND POWER	SOLAR RAD.	VEGETABLE WASTE	NOTES
DOMESTIC WATER SUPPLY				W		V	V ONLY SUPPLEMENTARY
WATER DISTILLATION					S		
IRRIGATION				W		V	V ONLY SUPPLEMENTARY
WATER HEATING				W	S		W ONLY SUPPLEMENTARY (water heating and steam raising)
STEAM RAISING				W	S		
	THRESHING			W		V	V ONLY SUPPLEMENTARY
	GRINDING			W			
	FOOD MIXING			W			
	FODDER CHOPPING			W			
	SMALL INDUSTRIAL OR AGRICULTURAL POWER			W		V	IN COMBINATION
		COOKING		W	S	V	IN COMBINATION (cooking and fans/air conditioning/refrigeration)
		FANS AND AIR CONDITIONING REFRIGERATION		W	S		
			LIGHTING	W			WITH BATTERY STORAGE (lighting and radio/small domestic power)
			RADIO AND SMALL DOMESTIC POWER	W			

Figure 4. Energy Needs in a Rural Community Classed by Their Timing Requirements and Means Supplied (From Golding and Thacker, 1956).

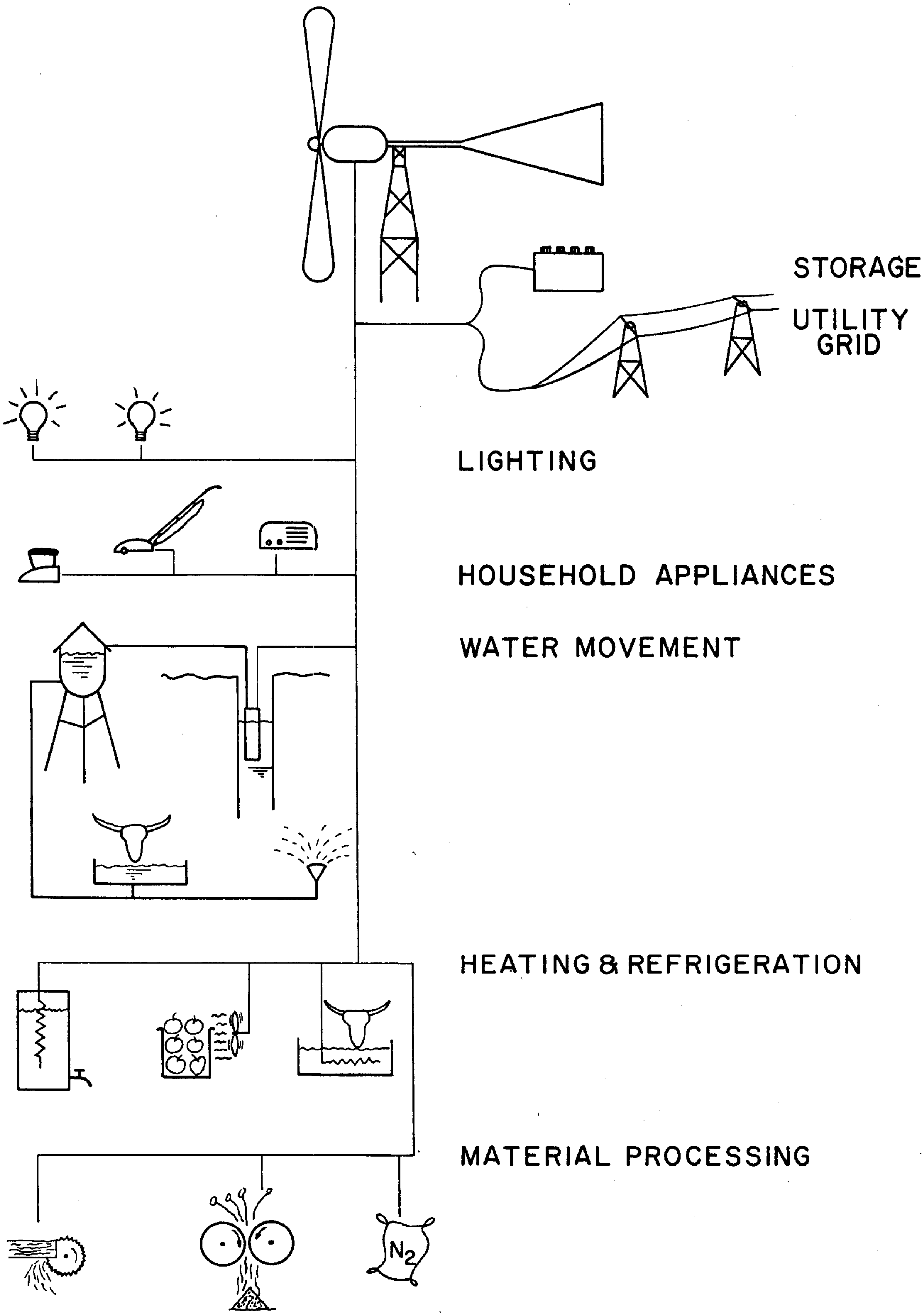
FIGURE 5. TABLE: SMALL COMMERCIAL WECS SYSTEMS

WINDMILL NAME	SIZE (kW)	BLADE DIAMETER (ft)	NO. BLADES	RATED SPEED (mph)	CUT IN SPEED (mph)	CUT OUT SPEED (mph)	GOVERNOR	GENERATOR TYPE	APPROX. PRICE (1976) ~ $
Aermotor (USA-Argentina)	water pumping	6	18	15-18	9-10	30	Vane deflector	-	412
	"	8	"	"	"	"	"	-	614
	"	10	"	"	"	"	"	-	1,060
	"	12	"	"	"	"	"	-	1,780
	"	14	"	"	"	"	"	-	2,886
	"	16	"	"	"	"	"	-	3,970
Aerowatt (France) 24FP7	0.028	3.3	2	15.7	6.7	-	Centrifugal pitch control	3ϕ Alternator	2,953
150FRP7	0.130	6.7	2	15.7	6.7	-	"	"	5,429
300FP7	0.350	10.7	2	15.7	6.7	-	"	"	7,120
1100FP7	1.125	16.7	2	15.7	6.7	-	"	"	12,809
4100FP7	4.100	30.7	2	16.8	8.9	-	"	"	16,476
American Wind Turbine SST (USA)	0.45	8	24	20	10	30	Vane deflect	-	250
	0.90	12	36	20	10	-	"	-	525
	1.80 or water pumper	16	48	20	10	-	"	Alternator	850
Baker (USA)	water pumper	6	20	15	~7	25	Vane deflect	-	468
		8	36	15	~7	25	"	-	608
		10	30	15	~7	25	"	-	950
		12	32	15	~7	25	"	-	1,395
Dempster-12 (USA)	water pumper	6	15				Vane deflect	-	410
		8	15				"	-	610
		10	24				"	-	1,050
		12	18				"	-	1,775
		14	18				"	-	2,850
Domenico Sperandio & Ager (Italy)	0.25								na
	0.50								na
	1.00								na
Dominion Aluminum DAF (Canada)	2	15	2-Darrieus	23	7	65	Spoilers or induction generation	Alternator	5,195
	4	15	"	23	7	65		"	5,195
	6	20	"	23	7	65		"	10,290
	8	30	"	23	7	65	"	"	na
Dunlite (Quirks) (Australia) L	1.0	12.0	3	25	10	-	Full feather	Alternator	2,025
M	2.0	12.0	3	25	10	-	Full feather	Alternator	2,975

(con't)

FIGURE 5. TABLE: SMALL COMMERCIAL WECS SYSTEMS (con't)

WINDMILL NAME	SIZE (kW)	BLADE DIAMETER (ft)	NO. BLADES	RATED SPEED (mph)	CUT IN SPEED (mph)	CUT OUT SPEED (mph)	GOVERNOR	GENERATOR TYPE	APPROX. PRICE (1976) - $
Electro (Switzerland)									
W50	.05	1.42	Savonius	39	7	none	-	Alternator	1,020
W250	.25	2.20	Savonius	40	7	none	-	Alternator	1,285
WV05	.60	8.33	2	20	7	50	Full feathering	Alternator	1,290
WV15G	1.20	9.83	2	23	7	50	"	Alternator	1,695
WV25G	1.80	11.50	2	22	7	50	"	Alternator	1,940
WV25/3G	2.50	12.50	3	23	7	50	"	Alternator	2,380
WV35G	4.00	14.42	3	24	7	50	"	Alternator	2,750
WVG50G	6.00	16.42	3	26	7	50	"	3ϕ Alternator	3,275
Enag (France)	0.40	na	2	na	na	na	na	na	1,587
	1.20	na	3	na	na	na	na	na	2,287
	2.50	na	3	na	na	na	na	na	4,164
Kedco-1200 (USA)	1.2	12.0	3	21.0	7	-	Centrifugal feathering	Alternator	1,695
Lubing (French) M022-3	water pumper/ 0.4	7.22 7.22	3 6	11.2 18	6.7	35	3 fired 3 feathered	Alternator	-- 2,500
NOAH (Switzerland)	55	36	10 double rotor	20	6.7	-	Electronic	28 perm. magnet AC generator	35,000
Sencenbaugh 750-14 (USA)	0.75	12	3	20	na	30	na	na	1,465
Winco Windcharger 1222H (USA)	0.20	6	2	23	7	-	Air brake	Dble. carbon brush	565
Windstream-25 Grumnan (USA)	15	25	3	26	9	60	na	Alternator	15,000-30,000



SUGGESTED APPLICATIONS FOR WECS

Figure 6. Specific Applications of WECS in Rural Environment.