Energy for Cattle

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Energy is defined as the capacity to perform work. Work is performed when muscles contract, glands secrete and complex molecules (carbohydrates, fats, proteins, nucleic acids) are sythesized. To perform work energy must be in an active (kinetic) form. When energy is kinetic there is motion. Such motion includes motion of photons (light), motion of electrons (electricity), motion of atoms and molecules (heat). All forms of energy are at least partially interconvertible.

The first law of therodynamics says that the amount of energy is constant and neither increased or lost by interconversions. At first glance it would seem that the same energy could be passed from organism to organism and no source of energy outside the system of all living things would be required. Further thought reminds us that energy is constantly passed from living to nonliving matter. Examples include heat lost from a body of air, energy imparted to a thrown rock or to a pencil in writing a sentence. Such energy is lost to the life system. In addition, energy containing molecules may leave the body in urine, fecal material or gases that escape orally.

There is still another reason why the life system would run down without a nonliving energy source. The second law of thermodynamics divides energy into free energy (available for work) and bound energy or entropy. Free energy exists in a highly organized and improbable state. The tendency is to progress toward randomness or entropy. The second law says that every energy transformation results in a reduction in the usable or free energy of a system. Conversely, the amount of energy that cannot be used for work increases steadily. A free energy state can only be maintained if an exogenous energy supply is provided. The living cell is an inherently improbable and unstable organization. The acquisition of energy in usable form is essential to maintain and propagate these cells.

The source of usable energy for animals is food that contains the energy nutrients (carbohydrates, fats and proteins). For animals, energy food is mostly supplied by plants. The ultimate energy source for all living things is sunlight. The organisms that transform light energy into chemical energy are primarily the green plants. The process that makes the transformation is called photosynthesis. The basic equation for green plant photosynthesis is:

$$CO_2 + H_2O + \text{light} \xrightarrow{\text{chlorophyll}} O_2 + CH_2O + H_2O$$

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multiplying the basic equation by 6 shows that glucose, a simple 6 carbon sugar, is often the end product.

$$6CO_2 + 12H_2O + \text{light} \xrightarrow{\text{chlorophyll}} 6O_2 + C_6H_{12}O_6 + 6\ H_2O$$

Both the CO_2 and the water on the left side of the equation are split and the water on the right side is new water. Photosynthesis then is a process that converts light energy into chemical energy and stores it by synthesizing energy rich sugar from energy poor carbon dioxide.

In photosynthesis, photons of visible light in the violet, blue and red portions of the spectrum are absorbed by photosynthetic units in the chloroplasts of photosynthesizing cells. Each unit contains about 300 pigment molecules including chlorophyll a, chlorophyll b and cartenoids. Light comes in discrete packages called photons. When a photon is absorbed by a chlorophyll or carotenoid molecule, its energy is transferred to an electron of that molecule. This electron is raised from its normal stable energy level to a higher and relatively unstable state. Accordingly, it will tend to fall back to its normal level and the absorbed energy will be given up. The process is not simple. The energized electron is passed to an acceptor molecule with a high affinity for electrons and enters a series of enzyme catalyzed reactions which convert the energy into a form that is readily usable by the cell.

Two types of endothermic (energy storing) reactions occur:

1. $ADP + P \rightarrow ATP$
2. $CO_2 + H_2O \rightarrow O_2 + CH_2O + H_2O$

ATP synthesis, dehydrogenation and electron transport occur in other energy systems (cellular respiration), but light induced production of high energy electrons to start the processes is unique to photosynthesis.

Thus far we have demonstrated a source of energy rich nutrients that can be utilized by the bovine. We now need to demonstrate a valid measuring system that enables the determination of energy concentrations in feeds and energy requirements of animals.

We have said that the various energy forms (heat, light, electricity, matter in motion) are interconvertible. We use heat energy measurements in ration formulation. The basic unit of energy measurement in animal nutrition is the kilocalorie. One kilocalorie is the amount of heat required to raise the temperature of 1 kilogram of water 1 degree Celsius. In bovine nutrition it is customary to use the megacalorie (1000 kcal) as the basic unit. Energy concentrations in feeds are expressed as Mcal/kg of dry matter. Energy requirements for maintenance and production are expressed as Mcal/kg of metabolic weight.

Computing the energy concentrations of feeds and requirements of animals are complicated by 2 phenomona:

1. The efficiency of utilization varies according to specific use. Energy used for maintenance, lactation and possibly the products of conception is utilized more efficiently than is energy used for increase in body weight.
2. Energy utilization is related to body surface more than to body weight. Generally speaking, the larger the animal, the smaller the energy requirement per unit of body weight.

The history of development of the concepts currently used to compute energy requirements in rations is of some interest.

Kleiber (1947) reviewed the work of the pioneers of energy research and made some observations:

1. Large animals use more energy per unit of time than do small animals.
2. Small animals use more energy per unit of weight than do large animals.

The problem was to find a unit of body size for which the metabolic rate is equal in both small and large animals. A suitable unit is the square meter of body surface.

The theory that in animals of different size the metabolic rate is proportional to their surface areas is over 140 years old. In 1839, Sarrus and Rameaux published a paper that takes for granted that it is nature's aim to make the rate of heat production in large and small animals proportional to their respective surface areas or the 2/3 power of their body weights. In 1889, Rubner deduced a simple rule that fasting homeotherms produce 1000 kcal of heat per square meter of body surface daily. Also in 1889, Richet calculated the surface area of rabbits. He assumed that they were spheres and that their specific gravity = 1 (1 kg/liter). The surface area of such a sphere is 4.84 /kg$^{2/3}$ square decimeters. Dubois, 1916, took into consideration that animals are not spheres and developed a formula which is possibly a good one for estimating the body surface of a man.

S= 71.84 W/kg$^{.425}$ X length in cm$^{.725}$ where S equals surface in square decimeters.

Many methods have been invented for measuring the surface area of animals, but the variations are great and the issue has not clarified. The surface area is not well enough defined to serve as a basis for measurement.

In 1932, Kleiber, in agreement with Krogh (1916), Stoetzer (1928) and Brody (1928), suggested a power function of body weight as the basis of metabolic body size. Plotting the logarithms of fasting metabolic rate against the logarithms of body weight for 10 groups of mammals revealed surprisingly small deviations from the mean trend. Kleiber reasoned that if the logarithm of metabolic rate is a linear function of the logarithm of body weight, then metabolic rate must be proportional to a given power of body weight.

If $\log M = \text{Log } a + p \log W$ then $M = a\,W^P$

Kleiber proposed the 3/4 power as the best fitting function. Soon after the Kleiber publication, Brody and Proctor proposed a more definite equation.

Metabolic rate = 70.5 kcal/kg wt$^{.734}$. Brody obtained the same equation using a wide range of animals including mice and elephants and concluded that this equation closely approaches the true relation between basal metabolism and body wt. of mature mammals. In 1935, the National Research Council endorsed the power function after reducing it to 2 decimals (.73) as the most suitable unit of metabolic weight. Ultimately, Kleiber's 3/4 power unit became preferred because of its convenience. Wt$^{3/4}$ could be easily obtained on a slide rule (extract the square root of the square root of the cube of the body weight).

For most species the energy requirements and concentrations in feeds are measured as digestible energy (D.E.) or metabolized energy (M.E.). It is generally accepted that each gram of dry digestible nutrients (TDN) contains 4.409 kcal of D.E. It is also accepted that M.E. is a function of D.E. For beef cattle M.E. = D.E. x .82 or 4.409 x . 82 = 3.6155 Kcal/gram of dry matter.

For ruminent animals metabolizable energy is not a satisfactory measurement. The heat increment that results from the metabolism of roughages is significantly greater than it is for concentrates. The M.E. system tends to overrate roughages as an energy source especially in the production area. For this reason, Lofgreen and Garrett in the late 1960's developed what is now known as the "California Net Energy System." This work was published in 1968 and since has been widely accepted by the feeding industry. The NRC publication for beef cattle has utilized this system to compile requirement and concentration tables since 1972.

Table 1 illustrates the discrepancy in heat production between roughage and concentrate feed components (California experiment).

TABLE 1. Relative Heat Production

Ration 1 Free choice alfalfa 19.45 lbs.		**Ration 2** 98% concentrates to yield gain equal to Ration 1
20.714 Mcal ←	ME intake	→ 13.919 Mcal
2.810 Mcal ←	NEg	→ 2.827 Mcal
17.904 Mcal ←	Heat produced	→ 11.092 Mcal
86% of intake ←	% intake as heat	→ (80% of intake)

To calculate energy requirements of animals, there must be a way to measure heat production. Necessary definitions include:

1. Gross energy (G.E.) = total energy in food
2. Combustible gas energy (CGE) = energy lost orally
3. Fecal energy (FE) = energy lost in fecal material
4. Urinary energy (UE) = energy lost in urine
5. Metabolizable energy (ME) = total energy change in a system (animal)

"The California Net Energy System" is based on the premise that metabolizable energy equals the energy of basal metabolizable (Hb) plus the energy of normal activity (Ha) plus the enery lost in body heat (the heat increment or Hi) plus the energy stored in production (Hp). Hp includes energy stored in gain, the products of conception and milk. Thus ME = Hb + Ha + Hi + Hp and total heat (Hb + Ha + Hi) = Me - Hp. Therefore, if we can measure ME and the energy deposited in a product, we can measure total heat production resulting from the use of a unit of feed. ME is obtainable by subtracting F.E., C.G.E. and U.E. from G.E. Lofgreen and Garrett measured NEp by the "Comparative Slaughter Technique" as follows:

1. A large number of animals are selected for uniformity.
2. A portion of these animals are weighed, slaughtered and measured for carcass specific gravity (C.S.G.)
   a. The dead carcass is weighed in air
   b. The dead carcass is reweighed in water
   c. The C.S.G. is measured mathematically and used to calculate body composition
3. The remaining animals are fed for a prescribed period:
   a. A valid sample of animals are slaughtered
   b. C.S.G. for these animals is measured
   c. Carcass composition is calculated from C.S.G.
   d. Energy is the final sampling minus energy in the initial sampling equals the NEp (in this case NEg)

It is now possible to measure heat production at different levels of intake and by extrapolation, measure the net energy required for maintenance. Such measurements tell us that at moderate temperatures the NEm requirement for cattle in feedlot conditions is .077 Mcal x $B.W/kg^{.75}$.

The NEm requirement is modified by weather. Handley at Colorado State University has derived a formula to compute NEm requirements according to the temperature wind index (T.W.I.). The T.W.I. equals the environmental temperature in degrees F minus the wind velocity in mph. If the temperature is 40° and the wind velocity is 10 mph, the T.W.I. = 40-10 = 30. Handley's formula has been modified to express the NEm requirement in Megacalories:

$$\text{NEm requirement} = \frac{(B.W/kg^{.75})\ (116 \times .8133\ T.W.I.)}{1000}$$

If an animal weighs 500 kg and the T.W.I. is 20, the daily NEm requirement is:

$$\frac{(500)^{.75})(116 - (.8133 \times 20)}{1000} = 10.55 \text{ Mcal}$$

The NEg requirements are calculated by equations formulated by Lofgreen and Garrett. The equations differ according to sex and are listed in metric units of the NRC publication for beef cattle as follows:

For steers:

$$\text{NEg (in Mcal)} = (.05272 \text{ gain} + .00684 \text{ gain}^2)(B.W/kg^{.75})$$

$$\text{gain (kg)} = 73.099\sqrt{.002779 + .02736\ NEg/W/kg^{.75}} - 3.8538$$

For heifers:

$$\text{NEg (Mcal)} = (.05603 \text{ gain} + .01265 \text{ gain}^2)(B.W/kg^{.75})$$

$$\text{gain kg} = 39.526\sqrt{.003139 + .0506\ NEg/B.W/kg^{.75}} - 2.2146$$

The above equations have been modified to express body weight and gains in pounds.

For both heifers and steers:

$$\text{NEm (Mcal)} = .042 \times B.W/lbs.^{.75}$$

For steers:

$$\text{Neg (Mcal)} = (.01326 \text{ gain} + .00078 \text{ gain}^2)(B.W/lbs.^{.75})$$

$$\text{gain lbs.} = \frac{\sqrt{.000176 + .00312\ NEg/B.W/lbs.^{.75}} - .01326}{.00156}$$

For heifers:

$$\text{NEg (Mcal)} = (.01408 \text{ gain} + .00144 \text{ gain}^2)(B.W/lbs.^{.75})$$

$$\text{gain lbs.} = \frac{\sqrt{.000198 + .00567 NEg/B.W/lbs.^{.75}} - .01408}{.00288}$$

Specific equations have been derived for cattle over 500 lbs. coming to the feedlot from grass pastures or crop residues. These equations express body wts. and gains in pounds.

For steers:

$$\text{NEg (Mcal)} = (.01226 \text{ gain} + .00072 \text{ gain}^2)(B.W/lbs.^{.75})$$

$$\text{gain lbs.} = \frac{\sqrt{.0001504 + .00288\ NEg/B.W/lbs.^{.75}} - .01266}{.00144}$$

For heifers:

$$\text{NEg (Mcal)} = (.01266 \text{ gain} + .001336 \text{ gain}^2)(B.W/lbs.^{.75})$$

$$\text{gains lbs.} = \frac{\sqrt{.0001688 + .00534\ NEg/B.W/lbs.^{.75}} - .01299}{.00267}$$

The energy concentrations in specific feeds have been determined by difference trials and by equations derived from data obtained from difference trials. Table 2 illustrates a difference trial to determine the NEm concentration (Mcal/kg) in alfalfa.

Table 2. Determination of NEm Concentration in Alfalfa Hay

Feeding Level	Feed Eaten (Grams/W.kg.75)	ME Intake (Kcal/W.kg.75)	Heat Produced (Kcal/W.kg.75)	Energy Gain (Kcal/W.kg.75)
1-Feeding	0	0	77	-77
2-Maintenance	64	131	131	0
3-Differences	64	131	54	77

64 grams D.M feed yielded 77 kcal retention so:

$$\text{NEm concentration} = \frac{77}{64} = 1.2 \text{ kcal/gram or } 1.2 \text{ Mcal/kg}$$

Table 3 illustrates a difference trial to determine the NEg concentration for alfalfa hay.

Table 3. Determination of NEg Concentration in Alfalfa Hay

Feeding Level	Feed Eaten (Grams/W.kg.75)	ME Intake Kcal/W.kg.75)	Heat Produced (Kcal/W.kg.75)	Energy Gain (Kcal/W.kg.75)
1-Maintenance	64	131	131	0
2-Above Main.	146	298	256	42
3-Differences	82	167	125	42

82 grams of feed yielded 42 kcal so NEg concentration equals:

$$\frac{42}{82} = .51 \text{ kcal/gram or } .51 \text{ Mcal/kg}$$

Since NEm and NEg values are not yet available for all feeds, a method has been devised to predict these values. The concept is based on the relationship of ME, NEm and NEg in feeds for which NEm and NEg concentrations have been established by difference trials. The formulas were developed by Lofgreen and Garrett.

$$\text{Log } F = 2.2577 - 0.2213 \text{ M.E}$$

$$\text{NEm} = 77/F$$

$$\text{NEg} \quad 2.54 - .0314 F$$

The terms used in the formulas are defined in NAS-NRC Publ. 1411 and are on a dry matter basis. Definitions include:

1. M.E = The metabolizable energy in Mcal/kg of dry matter (D.M.)
2. F = The grams of dry matter per Kg. B.W.$^{.75}$ required to maintain energy equilibrium
3. NEm = Net energy for maintenance in Mcal/kg D.M
4. NEg = Net energy for weight gain in Mcal/kg D.M

The correlation between M.E and the feed required for maintenance (and thus NEm) is -.97. The correlation between the feed required for maintenance and NEg is -0.96.

The NRC manuals (beef and dairy) list NEm and NEg values in metric units (Mcal/kg D.M). *The Great Plains Beef Cattle Feeding Handbook* lists these values as Mcal/100 lb. feed.

In cattle net energy is used with very similar efficiency for both maintenance and lactation. A single NE value can be used to calculate requirements in both of these areas. The NAS-NRC publication for dairy cattle used a single value (NE lact.) to express requirements for maintenance, gestation, lactation and body weight change. Because of the differences in the methods of derivation of NEm and NE lact. values, there are some differences in individual values in the nutrient concentration tables.

For beef cattle energy requirements for pregnancy assume a deposition of 400 kcal/day during the last trimester of gestation. The efficiency of M.E utilization for conceptsus development is assumed to be 16%. 400/16=2500 Kcal or 2.5 Mcal/day of M.E.

For dairy cows, the NE lact. requirements for maintenance plus gestation in the last 2 months of pregnancy (the dry period) are computedd as: (.104 Mcal x B.W/kg $^{.75}$. The NE lact. requirement for maintenance alone at moderate temperatures is assumed to be .08 Mcal x B.W/kg$^{.75}$.

NE lact. requirements for milk production are tabulated in the dairy manual according to butterfat content and range from .59 Mcal per kg of 2.5% butterfat milk to .93 Mcal per kg. of 6% butterfat milk.

The NAS-NRC manual for beef cattle divides lactating cows (nursing calves) into average (5 kg $\pm$ .5 kg milk per day) and superior (10 kg $\pm$ .5 kg. milk per day) and tabulates the requirements in Mcal NEm. The requirements are listed in table 1B of the manual and include maintenance plus lactation needs. These requirements are listed according to body wt. in 50 kg increments.

References

1. Garrett, W.N. and Hinman, N.: Revaluation of the Relationship Between carcass density and body composition of beef steers. J. Animal Sci., 28:1, 1969. 2. Johnson, D.E. and Crownover, J.C.: Energy Requirements of Feedlot Cattle in North Central Colorado: variation in maintenance requirements by the month: Research Highlights of the Animal Science Department, Colorado State University Experimental Station General Series 948, 1975. 3. Kleiber, Max: The Fire of Life, an introduction to animal energetics, Ch. 10, p. 179. 4. Lofgreen, G.P. and Garrett, W.N.: A system for expressing net energy requirements and feeding values for growing and finishing beef cattle. J. Animal Sci. 27:793-806, 1968. 5. National Research Council: Biological energy relationships and glossary of energy terms. 2nd ed. (Prepared by L.E. Harris), Publ. 1411, National Academy of Sciences, National Research Council, Washington, D.C., 1966. 6. National Research Council, Nutrient Requirements of Beef Cattle, 5th rev. ed., National Academy of Sciences, Washington, D.C., 1976.