# Estimating digestible energy values of feeds and diets and integrating those values into net energy systems

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**ABSTRACT:** The California Net Energy System (CNES) used a combination of measured and tabular metabolizable energy (ME) values and changes in body composition gain to determine net energy requirements for maintenance and gain and their corresponding dietary concentrations. The accuracy of the CNES depends on the accuracy of the feed ME values. Feed or diet ME values can be measured directly but are expensive and require specialized facilities; therefore, most ME values are estimated from digestible energy (DE) values, which are often estimated from the concentration of total digestible nutrients (TDN). Both DE and TDN values are often from tables and not based on actual nutrient analysis. The use of tabular values eliminates important within-feed variation in composition and digestibility. Furthermore, the use of TDN to estimate DE does not account for important variation in the gross energy value of feeds. A better approach would be to estimate DE concentration directly from nutrient composition or in vitro (or in situ) digestibility measurements. This approach incorporates within-feed variation into the energy system and eliminates the issues of using TDN. A widely used summative equation based on the commonly measured feed fractions (ash, crude protein, neutral detergent fiber, and fat) has been shown to accurately estimate DE concentrations of many diets for cattle; however, deficiencies in that equation have been identified and include an overestimation of DE provided by fat and an exaggerated negative effect of intake on digestibility. Replacing the nonfiber carbohydrate term (which included everything that was not measured) in the equation with measured starch concentration and residual organic matter (i.e., nonfiber carbohydrate minus starch) should improve accuracy by accounting for more variation in starch digestibility. More accurate estimates of DE will improve the accuracy of ME values, which will ultimately lead to more accurate NE values.

**Key words:** carbohydrates, digestibility, energy, feed evaluation

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## INTRODUCTION

The classical energy system used in nutrition (Figure 1) is a direct application of the first law of thermodynamics, which basically states that the energy in a system can be transformed, but it cannot be created or destroyed. The first law was the basis of the California Net Energy System (CNES) developed by Lofgreen and Garrett (1968). Net energy requirements for maintenance (NEm) and gain (NEg) and feed NEm and NEg could be estimated using their system. Over the

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past 50 yr, the system developed by Lofgreen and Garrett (1968) has had widespread acceptance and with some modification is still in use today.

The accuracy of the CNES to predict energy retention in growing animals or body energy change in gestating and lactating beef cows and to formulate diets depends on the accuracy of estimating feed NEm and NEg values. The starting point for feed NEm and NEg values used by Lofgreen and Garrett (1968) was feed metabolizable energy (ME) values. Some values were measured directly, but many were derived from values published by NRC (1966) or the concentration of total digested nutrients (TDN) published in Morrison (1956), which were converted to digestible energy (DE) and then to ME. The nutrient composition of feeds (not just forages) varies tremendously (NASEM, 2016) even within a farm (St-Pierre and Weiss, 2015), which will affect TDN and ME values; book values do not reflect that variation. Under field conditions, actual dietary ME will not be known, and it is not measured in the vast majority of nutrition research trials in which energy retention (i.e., growth) is determined. Therefore, to obtain NE values for diet formulation, to evaluate energy efficiency using growth data, and to compare the economic value of feeds, some method of estimating feed ME values is needed.

Following the classic energy system (Figure 1), estimating DE first and then estimating ME have advantages over estimating ME directly. Of the potential energy losses illustrated in Figure 1, fecal energy is the largest and most variable loss for dairy cows (Figure 2), which is likely true for beef cattle as well. Therefore, accounting for variation in DE will account for much of the variation in ME. The number of measured ME values is substantially less than the number of measured DE values. The greater number of data points for DE should improve the accuracy of derived equations and allow more robust evaluation of DE equations. Accurately estimating the digestibility of specific nutrients should improve our ability to estimate both methane and urinary energy losses. Lastly, by first estimating DE and then estimating ME, additional sources of variation can be included in the overall model.

This paper will discuss a commonly used method to estimate DE of cattle diets including recommended improvements to current equations and how DE values can be more accurately converted to ME values.

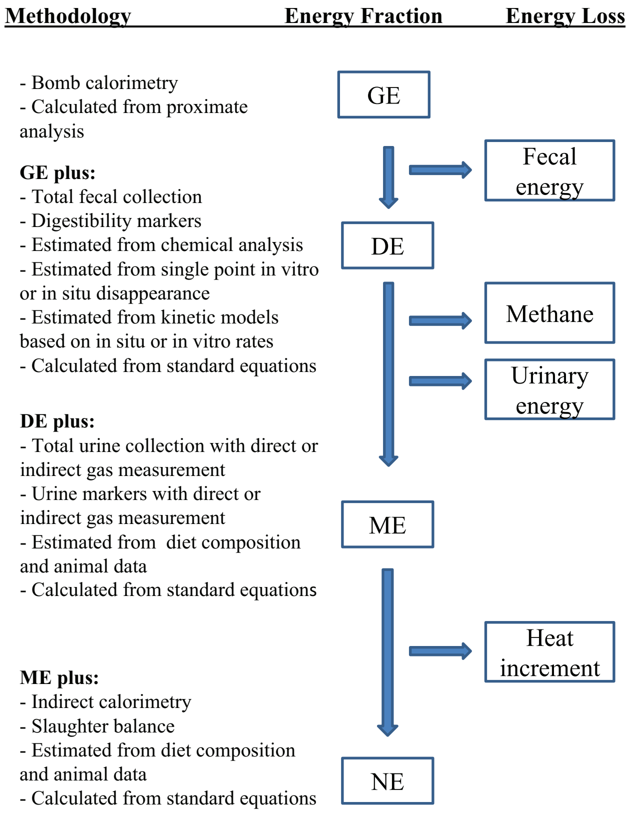

**Figure1.** The classical flow of energy through an animal including methods of measuring or estimating the various energy fractions of GE, DE, ME, and net energy (NE).

## CURRENT PRACTICES

Two systems that are widely used to formulate diets for cattle are the NASEM (2016) system for beef cattle (Beef System) and the NRC (2001) system for dairy cattle (Dairy System). The two systems use different methods for estimating ME, but the equations to convert ME to NEm and NEg are the same (the method used to calculate net energy for lactation will not be discussed). The Dairy System first calculates DE using a modified summative equation. The original equation (Weiss et al., 1992) estimated TDN and then calculated DE from TDN [DE, Mcal/kg = 0.04409 × TDN, %; (Crampton et al., 1957)]. Although TDN was estimated accurately (Weiss et al., 1992), DE values were not (data not shown). The reason for this is that the enthalpy

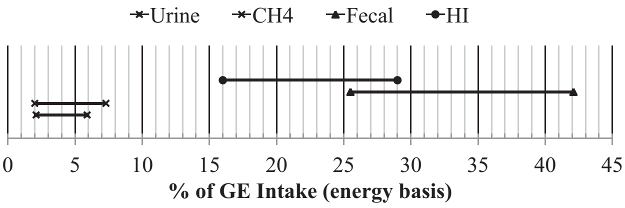

**Figure 2.** Range in dietary energy losses by dairy cows fed a variety of diets. HI = heat increment; $CH_4$ = methane (data derived from Wilkerson et al. (1997)).

of TDN is not constant at 4.409 Mcal/kg. Variation in concentrations of digestible fat and protein will affect the caloric value of TDN. The gross energy (GE) is the starting point for estimating various feed energy values, but depending on the approach followed to obtain DE values, it may not need to be estimated or measured. The GE concentration of feeds and diets is largely dependent on the concentrations of ash, fat, and crude protein (CP) and will increase as ash concentration decreases or as CP or fat concentrations increase (Table 1). The GE can be measured easily with a bomb calorimeter; however, few commercial feed-testing laboratories have that equipment. Fortunately, GE concentrations can be calculated reasonably accurately if feeds are analyzed for ash, CP, and fat concentrations (%), and the residue (100 − ash − CP − fat) is assumed to be mostly polysaccharides. Those fractions are multiplied by their average enthalpies (0, 5.6, 9.4, and 4.2 Mcal/kg for ash, CP, fat, and carbohydrates) to obtain GE,

$$\begin{aligned} \text{GE, Mcal/kg} = {} & \text{CP x } 0.056 + \text{fat x } 0.094 \\ & + (100 - \text{CP} - \text{Fat} - \text{ash}) \\ & \text{x } 0.042 \end{aligned} \tag{1}$$

where nutrients are expressed as percentages of dry matter.

Depending on the feed, variation in GE ranges from almost trivial to quite high. For example, when ash, CP, and fat concentrations were varied by ±1 standard deviation unit (SD), the difference in GE within a feed ranged from 1.1% (corn grain) to 10.9% (alfalfa silage). The GE of diets also varies (Table 1), which will contribute to inaccurate estimates of DE when TDN is used. Equation 1 will overestimate the GE of diets with urea, or any NPN source. Urea has an enthalpy of 0.89 Mcal/kg of CP equivalent (2.5 Mcal/kg of urea); therefore, when urea is included in a diet, GE should be calculated as follows:

$$\begin{aligned} \text{GE, Mcal/kg} = {} & \text{CP}_{\text{feed}} \text{ x } 0.056 + \text{CPE}_{\text{NPN}} \text{ x } 0.0089 \\ & + \text{fat x } 0.094 \\ & + \left(100 - \text{CP}_{\text{feed}} - (\text{CPE}_{\text{NPN}} / 2.81) - \text{Fat} - \text{ash}\right) \\ & \text{x } 0.042 \end{aligned} \tag{2}$$

where nutrients are expressed as percentage of dry matter and $\text{CP}_{\text{feed}}$ is the CP in feeds other than supplemental NPN and $\text{CPE}_{\text{NPN}}$ is the CP equivalent (i.e., N × 6.25) provided by NPN (assumed to be urea). If two diets were the same (3% fat and 5% ash) except one contained 13% CP with no urea and the other diet contained 10% CP from feeds and 3% CP from urea and source of CP was not considered the estimated GE would be 4.17 Mcal/kg for both diets. However, when the correct enthalpy for urea is used, the GE of the diet with urea would be 4.10 Mcal/kg (about 2% less GE).

**Table 1.** Potential variation in GE in feeds and diets (dry matter basis)

| Feed or diet* | Ash, % | Fat, % | CP, % | GE, Mcal/kg |
|---|---|---|---|---|
| Average corn silage | 4.2 | 3.3 | 8.2 | 4.31 |
| Low GE corn silage | 5.3 | 2.8 | 7.1 | 4.22 |
| High GE corn silage | 3.1 | 3.8 | 9.3 | 4.40 |
| Average corn grain | 1.4 | 3.8 | 8.8 | 4.46 |
| Low GE corn grain | 1.7 | 3.3 | 7.8 | 4.43 |
| High GE corn grain | 1.1 | 4.2 | 9.8 | 4.48 |
| Average distillers dried grains | 5.3 | 10.7 | 30.8 | 4.97 |
| Low GE distillers grains | 6.2 | 8.7 | 28.1 | 4.79 |
| High GE distillers grains | 4.4 | 12.7 | 33.5 | 5.14 |
| Average alfalfa silage | 12.1 | 2.0 | 20.1 | 4.08 |
| Low GE alfalfa silage | 14.6 | 0.9 | 16.9 | 3.87 |
| High GE alfalfa silage | 9.5 | 3.1 | 23.3 | 4.29 |
| Typical finishing diet (average)† | 7.0 | 4.2 | 10.5 | 4.27 |
| High distillers grain diet (average)† | 7.6 | 5.4 | 14.4 | 4.41 |

*Low-GE feeds were assumed to have ash concentrations that were equal to the mean +1 SD, and CP and fat concentrations that were equal to the mean −1 SD. High-GE feeds were assumed to have ash concentrations that were equal to the mean −1 SD and CP and fat concentrations that were equal to the mean +1 SD. This approach assumes no covariance among nutrients, which is incorrect; therefore, actual range in GE will likely differ from what is illustrated. Assumed enthalpies were 0, 4.2, 5.6, and 9.4 Mcal/kg for ash, carbohydrates, CP, and fat (NRC, 2001). Composition data are from NAESM (2016).

†The typical finishing diet was assumed to be 10% corn silage, 10% distiller grains, 5% minerals and vitamins, and 75% corn grain. The high-distillers grain diet was assumed to be 10% corn silage, 30% distillers grains, 5% minerals and vitamins, and 55% corn grain (DM basis).

The empirical level within the Beef System retained TDN as the starting point to calculate ME and then NE. Furthermore, the system is based on tabular TDN values. This approach ignores variation in digestibility and composition within a feed and introduces the error of using a constant caloric value for TDN. The mechanistic level within the Beef System calculates digestibility of different fractions using rates of digestion and passage, but then calculates TDN from digestible mass and uses the standard equation to estimate DE from TDN. This approach incorporates within feed variation in digestibility and composition, but the error associated with using TDN to estimate DE remains. A better approach is to simply eliminate TDN from the energy system. This was the approach used in the Dairy System; the summative equation was used to estimate the masses of digestible CP, neutral detergent fiber (NDF), fat, and nonfiber carbohydrate (NFC), and those masses were multiplied by 5.6, 4.2, 9.4, and 4.2 Mcal/kg.

## SUMMATIVE EQUATION AND POTENTIAL IMPROVEMENTS

The original equation (Weiss et al., 1992) estimated NDF digestibility using a lignin-based equation, estimated true protein digestibility using acid detergent insoluble nitrogen, and assumed the true digestibility of NFC (calculated as 100 − CP − NDF − Fat − Ash, where concentrations are in percentage of dry matter and NDF is expressed on a CP and ash-free basis) was constant at 98% when cows were fed at maintenance intake, and true digestibility of fat (expressed as fatty acids) was assumed to be 100% at maintenance intake. The Dairy NRC (2001) System modified the equation to convert the digestible mass of each fraction into energy and thereby eliminate TDN from the estimation of DE. After DE was estimated, it was decreased (or discounted) based on intake of the cow and energy concentration of the basal diet (i.e., an attempt to account for negative associative effects).

Over time, some weaknesses in the original equation were noted (White et al., 2017), and methods to account for additional sources of variation were suggested (Tebbe et al., 2017). Improvements to the discount equation used in NRC (2001), which used diet TDN as a proxy for starch, have also been suggested (de Souza et al., 2018). If the energy estimation was included in a diet formulation or evaluation model, another problem was that the digestibility of CP for the energy system was often different from the digestibility of the CP calculated by the protein system (NRC, 2001; NAESM, 2016).

### *Fat Digestibility*

Based on meta-analyses (White et al., 2017), average true digestibility of fatty acids was closer to 75% than 90% (true digestibilities adjusted to dry matter intakes at 3.5 times maintenance); however, metabolic fecal excretion of a nutrient and its true digestibility are correlated, and one must be careful in comparing coefficients across experiments. A greater slope with a smaller (i.e., more negative) intercept can give similar values as an equation with a lesser slope and less negative intercept. When we conducted a Lucas test on fatty acid digestibility data obtained from our lab over the past 20 yr (207 observations), we obtained a true digestibility between 73% and 75% (at an average intake of 3.5 times maintenance) and a 0 intercept (Figure 3; Weiss, unpublished). All digestibility data from our lab are measured using total collection of urine and feces; detailed methodology is provided in Weiss et al. (2009). Weiss et al. (1992) used 100% true digestibility for fat based on data from a single paper (Palmquist, 1991). Since that paper was published, much more data are available on digestibility of fatty acids, and the newer estimates better reflect the variety of diets that may be fed. Based on the preponderance of available data, the average true digestibility of fatty acids (at approximately 3.5 times maintenance intakes) is likely closer to 75% than to 90%. In the original equation, the estimated energy from fecal endogenous fat was 0.06 Mcal/kg of dry matter intake, but with the new data, estimated

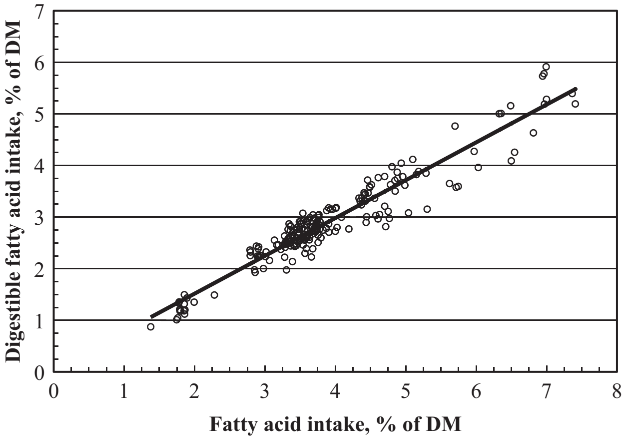

**Figure 3.** Lucas plot for fatty acids in diets fed to lactating dairy cows (data from 10 experiments conducted at The Ohio State University with 37 different diets and 206 total observations). The equation for the line was as follows: Digestible fatty acids, % = 0.0489 (± 0.0641) + 0.733 × Fatty acids, % ($R^2$ = 0.91; RMSE = 0.25). The intercept was not different from 0. The model with the intercept set at 0 was as follows: Digestible fatty acid intake, % = 0.745 × Fatty acids, % (RMSE = 0.259). The slopes (±SEM) are estimates of the true digestibility of fatty acids and the lack of a significant intercept (±SEM) indicates that there was no endogenous fecal fatty acids.

fecal fat is 0. This would mean that the DE concentrations of high-fat feeds were likely overestimated using the original summative equation because the overestimation of true digestibility was greater than the overestimation of metabolic fecal fat. For example, using average composition data for whole cottonseed (19.5% crude fat) and changing only fat digestibility and endogenous energy, its estimated DE concentration would be about 7% less with the new coefficients (3.66 vs. 3.40 Mcal/kg).

### *Starch and NFC Digestibility*

The original summative equation used NFC, which includes starch, soluble fiber, simple sugars, organic acids, and unknown compounds that are soluble in neutral detergent solution, and all the accumulated errors in measuring NDF, CP, ash, and fat. Starch has become a routine assay for commercial feed-testing labs, and we have extensive data on starch digestibility by cattle. Therefore, Tebbe et al. (2017) partitioned NFC into starch and residual organic matter (ROM; ROM = NFC − starch, where concentrations are as percentages of dry matter) so that additional sources of variation could be included in the equation. Based on the Lucas test (Tebbe et al., 2017), NFC, starch, and ROM behaved as nutritionally uniform fractions (Figure 4); however, the overall fits were better and standard errors of the intercept coefficients (i.e., estimated metabolic fecal content) were decreased for ROM and starch compared with NFC. Using average true digestibility coefficients for ROM and starch should result in greater accuracy in estimating DE than using the average true digestibility of NFC.

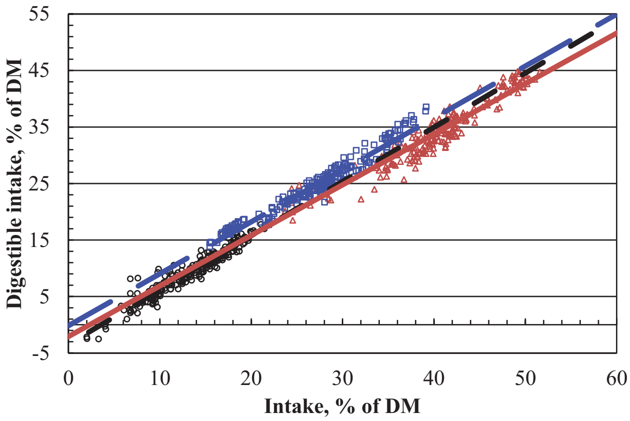

**Figure 4.** Lucas tests for NFC (solid line, red triangles), starch (long dashed line, blue squares), and residual organic matter [(ROM) short dashed line, black circles] in lactating cows (data from Tebbe et al. (2017)): digestible NFC = −2.08 (±0.800) + 0.903 (±0.020) × NFC intake [Bayesian information criterion (BIC) = 806]; digestible starch = −0.17 (±0.359) + 0.931 (±0.013) × starch intake (BIC = 578); digestible ROM = −3.43 (±0.295) + 0.961 (±0.295) × ROM intake (BIC = 688). The slopes (±SEM) are estimates of the true digestibility and intercepts (±SEM) are estimates of metabolic fecal content.

Additional accuracy could be garnered by replacing the average starch digestibility coefficient with feed or diet-specific digestion coefficients. Factors such as the type of grain (e.g., barley vs. corn) and grain processing affect starch digestibility independent of ROM digestibility. This is not true for the processing adjustment factors used by Dairy NRC System (2001), which adjust the entire NFC fraction. As a result, the processing adjustment factors will often under- or over-predict DE contents depending on the average adjustment and ROM concentration of the diet because of differences in enthalpies and digestibility. The enthalpy of ROM cannot be measured directly, but many of the known components in ROM (e.g., common silage fermentation acids and simple sugars) have enthalpies less than 3.8 Mcal/kg, whereas other components (soluble fiber and glycerol) have enthalpies of around 4.3 Mcal/kg. Therefore, a reasonable estimate of enthalpy for ROM is 4.0 Mcal/kg and is less than that of NFC, which was assumed to have the same enthalpy as starch (i.e., 4.2 Mcal/kg). The digestibility of ROM is constant at 96%, but digestibility of starch can range from about 89% to 99% in common diets (Owens, 2005). In addition to better accuracy, estimates of in vivo starch digestibility could be incorporated into the starch term if accurate lab assays are developed—this could account for variable starch digestibilities within a feedstuff.

The significance of adjusting for starch digestibility independent of ROM is simulated in Table 2. If all nutrients for DE calculations are similar, the NASEM (2016) will predict similar DE concentrations for finishing diets containing either corn silage or alfalfa silage, although the starch and ROM concentration differ by about 3% of DM. When dry-rolled corn is directly substituted for high-moisture corn in these diets, the estimated DE will increase but only by 0.07 Mcal/kg of DM. Average total tract starch digestibility is 10% lower in finishing diets with dry-rolled corn compared with high-moisture corn (89% vs. 99%; Owens, 2005), which suggests that DE concentrations should be about 4.5% less or 0.16 Mcal/kg of DM in these diets. The processing adjustment factors used by the Dairy System (NRC, 2001) adjust for differences in NFC digestibility caused by grain type and grain processing and predicts the diets with dry-rolled corn diets to have on average 0.15 Mcal/kg lower DE concentration than the high-moisture corn diets. However, the processing adjustment factors

**Table 2.** Example finishing diets for beef cattle weighing 475 kg (1.5 kg of ADG) and consuming 10 kg of DM/d (approximately two times maintenance)

| Ingredients, % (DM basis) | Low starch digest, Low ROM[*] | Low starch digest, high ROM | High starch digest, low ROM | High starch digest, high ROM |
|---|---|---|---|---|
| Corn silage | 37.0 | | 37.0 | |
| Alfalfa silage | | 40.0 | | 40.0 |
| Dry, rolled corn grain | 49.0 | 59.0 | | |
| High moisture corn grain | | | 49.0 | 59.0 |
| Soybean meal, 48% CP | 11.0 | | 11.0 | |
| Mineral | 3.0 | 1.0 | 3.0 | 1.0 |
| Nutrients | | | | |
| DM, % | 58.7 | 60.2 | 59.8 | 54.9 |
| Organic matter, % of DM | 93.9 | 93.3 | 93.9 | 93.3 |
| Crude protein, % of DM | 13.2 | 13.2 | 13.2 | 13.2 |
| Neutral detergent fiber, % of DM | 21.9 | 22.7 | 22.0 | 22.8 |
| Starch, % of DM | 47.6 | 43.3 | 47.2 | 42.8 |
| Fat, % of DM | 3.3 | 3.1 | 3.3 | 3.1 |
| ROM, % of DM | 7.9 | 11.0 | 8.1 | 11.4 |
| Beef DE[†], Mcal/kg | 3.38 | 3.39 | 3.44 | 3.46 |
| Dairy DE[‡], Mcal/kg | 3.37 | 3.30 | 3.50 | 3.46 |
| DE from adjusted NFC[‖], Mcal/kg of DM | 2.08 | 2.06 | 2.23 | 2.21 |
| DE from starch + ROM[§], Mcal/kg of DM | 2.12 | 2.07 | 2.30 | 2.23 |

[*] Residual OM (ROM) = % OM − % CP − % NDF − % starch − % fat.

[†] DE calculated according to NASEM (2016).

[‡] DE calculated according to NRC (2001).

[‖] DE from nonfibrous carbohydrate (NFC), Mcal/kg = 0.94 × 4.2 Mcal/kg of NFC × [(% NFC) × feed-specific processing adjustment factor from NRC (2001)]. NFC, % = % starch + % ROM and digestion adjusted for 2× maintenance.

[§] DE from starch and ROM, Mcal/d = 0.96 × % ROM × 4.0 Mcal/kg of ROM + 4.23 Mcal/kg of starch × starch digestibility × % starch. Average starch digestibility of dry, rolled corn (89.3%) and high-moisture corn (99.2%) from Owens (2005).

likely underpredict DE when ROM is lowered less and as starch digestibility increases. For the diets simulated, the worst-case scenario (i.e., high-starch digestibility and low-ROM diet) has a 0.07 Mcal/kg difference in DE, which is equivalent to the energy needed for about 0.2 kg of ADG. The extent of over- or under-predicting DE concentrations will differ across the vast number of diets and multiples of maintenance consumed by cattle.

### *Neutral Detergent Fiber*

NDF is a heterogeneous fraction both chemically and nutritionally making it difficult to estimate its digestibility accurately. Furthermore, NDF digestibility is sensitive to diet composition (e.g., inadequate CP or excess starch can decrease NDF digestibility) and feed intake (increasing intake usually decreases fiber digestibility). These effects are discussed in the next section. The original summative equation used lignin to estimate fiber digestibility. Several other lignin-based equations are available to estimate NDF digestibility (Harlan et al., 1991; Jung et al., 1997; Traxler et al., 1998; Palmonari et al., 2016) and in general they all work reasonably well for forages and forage-based diets. In vitro NDF digestibility has also been used to estimate in vivo digestibility (Lopes et al., 2015), and it works reasonably well when the total diet, rather than only the forage, is the substrate for the in vitro assay. However, in vitro NDF digestibility is not equal to in vivo digestibility; equations must be used to convert in vitro values to in vivo values (e.g., Lopes et al, 2015). Equations are likely diet-specific.

### *Endogenous Fecal Energy*

In the original summative equation, endogenous fecal TDN was estimated from a variety of papers and included endogenous CP, fat, and NFC. In the modified equation, endogenous fat was set at 0 as discussed above and endogenous fecal ROM energy was set at 0.137 Mcal/kg. This was calculated by multiplying endogenous ROM (Figure 4; Tebbe et al., 2017) by an assumed enthalpy of 4.0 Mcal/kg (i.e., 0.0343 kg/kg DM × 4.0 Mcal/kg = 0.137 Mcal/kg). Metabolic fecal CP remained the same as in Weiss et al. (1992) with an assumed enthalpy of 5.65, yielding an energy value of 0.166 Mcal/kg (i.e., 0.0294 kg metabolic fecal CP/kg DM × 5.65 Mcal/kg = 0.166 Mcal/kg). In total, endogenous fecal energy equaled 0.30 Mcal/kg of DM. In the original equation, metabolic fecal TDN was 70 g/kg of DM, assuming 4.4 Mcal of GE/kg of TDN, that is, equivalent to 0.31 Mcal/kg of DM.

### *Associative Effects*

A major problem with estimating digestibility of nutrients is that digestibility not only depends on inherent characteristics of feedstuffs (e.g., particle size or lignification), but it also depends on the composition of the total diet and feed intake by the animal. Hence, energy values given to individual feeds are not necessarily additive. After a diet is formulated using feed energy values, various adjustments based on total diet composition and feed intake may be needed to obtain a more accurate estimate of diet energy. Examples of associative effects include the effect of diet CP concentration on fiber and DM digestibility. Diets that are clearly deficient in protein show marked increases in digestibility when CP is added. For example, supplementing a diet based on prairie hay (approximately 2% CP) with about 3% casein increased digestibility of OM and NDF by approximately 10 and 8 percentage units (Köster et al., 1996). The marked improvement in digestibility in Köster et al. (1996) is not unexpected because CP supplementation is correcting a clear deficiency. Somewhat surprising is the positive response that increasing dietary CP has on digestibility even when diets have excess CP. In a review, Oldham (1984) summarized studies that evaluated the effect of changing dietary CP concentration on DM digestibility and reported that even when the control diet contained more than 20% CP, increasing CP often increased OM or DM digestibility. This may be an effect of increasing protein, but it could also be a response to the decreasing concentration of the nutrient that CP replaced. Broderick et al. (2008) increased dietary CP from about 15% to 18.6% (mostly by increasing the concentration of rumen degradable protein) and concurrently, starch decreased from about 28% to 23%. As CP (or rumen degradable protein) increased (or starch decreased), DM digestibility increased. It is impossible to determine whether the change in DM digestibility was caused by increased CP, increased rumen degradable protein, or decreased starch, or some combination of those changes. Nonetheless, data such as these suggest that equations or models designed to estimate DE concentrations should include a function that modifies digestibility based on dietary (not ingredient) CP or rumen degradable protein concentrations.

Conversely, increasing dietary starch often reduces fiber digestibility (Ferraretto et al., 2013); however, if starch is replacing NDF, DM digestibility of the diet often increases because starch is more digestible than fiber. Based on average NDF digestibility (48%) and average starch digestibility (91%) measured in dairy cattle in our laboratory over the past 25 yr ($N > 434$) and assuming dietary starch increased 5 percentage units and NDF decreased 5 percentage units, DE concentration would be expected to increase about 3.1% (assuming no other changes in nutrient composition or digestibility). If NDF digestibility decreased 0.5 percentage unit per 1 percentage unit increase in dietary starch (Ferraretto et al., 2013), then DE concentration would only increase 2.4% (i.e., 77% of expected). Associative effects can be substantial and future equations and models must include those effects.

### *DE to ME Conversions*

The Beef System uses a constant 0.82 X DE to estimate ME, but the text (NASEM, 2016) included substantial discussion on the limitations of that value. Galyean et al. (2016) reviewed the literature in which ME was measured and found a strong linear relationship between DE and ME but rather than a constant 0.82, the resulting equation was 0.96 X DE − 0.3 (units are Mcal/kg). At 3.0 Mcal/kg of DE (approximate mean of the dataset), ME was about 86% of DE, not 82%. As would be expected, efficiency of converting DE to ME decreased with increasing CP and increased with increasing ether extract. Feeding CP above requirement results in oxidation of amino acids for energy with the nitrogen excreted in urine, resulting in increased urinary energy and lower DE to ME efficiency. Increased dietary ether extract (i.e., fat) can decrease methane production, which increases the DE to ME efficiency. The Dairy System set ME as 1.01 × DE − 0.45 (units are Mcal/kg) plus an adjustment for dietary fat concentration. However, our ability to use dietary factors to estimate methane production (Ellis et al., 2007) and urinary N excretion (Spek et al., 2013), which is highly correlated with its energy content, has improved. Direct incorporation of dietary factors (e.g., CP, NDF, and fat) into equations used to convert DE to ME may improve the accuracy of estimating ME.

## CONCLUSIONS

The CNES has been widely and successfully used in the beef industry; however, improvements in the system can be made. Increasing the accuracy of the ME values used for feed and diets should improve the accuracy of estimated NEm and NEg values. This is possible by incorporating easily measured sources of variation into the equations used to estimate DE and ultimately ME. This will require decreased reliance on tabular values and increased use of feed analysis, elimination of the use of TDN by estimating DE using enthalpies of nutrients, and the use of equations rather than constants to convert DE to ME.

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