What's New in the NRC for How We Formulate for Energy in Diets for Dairy Cattle?

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The publication of the 2021 NASEM *Nutrient Requirements of Dairy Cattle* was a highly anticipated event by many in the dairy nutrition community, especially for those of us who were on the committee! Few of us imagined it could take that long or be so much work. So now that it is published, we can enjoy telling others about what we did. The energy supply and requirements were addressed in Chapter 3. We retained the net energy **(NE)** system that has been the core of the NRC for many versions but made some important changes to how energy supply and requirements are calculated.

Changes to Energy Supply

The method to estimate dietary NE content was modified (Table 1). Most importantly, changes were made to feed fractions and their digestibilities, largely due to improvements in standard laboratory analytical methods, most notably the measurement of starch. In addition, some corrections were made to improve how the energy value of protein was calculated. A diagrammatic version of the new system is shown in Figure 1. Major differences are described below. As in the 2001 NRC, the conventional energy scheme was used as the base for describing energy transactions. The total chemical energy of the diet is Gross Energy **(GE)**, of which only some is Digestible Energy **(DE)**. Most DE becomes Metabolizable Energy **(ME)** but some is lost as Gas Energy (mostly methane) and some as Urinary Energy (mostly urea). Some ME is lost as heat but most is converted to NE.

In the 2001 NRC, the base DE of a feed was calculated as the sum of digestible feed fractions containing energy; these fractions consisted of neutral-detergent fiber **(NDF),** fatty acid **(FA)**, crude protein **(CP)**, and non-fiber carbohydrate **(NFC)**. In the new version, we replaced NFC with starch and a new fraction called Residual Organic Matter **(ROM)**. ROM is everything that was not accounted for in the other fractions and includes sugars, soluble fiber, fermentation acids, and glycerol. The gross energy of a feed is now calculated as (4.2 x NDF) + (4.23 x starch) + (9.4 x FA) + (4.0 x ROM) + (5.65 x CP), unless the CP is from supplemental NPN, when it is multiplied by 0.89. These feed fractions are then multiplied by base digestibility coefficients to derive a DE value for a feed at base. Unlike NRC 2001, the digestibility of protein in the 2021 NASEM is determined by the protein model equations, so that digested protein is the sum of rumen-degraded protein and the portion of rumen-undegraded protein that is digested in the small intestine.

In the 2001 NRC, DE was calculated at a base level of 1X (maintenance intake) and then adjusted downward as intake increased with the adjustment influenced by the basal TDN content of the diet (TDN from high fat feeds

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was not included in basal TDN). Diets with the highest TDN content were discounted the most for higher intakes. In the 2021 NASEM, instead of using a cow at maintenance for the base, we now use a cow eating a 26% starch diet at 3.5% of BW for the base. In addition, in the new model, starch content of the total diet is used to adjust digestibility rather than basal TDN, and this effect of starch is specific to the digestibility of NDF rather than all feed fractions. The effect of intake on digestibility is specific to the starch and NDF fractions in the 2021 model. Thus, in the 2021 NASEM, each fraction for each individual feed has a base digestibility and only the digestibility of starch and NDF are altered from the base. Whether digestibility of other feed fractions is altered by intake is not clear, but data were inadequate to estimate a value. With the new model, predictions of the energy values of feeds are still less accurate than desired, but at the least, our database of feed digestibilities was based on cows eating 26% starch at 3.5% of BW, which is reasonable for the diet and intake of most cows on most commercial farms, instead of starting with maintenance intakes (Table 2). With the new model, the digestibility discount with increasing intake is less than in the 2001 NRC, and the effect of starch on NDF digestibility is greater than is the effect of intake. Because the energy scheme is based on apparent, not true, digestibilities, estimates for fecal energy from endogenous sources are subtracted; these calculations were updated. Similar to the 2001 system, DE, ME, and NEL values can only be estimated for complete diets, not individual feeds.

In the 2001 NRC model, the conversion of DE to ME was a constant with a slight adjustment for fat and base DE density but no adjustment for overfeeding protein. This resulted in protein being overvalued because the DE value of protein is greater than that of starch, but in reality, much of that extra DE is lost as urinary energy. In fact, about two-thirds of dietary N is usually excreted, and all of the N fed above requirements will be excreted. Replacing starch with protein in the 2001 model increased the predicted energy available for milk because the model assumed that urinary energy excretion was a constant fraction of DE intake.The 2021 model corrected this error. Now, urinary energy depends on expected protein excretion, which is predicted based on the amount of protein consumed and the amount required. In addition, methane is produced largely from fiber fermentation, but its emissions are decreased by dietary fat. In the 2021 model, gas energy is a function of the fat and digestible NDF contents of a diet.

In the 2001 NRC, the conversion of ME to NE was about 0.63 with this value slightly higher (by 0.007 units) for TMR of greater energy density and 0.003 units higher if the diet contained 2% added fat. In 2021, no distinction is made based on feed type, but the conversion of ME to NE is slightly higher (0.66) based on recent data explained in the text.

Changes to Energy Requirements

The major change for energy requirements is that maintenance requirements were increased by 25%; NE for maintenance is now 0.10 Mcal per unit of $BW^{0.75}$ (Table 3). This change was based on multiple publications, as cited in the text. In addition, refinements were made to NE requirements for pregnancy, lactation, and body gain. As in NRC 2001, body gain was portioned into frame growth (true structural growth) and body condition change, but this time the equations are functional in the model. The 2021 system assumes that gut fill is 18% of frame gain but that it does not change with body condition change. Thus, in the 2021 NASEM, frame gain is only 82% body tissue gain, but condition change is all body tissue change, which is essentially the opposite of the 2001 NRC assumptions. New equations were developed to quantify the energy content of both frame gain and condition change, but after considering the changes in gut fill, the impact of BW gain on energy requirements is not that different than in 2001. In addition, most requirements were based on Holstein cattle but size-scaled so that they will hopefully work well for smaller framed cattle as well.

Impact on Diet Energy Calculations

The most important changes for balancing diets are that increasing intake will cause a smaller drop in the NE value of a diet and that replacing fiber with starch may change the NE value of a diet differently than in the 2001 NRC, depending on the level of intake, the total NDF content of the diet, and the NDF digestibility of the fiber sources. Figure 2 shows how the DE value of a diet changes as starch is replaced by NDF from forage or nonforage sources with or without the adjustment to NDF digestibility **(NDFD)** for dietary starch content and level of intake. Especially of note is that diets high in digestible nonforage fiber sources, such as soyhulls, are estimated to contain nearly as much DE per kg as diets with an equivalent content of corn grain; this is because starch impairs fiber digestibility in the total diet, and this impairment counters the greater energy available from the corn grain itself. The effect on NEL, however, is greater because more fiber increases methane loss and thus decreases the conversion of DE to ME, and subsequently NEL.

How these changes can impact the expected milk production and energy balance of high-producing cows is shown in Table 4. For this example, I chose a base diet and made 5 test diets for comparison. In these diets, the fat supplement was half tallow and half calcium soaps, and the soybean meal was half solvent-extracted dehulled and half expeller soy. The test diets were designed to be reasonable diets; thus, the high soyhull diet has less forage NDF than the other diets. As diets contain more starch and less fiber, the NEL density of the diet is increased with either system, and the benefit is even greater with NASEM 2021 than NRC 2001. In either system, increasing the base energy density of the diet does depress overall digestibility compared to a system of fixed energy values for each feed, as in the 1989 version of NRC. However, in the 2021 NASEM, the depression in digestibility is specific to NDF and is caused by starch; whereas, in the 2001 NRC, the depression was for all DE and was caused by the base nonfat TDN. Thus, the high soyhull diet had a lower NEL value than the high forage with the 2001 system, but similar NEL with the 2021 system (note that soyhulls replaced both forage and grain in the high soyhull diet). The high fat diet increased energy similarly for the two systems. The high protein diet increased NEL in the 2001 NRC but not in the 2021 system. The effect of these diets at lower intake for a lower producing cow will be less pronounced in the 2001 system but similar in the 2021 system because no interaction of starch content and intake level was noted in the 2021 NASEM.

One important point is that Table 4 assumes that cows will eat the same amount of feed regardless of diet composition. This is almost certainly not likely to happen in real life. The NRC 2001 made no attempt to include ration effects on expected feed intake. The NASEM 2021 model does, but they were not included below. In addition, these diets would likely alter nutrient partitioning.

Conclusion

Compared to the 2001 NRC, both predicted NEL supply from a diet and NEL requirements for cows are higher for the 2021 NASEM. The new system does a better job of estimating the energy supply of diets as diet protein and nonforage NDF contents are altered. However, balancing diets for energy still requires more than the model. How diet composition affects intake and nutrient partitioning must be considered and monitored when feeding dairy cattle.

References

National Research Council. 2001. Nutrient requirements of dairy cattle: 2001. 7th rev ed. National Academies Press. Washington, DC.

National Academy of Science, Engineering, and Medicine. 2021. Nutrient requirements of dairy cattle. 8th rev ed. National Academies Press. Washington, DC.

Table 1. Energy supply in the 2021 NASEM and 2001 NRC.

	2001 Dairy NRC	2021 Dairy NASEM
NE_L supply	Calculated from ME and fat concentrations	0.66 x ME
ME supply	Calculated from DE and fat concentrations	DE − urinary energy − methane Methane from diet %fat and %digested NDF Urinary energy from predicted N excretion
DE supply	Calculated from DE1X supply and the digestion discount.	= 4.2 × digested NDF + 4.23 × digested starch + 9.40 × digested FA + 5.65 × (RDP− sNPNCPE + digested RUP) + 0.89 × sNPNCPE + 4.0 × digested ROM − 0.565 × Metabolic Fecal CP − 0.565 × fecal Microbial CP − 0.40 × endogenous fecal ROM
Digestion discount	Function of fat-free TDN1X content of diet and energy intake as multiple of maintenance.	See adjustments to NDF and starch below.
DE1X	= 4.2 x digestible carbohydrates + 5.6 x digestible CP x 5.6 + 9.4 x digestible fatty acids x − 0.3 x fat-free dry matter intake	Not calculated
TDN1X	= 1.0 x digestible carbohydrates + 1.0 x digestible CP x 5.6 + 2.25 x digestible fatty acids x − 7.0 x fat-free dry matter intake	Not calculated
NDF digestion	Function of lignin content.	A function of lignin or IVNDFD48, level of intake, and diet starch content.
Starch digestion	ROM and starch were combined as NFC. NFC digestibility was a fixed value dependent on feedstuff.	Fixed value for each feedstuff, modified by level of intake.
ROM digestion	Not used.	96%
CP digestion	Function of acid detergent insoluble CP for forages and concentrates and a fixed value for animal products	Function of protein model.
Fat digestion	Fixed value for each feedstuff.	Fixed value for each feedstuff.

Table 2. Examples of base true digestion coefficients of various feed fractions in selected feedstuffs.

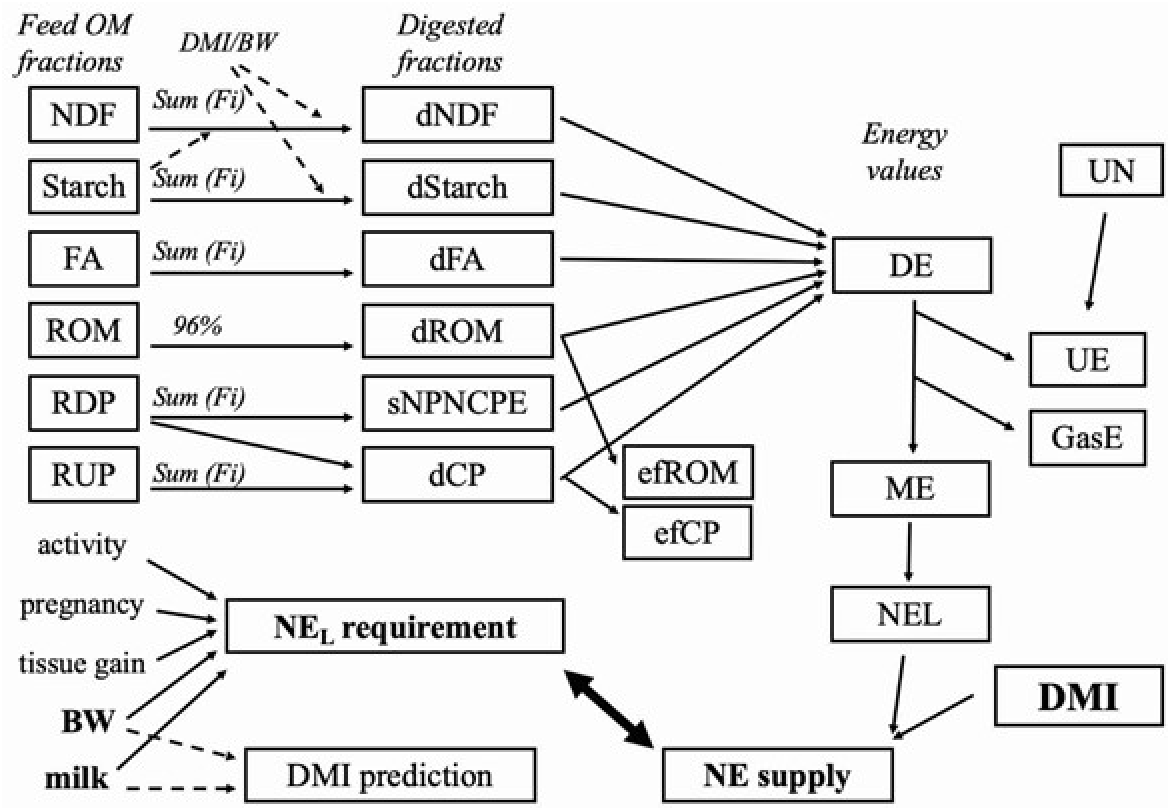
Feed Fraction	Source	Digestion Coefficient	
Starch	Default	0.91	
	Corn grain, coarsely ground dry	0.77	
	Corn grain, finely ground dry	0.92	
	Corn grain, finely ground high-moisture	0.96	
	Corn silage, normal	0.89	
	(coefficient decreases 0.01 for every percentage DMI/BW above 3.5%)		
Fatty acid	Default	0.73	
	Extensively saturated triglycerides	0.44	
	Calcium salts of palm fatty acid	0.76	
ROM	Fixed value	0.96	
Protein	*(based on RDP + digested RUP)*		
	Legume silage, early bloom	0.92	
	Solvent SBM	0.97	
	Finely ground corn grain	0.88	
		Using lignin	Using IVNDFD48
NDF	Corn silage, typical	0.57	0.44
	Legume silage, immature	0.43	0.45
	Legume silage, mid maturity	0.43	0.42
	Silage, mostly grass	0.53	0.46
	Wheat straw	0.52	0.37
	Soyhulls	0.64	0.66
	(coefficient decreases 0.0059 for every percentage starch >26% and 0.011 for every percentage DMI/BW above 3.5%)		

Table 3. NEL requirements in Mcal for the 2021 NASEM and 2001 NRC.

Item	2001 Dairy NRC	2021 Dairy NASEM
Maintenance	0.08 x kg $BW^{0.75}$	0.10 x kg $BW^{0.75}$
Milk	kg milk x (0.0929 x %fat + 0.0547 x %CP + 0.0395 x %lactose) (true protein = CP/0.93)	= 9.29 x kg fat + 5.85 x kg True P + 3.95 x kg lactose Or = 9.29 x kg fat + 5.5 x kg CP + 3.95 x kg lactose
Grazing Activity	= 0.00045 x kg BW x km walked + 0.0012 x kg BW + 0.006 x kg BW if pasture is "hilly"	= 0.00035 x kg BW x km horizontal + 0.0067 x kg BW x km vertical + 0.0075 x 0.88 x kg $BW^{0.75}$
Pregnancy	= 0.64 x (0.00318*DaysPregnant - 0.0352) x CalfBirthWt / 0.14	A curvilinear function that is considerably longer than the previous.
Body Reserves	Gain: 0.85 x (9.4 x kg change in body fat + 5.6 x kg change in body protein) Loss: use 0.82 instead of 0.85 (body fat and protein changes are a function of BW and condition change so NEL for BW change was ~3 + 3 x BCS)	= 5.6 Mcal NEL/kg BW change, whether loss or gain, regardless of BCS
Growth	retained energy (RE) for growth = 5.668 x kg BW $gain^{1.097}$ x (current $BW^{0.75}$ / mature $BW^{0.75}$) NEL = RE for growth / 0.7	For growing cows, 5.9 Mcal NEL/kg BW gain

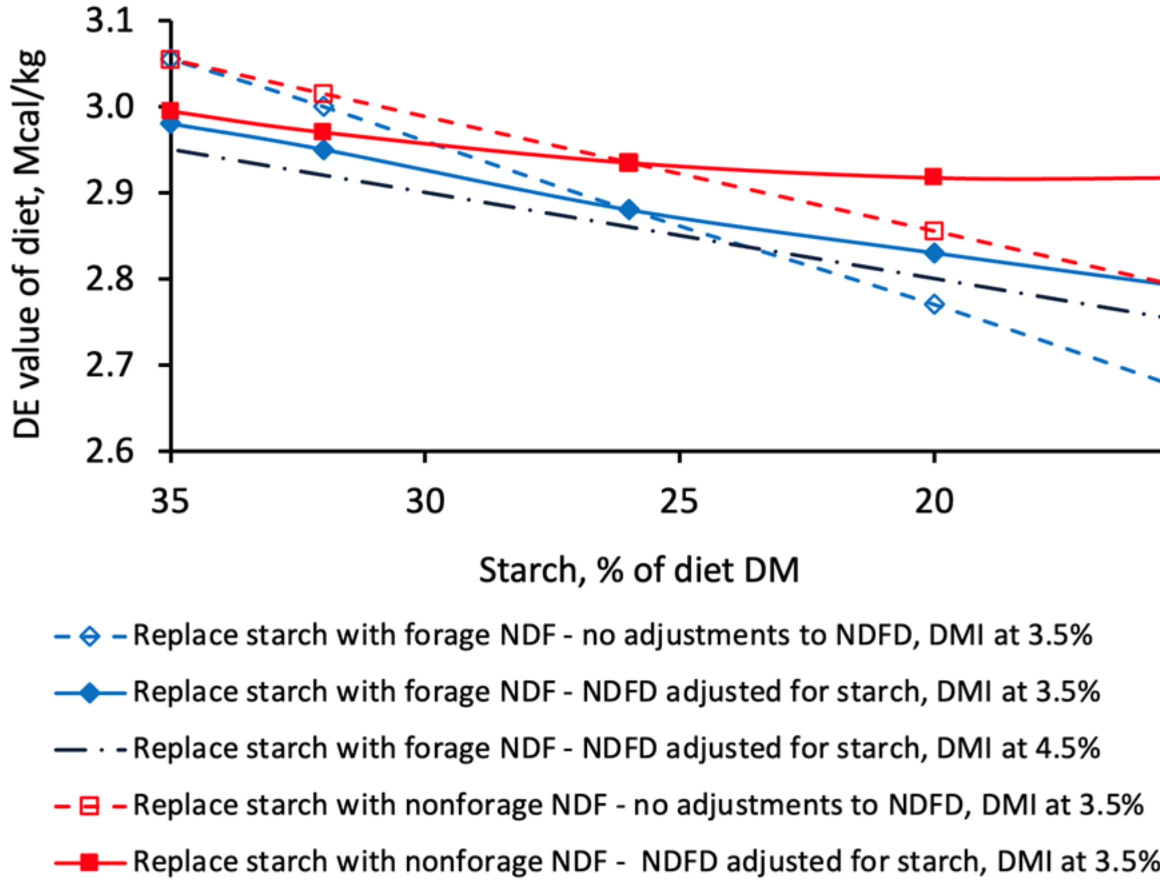
Table 4. Example of energy calculations from the NRC2001 and the NASEM 2021 for a high-producing cow. The target cow is a 700-kg Holstein cow eating 28 kg of feed DM at 100 days-in-milk producing 50 kg of milk with 3.8% fat and 3.1% true protein.

	Base	High Forage	High Soyhulls	High Starch	High Fat	High Protein
Corn silage, % of DM	33	40	28	33	33	33
Alfalfa silage, % of DM	17	20	14	17	17	17
Soyhulls, % of DM	11	9	32	0	11	11
Corn grain, % of DM	21	13	8	31	17	17
Fat supplements, % of DM	0	0	0	0	3	0
Soybean meal, % of DM	16	15	15	17	17	20
Minerals and vitamins, % of DM	3	3	3	3	3	3
NDF, % of DM	32	34	42	26	32	32
For NDF, % of DM	20	24	17	20	20	20
Starch, % of DM	26	23	16	33	23	23
CP, % of DM	17	17	17	17	17	19
Fatty acid, % of DM	2.7	2.5	2.3	2.9	5.2	2.6
Values from NASEM 2021						
NDFD (base) % of NDF	54.9	54.4	58.3	52.0	54.9	54.9
NDFD (adjusted) % of NDF	54.2	55.5	63.8	47.3	56.0	55.9
DE, Mcal/kg	3.07	3.03	3.05	3.13	3.17	3.11
ME / DE	85.3%	85.0%	84.7%	85.8%	86.7%	84.3%
NEL, Mcal/kg	1.73	1.70	1.70	1.77	1.81	1.73
Energy-allowable milk, kg/day	48.1	47.1	47.2	49.7	51.2	48.1
NEL supply, Mcal/day	48.5	47.8	47.8	49.7	50.8	48.5
NEL requirement (50 kg milk)	49.9	49.9	49.9	49.9	49.9	49.9
NEL balance (if 50 kg milk)	-1.4	-2.1	-2.1	-0.2	0.9	-1.4
Difference from base diet		-0.8	-0.7	1.1	2.3	0.0
Values from NRC2001						
NEL, Mcal/kg	1.55	1.53	1.52	1.57	1.64	1.56
NEL supply, Mcal/day	43.5	43.0	42.5	44.1	46.0	43.9
NEL requirement (50 kg milk)	47.2	47.2	47.2	47.2	47.2	47.2
NEL balance (if 50 kg milk)	-3.7	-4.2	-4.7	-3.1	-1.3	-3.4
Difference from base diet		-0.5	-1.0	0.6	2.4	0.3



[1]Abbreviations are as follows. OM = Organic Matter, DMI = Dry Matter Intake, BW = Body Weight, Sum (F_i) = the sum of all feeds for a given feed fraction, NDF = Neutral Detergent Fiber, dNDF = digested NDF, dStarch = digested starch, FA = fatty acid, dFA= digested FA, ROM = Residual Organic Matter, dROM = digested ROM, RDP = Rumen Degraded Protein, RUP = Rumen Undegraded Protein, sNPNCPE = supplemental Non-Protein Nitrogen on a Crude Protein Equivalent basis, dCP = digested Crude Protein, efROM = endogenous fecal ROM, efCP = endogenous fecal CP, which includes fecal Microbial CP in this diagram, DE = Digestible Energy, UN = Urinary Nitrogen, UE = Urinary Energy, GasE = Gas Energy, ME = Metabolizable Energy, NEL = Net Energy for Lactation.

Figure 1. The energy system of the 2021 NASEM model.[1]



DE = Digestible Energy, DM = Dry Matter, DMI = DM Intake, and NDF = Neutral Detergent Fiber.

Figure 2. Effect of replacing dietary starch with fiber on the DE value of diets