3-2008

Steady Supplies or Stockpiles? Demand for Corn-Based Distillers Grains by the U.S. Beef Industry

Roxanne L. B. Clemens
Iowa State University, rclemens@iastate.edu

Bruce A. Babcock
Iowa State University, babcock@iastate.edu

Steady Supplies or Stockpiles? Demand for Corn-Based Distillers Grains by the U.S. Beef Industry

Abstract
The projected expansion in U.S. corn-based ethanol production over the next several years has created concern that large surpluses of distillers grains may result. Most of the distillers grains currently being produced are consumed by the domestic livestock and poultry industries, especially the beef industry. A recent study by the Center for Agricultural and Rural Development projects that the U.S. ethanol industry could produce between 40 million and 88 million metric tons of distillers grains (dry matter basis) per year by 2011. The proportion of these distillers grains that would need to be consumed by the beef industry to prevent surpluses poses questions about how much distillers grains can be included in beef rations, the effects of feeding distillers grains on beef quality, and how current consumption patterns are likely to change as production of distillers grains increases. As more data from feeding trials have become available, a better understanding of the benefits and effects of feeding distillers grains is emerging. In this paper, we use results from a recent USDA producer survey about co-product use in beef production to project how current patterns of use are likely to change as the volume and availability of distillers dried grains increases. We then review recent results from feeding trials using distillers grains in beef rations, including nutritional value and effects on live animal performance and beef quality. Finally, we discuss some of the new technologies being used to improve distillers grains as a ration ingredient and present some general conclusions.

Keywords
beef feeding trials, beef quality, distillers dried grains, ethanol co-products

Disciplines
Agribusiness | Agricultural and Resource Economics | Agricultural Economics | Animal Sciences | Economics

Steady Supplies or Stockpiles? Demand for Corn-Based Distillers Grains by the U.S. Beef Industry

Roxanne Clemens and Bruce A. Babcock

MATRIC Briefing Paper 08-MBP 14
March 2008

Midwest Agribusiness Trade Research and Information Center
Iowa State University
Ames, Iowa 50011-1070
www.matric.iastate.edu

Roxanne Clemens is the managing director of the Midwest Agribusiness Trade Research and Information Center (MATRIC). Bruce A. Babcock is the director of MATRIC and of the Center for Agricultural and Rural Development, and a professor of economics at Iowa State University.

The authors would like to acknowledge the contributions of Chad E. Hart for providing valuable information and insights during the preparation of this paper.

Questions or comments about the contents of this paper should be directed to Roxanne Clemens, 568F Heady Hall, Iowa State University, Ames, IA 50011-1070; Ph: (515) 294-8842; Fax: (515) 294-6336; E-mail: rclemens@iastate.edu.

MATRIC is supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, under Agreement No. 92-34285-7175. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture.

Executive Summary

The projected expansion in U.S. corn-based ethanol production over the next several years has created concern that large surpluses of distillers grains may result. Most of the distillers grains currently being produced are consumed by the domestic livestock and poultry industries, especially the beef industry. A recent study by the Center for Agricultural and Rural Development projects that the U.S. ethanol industry could produce between 40 million and 88 million metric tons of distillers grains (dry matter basis) per year by 2011. The proportion of these distillers grains that would need to be consumed by the beef industry to prevent surpluses poses questions about how much distillers grains can be included in beef rations, the effects of feeding distillers grains on beef quality, and how current consumption patterns are likely to change as production of distillers grains increases. As more data from feeding trials have become available, a better understanding of the benefits and effects of feeding distillers grains is emerging. In this paper, we use results from a recent USDA producer survey about co-product use in beef production to project how current patterns of use are likely to change as the volume and availability of distillers dried grains increases. We then review recent results from feeding trials using distillers grains in beef rations, including nutritional value and effects on live animal performance and beef quality. Finally, we discuss some of the new technologies being used to improve distillers grains as a ration ingredient and present some general conclusions.

Keywords: beef feeding trials, beef quality, distillers dried grains, ethanol co-products.

STEADY SUPPLIES OR STOCKPILES? DEMAND FOR CORN-BASED DISTILLERS GRAINS BY THE U.S. BEEF INDUSTRY

Introduction

The ongoing expansion in U.S. corn-based ethanol production has generated concern that the ethanol industry will create large surpluses of co-products. Expected production levels are, indeed, high. Using a relatively conservative set of assumptions, a recent study by the Center for Agricultural and Rural Development (CARD) projects that the U.S. ethanol industry will produce nearly 15 billion gallons of ethanol and 40 million metric tons of distillers grains (dry matter basis) per year by 2011.[1] Under a much more aggressive set of assumptions, the CARD study projects that ethanol production could reach nearly 30 billion gallons annually by 2016, generating more than 88 million metric tons of distillers grains per year (Tokgoz et al. 2007).

Some U.S. distillers grains are exported, but the primary users are the domestic livestock and poultry industries, especially beef and dairy cattle because ruminants are best suited to the low starch and high fiber levels in conventional distillers grains. As will be discussed in this paper, estimates vary on how much distillers grains can and should be used in rations. A recent USDA report states that optimal inclusion levels are 30% to 40% in beef rations, although higher rates can be used (Westcott 2007).[2] Beef feeding trials have shown that excellent performance has been achieved at inclusion levels of 40% to 50% (Loy 2007). By comparison, "recommended maximum inclusion levels are 20 to 25 percent for dairy, 20 percent for growing and finishing hogs, and 15 percent for the grower and finisher stages of poultry feeding" (Westcott 2007, p. 12). USDA (2007a) estimates that beef cattle consume about 80% of the distillers grains being fed to domestic livestock and poultry.

---

[1] Volumes of distillers grains and other co-products are expressed on a dry matter basis.
[2] Inclusion level is the percentage of the ration comprised of the specified ingredient, on a dry matter basis.

The projected volume of distillers grains that will need to be consumed to prevent surpluses as production increases has raised questions about the amount of distillers grains that can reasonably be included in beef rations and whether high inclusion levels affect beef quality. As more data from feedings trials have become available, a better understanding of the benefits and effects of feeding distillers grains is emerging to help answer these questions. In this paper, we review several of the studies from the growing body of research examining the use of distillers grains in beef production. Following a brief overview of distillers grains for beef rations, we use data from a recent USDA producer survey to evaluate the potential for increased co-product use and how patterns of use in beef production may change as the volume and availability of distillers grains increase. Then, we summarize recent research regarding nutritional and environmental factors that affect optimal, practical, and maximum inclusion levels of distillers grains in beef rations and the effects of inclusion on animal performance and beef quality. Finally, we discuss new technologies the ethanol industry is already using or may adopt to improve distillers grains as an ingredient for livestock and poultry rations and present some general conclusions.

Distillers Grains for Beef Rations

The two basic systems for corn-based ethanol production are the wet milling process and the dry grind process. The main co-products of the wet milling process used in livestock feeds are corn gluten feed, corn gluten meal, and condensed steep water solubles. The main co-products from the dry grind process used in livestock feeds are distillers grains and condensed distillers solubles. In 2006, more than 70% of corn-based ethanol was produced at dry grind plants. This percentage is expected to increase because "all newly constructed ethanol plants employ some variation on the basic dry grind process because such plants can be built at a smaller scale for a smaller investment" (Mosier and Ileleji 2006). Given the increasing dominance of the dry grind process, this paper focuses on distillers grains as the primary co-product that will be available for use in beef cattle rations as ethanol production increases.

Adding distillers grains to feedlot rations can improve average daily gain and feed conversion, making this co-product a viable source of supplemental protein and a replacement for some corn as a source of energy. According to Klopfenstein (2001, p. 2), "Distillers byproducts have essentially all of the starch removed, leaving protein, highly digestible fiber, and fat. The feeding of the byproducts appears to reduce acidosis and enhances feed efficiency." Depending on the feeding situation, stocker calves, developing heifers, and beef cows may also benefit from the inclusion of distillers grains in their diets.

Distillers grains are sold in wet, modified wet (partially dried), or dry form, with or without solubles. Wet distillers grains with solubles (WDGS) are about 30% dry matter (70% moisture), modified wet distillers grains with solubles (MDGS) are about 50% dry matter, and distillers dried grains with solubles (DDGS) are about 90% dry matter (Lardy 2007). Many experts agree that transportation costs generally limit the distance wet distillers grains can profitably be hauled to within about 100 miles of the ethanol plant, and the distance for modified wet distillers grains to within about 300 miles of a plant (Amaral-Phillips 2004, Weiss et al. 2007). Recent models developed by Jones et al. (2007, p. 14) estimate that, "even at a transport cost of $3.50/loaded mile, WDGS is still more profitable than DDGS up to 150 miles from the plant." In some cases, large beef feedlots and dairies are co-locating with ethanol plants to reduce the costs of drying and transporting distillers grains. However, given the large volumes of distillers grains that are expected to be produced, the relatively short shelf life of wet distillers grains, and the distance between many existing feedlots and ethanol plants, much of the expanded production is expected to be dried. Thus, although other forms of co-products will continue to be produced, the challenge for the ethanol industry will be to market very large volumes of corn-based distillers dried grains.

Increasing the use of distillers dried grains in the beef industry can be accomplished in two ways: increasing the percentage of U.S. producers who use distillers grains in rations (adoption rate) and increasing the amount used in rations (inclusion level). As noted by Jones et al. (2007), nutritionally optimal inclusion levels may be different from economically optimal inclusion levels. As used in this paper, optimal inclusion levels are the percentages of distillers grains that result in maximum animal health, performance, and/or beef quality. Economic incentives may encourage many producers to feed above optimal levels. According to Rincker and Berger (2003, p. 7), “Feeding up to 50% distillers grains can decrease performance but may be profitable if distillers grains is purchased at a low enough price.” Thus, practical inclusion levels are defined here as inclusion levels that may not fully optimize performance and carcass quality but that do not exceed recommended feeding levels. Finally, maximum inclusion levels are defined as the highest nutritionally feasible percentage of distillers grains that can be included in rations in most feeding situations without adversely affecting live animal growth performance and/or carcass and meat quality beyond acceptable limits.

Cost will be the primary factor in producer decisions about inclusion levels and adoption rates. According to the Iowa Beef Center (2007), “As a rule, adding [distillers grains at] 15% to 20% of the ration dry matter will often meet the protein requirements and contribute to the energy needs of the cattle. Higher levels can be fed when co-products are competitive with corn as an energy source.” And, according to Loy (2007), “Any time the net cost of distillers grains in the feed bunk, adjusted for moisture, is less than the cost of corn, then the incentive is to feed levels beyond meeting the protein requirement.”

However, product availability, nutritional considerations, and carcass and meat quality issues also guide decisions about use of distillers grains. The USDA producer survey, discussed next, indicates that the number one reason beef producers give for not feeding distillers grains is availability. According to most expectations, future availability of distillers grains will not be a problem in terms of volume. Although issues of transporting, handling, and storing co-products are important factors affecting availability, these topics are beyond the scope of this paper, but we assume that a continuous supply of distillers grains will gradually become available to all cattle producers as production increases.

Co-product Use Patterns

A recent USDA survey reported co-product use in Midwest livestock operations for calendar year 2006. The survey was sent to 9,400 Midwest livestock producers of dairy, cattle-on-feed, beef cattle, and hog operations (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin). This section discusses the survey results for the cattle-on-feed and beef cattle operations and the potential for increased use (USDA 2007b).

On average, the producers who used co-products in beef feedlots and beef cattle operations had done so for about five years. Among the survey results that indicate excellent potential for increased use of distillers grains is the reported adoption rate for all co-products. In 2006, only 36% of the feedlots and 13% of the beef cattle operations surveyed fed any type of co-product (see Table 1). Of the operations that did not use co-products, 34% of the feedlot operations and 30% of beef cattle operations were considering doing so.

A second result that signals the potential to increase use is the average inclusion levels of co-products reported by users. As shown in Table 2, average inclusion levels for distillers grains in feedlot rations ranged from 11% (distillers dried grains) to 26% (wet distillers grains with greater than 40% solids). Average inclusion levels in beef cattle rations were higher, ranging from 22% each for DDGS and wet distillers grains with 25% to 40% solids, to 31% for wet distillers grains with greater than 40% solids. These reported inclusion levels and the research discussed in the following sections indicate that average inclusion levels for distillers grains could increase, depending on cost and feeding situation.

A third result regarding potential use is the reason given for not feeding co-products. Among the respondents who do not feed co-products, the number one reason given for not doing so was lack of availability (35% of feedlot operations and 38% of beef cattle operations), followed by infrastructure and handling (22% and 12%, respectively), and cost issues (11% and 10%, respectively). These responses indicate strong potential for increased use as availability, infrastructure, and handling problems are resolved.

Based on the responses to the survey, patterns of co-product use would be expected to change if the projected production and consumption of distillers dried grains are to be realized. As shown in Table 2, corn gluten feed was the most commonly used co-product at both feedlots and beef cattle operations in 2006, followed by wet distillers grains and

TABLE 1. Selected results from the USDA survey for ethanol co-product use by feedlot and beef cattle operations

	Cattle on Feed	Beef Cattle
	(percent)	
Operations feeding co-products	36	13
Not feeding co-products but considering doing so	34	30
Not feeding co-products and not considering doing so	30	57
Reason not feeding co-products(percent of respondents who do not feed co-products)		
Availability	35	38
Infrastructure and handling	22	12
Cost issues	11	10
Raises own feed	5	9
Rating of co-product characteristics	(1 [no importance] – 4 [high importance])	
Price	3.9	3.8
Quality	3.8	3.8
Consistent protein	3.6	3.8
Source of co-products	(percent)	
Ethanol or other processing plant	52	20
Feed company/coop	33	66
Brokers and other	15	14
Form of co-products being fed		
Wet	64	21
Dry coarse meal	13	22
Dry fine meal	20	26
Pellets and cubes	15	43
Preferred co-product form		
Wet	65	20
Dry coarse meal	15	30
Dry fine meal	19	19
Pellets and cubes	17	48

Source: USDA 2007b.

TABLE 2. Selected results from the USDA survey on ethanol co-product use by feedlot and beef cattle operations, by type of co-product, inclusion level, and average amount fed per animal

	Cattle on Feed			Beef Cattle		
	Operations Using (percent)	Inclusion Level (percent)	Pounds Fed per Animal per Year	Operations Using (percent)	Inclusion Level (percent)	Pounds Fed per Animal per Year
Condensed distillers solubles	3	24	1,080	3	15	618
Distillers dried grains	19	11	390	25	28	710
Distillers dried grains with solubles	14	23	916	13	22	396
Corn gluten feed	38	26	1,330	46	28	3,576
Brewers grains	(included in Other Co-products)			3	31	398
Wet distillers grains (25-40% solids)	19	23	3,306	6	22	1,542
Wet distillers grains (> 40% solids)	17	26	1,380	5	31	1,778
Complete commercial feed	3	NER	176	9	36	322
Co-products from new processes	(included in Other Co-products)			1	NER	286
Combination of co-products	(included in Other Co-products)			3	37	748
Other co-products	6	NP	1,568	7	NP	676

Source: USDA 2007b.

Notes: NER = Not enough reports for statistically defensible estimate.
NP = Not published because of reporting of multiple co-products.

distillers dried grains. Given that most of the ethanol expansion will occur in dry grind plants, distillers grains will be in much higher supply than will corn gluten feed, and the proportion of producers using distillers grains will be much higher. Further, 64% of feedlot producers use wet distillers grains and 65% prefer the wet form to other forms such as dry or pelleted. The dominance of wet co-product use would also be expected to change as supplies of distillers dried grains increase.

As expected, producers cite price as the most important characteristic of co-products, followed closely by quality and consistent protein content. Overall, the survey results indicate that, if producers have the economic incentive to feed distillers grains and if product availability, quality, and consistency improve, there is excellent potential for increased use in the U.S. beef industry. As discussed next, nutritional issues will affect how much distillers grains can be fed in many feeding situations, at least over the short term.

Nutritional Issues in Feeding Distillers Grains

In dry grind plants, the entire corn kernel is ground and fermented, converting most of the starch to ethanol. Aside from the removal of starch, most of the nutrients from corn are concentrated threefold in the distillers grains and condensed steep water solubles, and the high concentration of some nutrients requires special attention in ration formulation. Further, significant variation in the overall nutrient content of co-products, even in those produced by the same plant, has been well-documented (see Table 3).

Rausch and Belyea (2005) note that plant managers often do not have the time and resources to address co-product quality and compositional variation, and the lack of documentation on the causes of variation makes it difficult to develop strategies to alleviate these problems. In addition, drying distillers grains can introduce further variability and quality problems. “Any time you dry a feed there is potential for altering nutritional availability. The sugars can undergo a chemical ‘browning reaction’ that renders part of the carbohydrate and protein unavailable to the animal” (Boyles 2007). As discussed in the following sections, concentrations and variability of specific nutrients have the potential to limit the use of distillers grains in some feeding situations.

TABLE 3. Value of selected nutrients in co-products and feedstuffs

(percent, dry matter basis)

Traditional Feedstuffs	Ground Corn	Corn Silage	Alfalfa Silage	Soybean Meal	
Crude Protein	9.0	8.0	21.0	50.0	
Fat	4.0	3.0	4.0	4.0	
Calcium	0.04	0.27	1.40	0.43	
Phosphorus	0.30	0.24	0.33	0.74	
Sulfur	0.10	0.10	0.25	0.39	
Wet Milling	Dry Corn Gluten Feed	Corn Gluten Meal	Wet Corn Gluten Feed	Condensed Steep Water Solubles	
Crude Protein	20.0 - 25.0	66.0	14.0 - 22.0	35.0	
Fat	2.0 - 3.3	2.2	3.0 - 5.0	3.0	
Calcium	0.06 - 0.20	0.08	0.03 - 0.10	0.07	
Phosphorus	0.8 - 1.1	0.53	0.45 - 1.0	2.0	
Sulfur	0.16 - 0.50	0.72	0.35 - 0.5	1.8 - 2.0	
Dry Milling	DDGS	DDG	WDG	MDG	Condensed Distillers Solubles
Crude Protein	25.0 – 32.0	25.0 - 35.0	30.0 - 35.0	30.0 - 35.0	20.0 - 30.0
Fat	8.0 - 10.7	8.0 - 13.0	8.0 - 12.5	8.0 - 12.0	9.0 - 15.0
Calcium	0.10 - 0.26	0.11 – 0.30	0.02 - 0.03	0.02 - 0.03	0.03-0.17
Phosphorus	0.40 – 1.08	0.40 – 0.80	0.03 - 0.17	0.50 - 0.80	1.30 - 1.45
Sulfur	0.37 - 0.44	0.46 - 0.63	0.46 - 0.70	0.38 - 0.70	0.37 - 0.95

Sources: Blasi et al. 2001, Kononoff and Janicek 2005, Lardy 2007, Loy and Miller 2002, Tjardes and Wright 2002.

Sulfur

According to Loy (2007), "Sulfur is likely the first factor to limit the amount of corn co-products that can be fed in many situations." The sulfur composition of unprocessed corn is approximately 0.1% (dry matter basis). As shown in Table 3, the sulfur content of co-products from both wet milling and dry grind facilities is highly variable and several times greater than the sulfur level of corn because both processes concentrate the sulfur in corn and some add even more sulfur. In a conventional wet milling facility, grain is steeped in water and dilute sulfurous acid/sulfur dioxide. In a conventional dry grind facility, sulfuric acid is often used to maintain the desired pH during the saccharification phase (Kwiatkowski et al. 2006). Hydrochloric or citric acids may be used in the dry grind process, but sulfuric acid is more economical. In addition, sulfur is present in yeast, and "yeast naturally creates some sulfites during fermentation" (Snider 2004, p. 1).

Sulfur is a required macromineral for cattle that is ingested through food and/or water and that must be managed to meet nutritional requirements and maintain health. However, consumption of high levels of sulfur by cattle can reduce feed and water intake and cause sulfur toxicity, which can result in polioencephalomalacia (PEM), a potentially fatal, noninfectious neurologic disease in ruminants. The recommended level for growing and finishing, gestating, and early lactation cattle is 0.15% (1,500 ppm) intake, and the maximum tolerable concentration is generally accepted as 0.40% (4,000 ppm) intake (National Research Council 2000). Some studies recommend 0.30% as the maximum tolerable concentration for feedlot cattle, and live animal performance has been shown to decline at even lower levels (Crawford 2007a, Pritchard 2007).

Using the National Research Council's recommendation of 0.40% as the maximum tolerable sulfur concentration and based strictly on sulfur content, the maximum inclusion level for distillers grains would range from 30% at high sulfur levels (0.90%) to more than 70% at low levels (Loy 2007). As shown in Table 3, other feedstuffs may contribute significant amounts of sulfur to the diet and must be included in calculating total sulfur intake.

The sulfate concentration in water must also be considered in some regions of the United States. A 1999 USDA study of water from U.S. feedlots found that 77.4% of the samples had safe water sulfate concentrations (less than 300 mg/L, or ppm), including feedlots in the largest beef-feeding states (Texas, Kansas, Nebraska, Colorado). About 8% of samples had concentrations of 1,000 mg/L or greater—more than three times the USDA accepted safe concentration. The mean sulfate concentration in South Dakota feedlots was 1,007.1 ppm (USDA 2002, p. 3). The conversion from water sulfate concentration to sulfur is 3:1, so ingesting 30 g of sulfate through drinking water is equivalent to ingesting 10 g of sulfur.

Two additional factors must be considered regarding water sulfate levels. First, higher water intake by cattle during warmer weather can increase ingestion of sulfates. According to Crawford (2007b), a 1,000-lb steer will drink more than twice as much water (more than 20 gallons per day total) when the outdoor temperature exceeds 80°F compared to when the temperature is 40°F (9.5 gallons). Second, extreme variation has been shown between different water sources in the same area (e.g., the Cedar River Basin and the Des Moines River Basin in southern Minnesota), and between types of water source (e.g., run-off fed dugouts, spring-fed dugouts, and wells in South Dakota) (Crawford 2007b).

In terms of animal health and nutrition, sulfur is one of two components in distillers grains most likely to limit distillers grains inclusion levels; the other is fat. "Changes in milling technology that reduce oil and/or sulfur content could dramatically increase" practical limits on the levels of distillers grains that can be fed to beef cattle (Loy 2007, p. 1). Fat content is discussed next.

Fat

Distillers grains are an excellent source of energy for cattle, but high fat content can create a hurdle to high inclusion levels. Feedlot rations usually contain 3% to 5% fat, and the maximum recommended level is 6% (Gould and Rust 2007). According to Loy (2007, p. 2), "previous research with high-oil feeds … suggest[s] that feed intake in feedlot cattle starts to back off when greater than 5% of the ration dry matter in the form of fat is added." Higher fat levels can depress fiber intake and digestion (Tjardes and

Wright 2002). And, as will be discussed, carcass and meat quality issues appear to be related to fat content in rations that include high levels of distillers grains.

As with other nutrients, fat content can be highly variable in ethanol co-products (see Table 3). Fat content is lower in corn gluten feed and corn gluten meal from wet milling plants than in the co-products from dry grind mills because of major differences in the processes. During wet milling, the corn kernel is fractionated prior to fermentation to separate the germ and fiber. Fractionation allows for separate processing of the kernel components, and corn oil can be extracted as a separate co-product. In the conventional dry grind process, the entire corn kernel is ground and fermented, so all the oil remains in the co-products. Distillers dried grains and condensed distillers solubles can contain up to 13% and 15% fat, respectively. "Since distillers grains are 9% to 12% oil, fat would restrict their use to around 50% of the ration. This would give a total fat content of the ration of around 8%" (Loy 2007, p. 2).

Table 4 shows predicted fat levels in rations that use distillers grains with solubles at varying fat contents and inclusion levels. As shown, a 50% inclusion level of distillers grains with solubles with 10% fat content exceeds the level at which feed intake can begin to decline. Based strictly on the total fat content in the ration, reducing the fat content in distillers grains could contribute toward increasing inclusion levels.

TABLE 4. Predicted total fat level in rations using distillers grains with solubles at different inclusion levels and fat contents

Percent Dietary Inclusion Level	**Fat Content of Distillers Grains with Solubles**		
	10%	**14%**	**18%**
	Total ration fat content (percent)		
20	4.4	5.2	6.0
30	5.1	6.3	7.5
40	5.8	7.4	9.0
50	6.5	8.5	10.5
60	7.2	9.6	12.0

Source: Gould and Rust 2007, p. 4.

Phosphorus

Most distillers grains contain higher levels of phosphorus than does corn, which has raised nutritional and environmental concerns about inclusion levels (see Table 3). The nutritional concern is ensuring that rations contain an appropriate ratio of calcium and phosphorus. “It is recommended that the calcium to phosphorus ratio be at least 1:1 to 1.5:1” because urinary calculi (water belly) can result from an unfavorable ratio (Iowa Beef Center 2007). Because this ratio can be achieved by supplementing calcium, phosphorus is generally considered a management issue and is not a nutritionally limiting factor for including distillers grains in beef rations.

The environmental concern is that increasing phosphorus intake by cattle will increase phosphorus excretion, potentially increasing phosphorus levels in feedlot run-off that could harm streams and rivers. Several studies confirm increased phosphorus excretion. Benson et al. (2006), for example, found that phosphorus intake in feedlot steers increased from 18.6 to 27.8 g/day as the DDGS inclusion level increased from 0% to 36% in a rolled-corn ration. “Urinary P, total P excretion, and P retention increased as the level of DDGS in the diets increased. … Results of the experiment clearly demonstrate that as the levels of DDGS in the diets of finishing steers increases P excretion increases” (Benson et al. 2006, p. 1). Trenkle (2007, p. 1) found that “feeding 20% or 40% distillers grains with solubles increased phosphorus in the manure from the feedlot by 60% and 120%, respectively.” And, Rincker and Berger (2003) found that significantly higher manure phosphorus levels resulted from dairy steers fed distillers dried grains than from steers fed wet distillers grains. In this trial, the highest manure phosphorus level (0.1973 lb/head/day) occurred with the highest (50%) distillers dried grains inclusion level. The lowest manure phosphorus levels resulted for steers fed 20% wet distillers grains to 750 pounds body weight and then 37.5% to harvest (0.1087 lb/head/day, respectively).

However, in much of Iowa and other Corn Belt states where both corn and cattle are produced, the acres needed to provide corn and DDGS up to a 40% inclusion level in feedlot rations exceed the acres needed for manure application. In these areas, nutrient distribution during manure application, rather than higher phosphorus excretion, is the issue when feeding DDGS (Powers et al. 2006). "Use of phosphorus balance for a farm and feedlot should allow feeding DGS to finishing cattle without causing an environmental problem" (Trenkle 2007, p. 3).

However, "there are huge regional differences in crop and manure production, and problems with excess manure nutrients generally arise where crop production is low and manure production is high" (Maguire, Crouse, and Hodges 2007, p. 1240). High phosphorus content in distillers grains may limit inclusion and adoption rates for beef producers in regions such as the Southern Plains, a corn-importing region with larger feedlots, different soils types, and different environmental issues compared with much of the Corn Belt. Rausch and Belyea (2005) contend that, under increasingly stringent regulations for disposal of animal wastes based at least in part on phosphorus content, "it is possible that some animal producers will not purchase dietary ingredients with high phosphorus, such as DDGS, because of lack of disposal alternatives" (pp. 13-14). Rausch and Belyea also note that reducing the average phosphorus concentration in DDGS by 50% would allow high inclusion levels in ruminant production diets with little effect on animal waste disposal.

Steam-Flaked vs. Dry-Rolled Corn

Processing corn can improve feed conversion, and steam-flaking is the most intensive and most common method of processing for feedlot rations. According to Owens and Gardner (2000, p. 3), "Cattle fed steam-flaked grains gained more efficiently and had heavier carcass weights than those fed dry-rolled, high-moisture, or whole-grain diets. These efficiency improvements can be attributed to increased starch availability of steam-flaked grains."

A recent survey by Vasconcelos and Galyean (2007) indicated that 65.5% of the responding feedlot consulting nutritionists recommended steam-flaking as the primary corn processing method for the feedlots they serviced. Producers in the Southern Plains generally use steam-flaked corn as the primary energy source, with large-scale U.S. feedlots using it almost exclusively. Feedlots in the Northern Plains are more likely to use dry-rolled corn (Corah and McCully n.d., Lawrence 2007). As discussed next, several recent feeding trials indicate that the heavy reliance on steam-flaked corn in U.S. beef feedlots may limit overall consumption of distillers grains. (See Appendix A for selected results from feeding trials discussed here and elsewhere in this paper.)

Feeding trials have shown that adding distillers grains to steam-flaked corn rations at moderate to high inclusion levels can result in lower feedlot performance and carcass quality compared to feeding no distillers grains or feeding distillers grains with dry-rolled corn or high-moisture corn. Studies have been done for both dried and wet distillers grains. According to Hicks (2007, p. 2), “recent trials suggest that higher levels of DDGS can be used in dry-rolled corn diets than in steam-flaked corn diets. The optimum level of DDGS in stream-flaked corn diets is probably around 15%.” In a feeding trial using 0% to 75% DDGS (Dakota Gold) with steam-flaked corn, Gordon et al. (2002a) found that (1) 15% DDGS resulted in the highest growth performance, (2) 30% DDGS achieved performance similar to including no DDGS, and (3) 45% or more DDGS “tended to reduce performance and carcass grade” (p. 28). Depenbusch, Gordon, and Drouillard (2007, p. 92) found that “animal performance was maximized” with steam-flaked corn plus 15% DDGS, that 30% DDGS could be included without decreasing performance, and gain efficiency declined as DDGS inclusion increased from 0% to 75%. Further, “Carcasses grading USDA Choice or better decreased with increasing levels of distillers grains, while the number of USDA 4 and 5 carcasses doubled compared to heifers fed no distillers grains.”

Optimum inclusion levels for WDGS have also been shown to be lower in steam-flaked corn rations than in dry-rolled corn rations. In a study comparing WDGS inclusion levels in rations with dry-rolled corn, high-moisture corn, or steam-flaked corn, Corrigan et al. (2006) found optimal hot carcass weight, final body weight, average daily gain, and feed-to-gain ratio in the dry-rolled corn ration using 40% WDGS, in the high-moisture corn ration using 27.5% WDGS, and in the steam-flaked corn ration using 15% WDGS. These researchers concluded that “a greater performance response to WDGS inclusion in diets based on less intensely processed grain may render them an economically attractive alternative to diets based on more intensely processed grain” (p. 35).

Vander Pol et al. (2005) measured the performance of animals fed 30% WDGS in rations with corn from six different processing methods, including dry rolling and steam flaking. The authors found that feeding 30% WDGS and dry-rolled corn yielded higher final body weight, average daily gain, fat thickness, kidney/pelvic/heart fat, and calculated yield grade than feeding 30% WDGS with steam-flaked corn (p. 50). Marbling scores were highest using WDGS and high-moisture corn, second highest for the WDGS and dry-rolled corn, and lowest for the WDGS and steam-flaked corn. Vander Pol et al. concluded that steam flaking was not as favorable as dry-rolling when using 30% WDGS in rations. May et al. (2007, p. 58) found that "cattle fed steam-flaked corn diets showed little improvement when wet distiller's grains were added to the diet." Finally, Depenbusch et al. (2007a, p. 74) concluded that including 25% corn-based WDGS in steam-flaked diets reduced animal performance and carcass value.

These and other findings suggest that optimum and maximum inclusion levels for distillers grains are lower when producers use steam-flaked corn than when they use dry-rolled corn. As a result, higher inclusion levels work better in the Upper Midwest, where dry-rolled corn is commonly used in feedlots. To substantially increase consumption of distillers grains while maintaining feedlot performance and carcass quality, it appears that many producers will need to replace steam-flaked corn with a less processed form of corn, such as dry-rolled or high-moisture, in feedlot rations.

Beef Carcass and Meat Quality Issues

Many recent feeding trials have also measured the effects of feeding distillers grains on carcass quality characteristics. As more data on feeding distillers grains at different inclusion levels have become available, concern has arisen about effects on beef quality, especially from feeding distillers grains at high (40% or more) levels. Tjardes and Wright (2002), for example, report that "distiller's grains (wet or dry) at up to 40% of the diet dry matter can replace corn for growing and finishing cattle," but "Kansas and Iowa research shows that feeding distiller's grains at or above 40% of the diet dry matter may reduce performance and efficiency of gain and/or decrease carcass quality when compared to lower levels" (2002, p. 2-3).

To evaluate the effects of feeding distillers grains on carcass merit and meat quality across studies, Owens (2007) analyzed the results from 29 feeding trials. Distillers grains inclusion levels in the trials ranged from 0% to 50% for WDGS and 0% to 75% for DDGS. Focusing on marbling score as a carcass attribute of high economic importance to packers, Owens found that feeding up to 50% WDGS had no significant effect on marbling score. However, a regression analysis showed that marbling score was optimum at about 17% DDGS inclusion and declined at levels above 40%. The finding that marbling scores may begin to decline at lower inclusion levels for DDGS than for WDGS is important because so much distillers grains is expected to be dried for efficient and economical transport to production sites.

Owens also found that, across the 29 studies, hot carcass weight was maximized at about 21% DDGS inclusion and then declined as DDGS inclusion rose to 75%. The drop-off in marbling score was greater than would be expected based only on lighter carcass weights. Owens notes that several factors related to feeding DDGS could affect marbling scores, including shorter feedlot periods, lighter carcass weights, higher fat content of the diet, high protein content of the diet, lower starch substrate, and implant strategies. Of these factors, Owens suggests that high fat content may be the most important in affecting marbling scores.

Fewer studies have been conducted to address quality and sensory evaluation of beef cuts harvested from animals fed distillers grains. Gordon et al. (2002b) fed diets containing 0%, 15%, 30%, 45%, 60%, or 75% DDGS to finishing heifers and observed a small linear improvement in tenderness of ribeye steaks at increasing inclusion levels. Gill, Roeber, and DiCostanzo (2004) examined quality traits and sensory attributes for strip loins from Holstein steers fed up to 50% wet distillers grains or 50% distillers dried grains. A consumer taste panel found no detriment to palatability attributes (tenderness, juiciness, and flavor) as the percentage of either wet or dry distillers grains increased, and the authors concluded that "feeding distillers' grains at up to 50% of the diet [dry matter] does not have a detrimental affect on color stability, tenderness, or sensory/palatability traits" (Gill, Roeber, and DiCostanzo 2004, p. 2).

Owens (2007) analyzed the results of five meat quality studies using distillers grains inclusions rates ranging from 0% to 40%. Owens focused on effects related to retail demand (color and shelf life) and consumer demand (tenderness and flavor). With regard to color, WDGS or DDGS inclusion levels of about 30% resulted in brighter meat color, but inclusion levels greater than 45% resulted in more rapid discoloration. With regard to shelf life, “feeding ethanol byproducts at any level speeded beef rancidity, perhaps due to higher concentrations of polyunsaturated fatty acids in beef” (Owens 2007, p. 32). Finally, with regard to tenderness, juiciness, and flavor, no effects were found for the inclusion levels evaluated in the studies. Owens concluded that “except for potentially increasing rancidity, feeding 20% to 30% distillers grains with solubles often improved marbling and meat quality” (p. 37).

Recently, three studies at the University of Nebraska (Mello, Jenschke, and Calkins 2007a, 2007b, and 2007c) evaluated several quality characteristics in beef from cattle 15% and 30% WDGS in finishing diets. Among their findings were significantly higher values of polyunsaturated fatty acids (PUFA) in beef from cattle fed WDGS, which “could support greater oxidation, reduction in color stability, and possibly impact flavor” (Mello, Jenschke, and Calkins 2007b, p. 121). A second study measured lipid oxidation and objective color in steaks cut from strip loins, tenderloins, and shoulder clods. The researchers found that individual cuts may respond differently to WDGS in finishing diets and that “including WDGS in finishing diets can compromise the color and oxidation capacity of beef steaks resulting in lower shelf life” (Mello, Jenschke, and Calkins 2007c, p. 123). A third study measured effects on fat content and marbling score. Here, the authors found that “feeding 15 percent or 30 percent WDGS did not significantly influence marbling score, marbling distribution, marbling texture or fat content when compared to 0% WDGS. … Thus, there appears to be no detrimental effects on fat and marbling from feeding WDGS to cattle” (Mello, Jenschke, and Calkins 2007a, p. 125).

Finally, a study by Jenschke et al. (2007) examined the effects of adding varying amounts of different roughages to rations with equal amounts of dry-rolled corn and high-moisture corn and 30% WDGS, fed to cattle from specific locations (Nebraska and

South Dakota). The study found no significant locational effects but found that including silage "could increase the probability of oxidation due to increases in PUFA. Furthermore, PUFA, but not cattle source, played a significant role in the development of liver-like off flavor" (Jenschke et al. 2007, p. 119).

In general, feeding trials indicate that low to moderate levels of distillers grains in rations have no detrimental effects on most carcass and beef quality characteristics and may improve some characteristics. Several carcass and beef quality characteristics tend to decline at high inclusion levels (see Appendix A for summarized results). Results from some of the trials indicate that feeding either wet or dry distillers grains can result in increased brightness but can speed beef rancidity and discoloration and decrease shelf life.

The relatively small number of studies, especially studies that evaluate beef quality, and differences in variables between studies make generalization difficult, and more studies are needed to understand fully the effects of feeding distillers grains on meat quality. Also, researchers acknowledge that the fixed feeding periods generally used in research may affect the outcome of the trials for some cattle. Because all the cattle enter and exit the feedlot at the same time, some cattle inevitably will be harvested before or after their individually optimal date. As a result, average animal performance and carcass and meat quality may be different in feedlot operations where cattle are marketed based on individual readiness rather than all-in/all-out. In addition to the need for more data from feeding trials, data from real-life feeding situations are needed to add to our knowledge about the effects of feeding distillers grains.

Increasing the Value and Use of Distillers Grains

Returning to the CARD study mentioned at the beginning of this paper, U.S. beef rations would have to include an average of 48% distillers grains under the conservative assumptions and 62% under the aggressive assumptions if the beef industry is to consume its projected share, relative to shares that would be consumed by other species and exported. Inclusion levels in both scenarios exceed optimal rates based on results from many of the feedlot trials, and the aggressive projection exceeds the current maximum rate. Under either scenario, adoption rates must increase dramatically.

Based on the research results discussed in this paper, large increases in inclusion levels and adoption rates will require solving the problems that currently limit use and doing so in a manner that is cost-effective for both the ethanol plants and beef producers. According to Rausch and Belyea (2005), the co-products from ethanol production are such an important source of revenue that the ethanol industry has great incentive to adopt technologies that increase the number and value of co-products, especially as margins tighten under increased competition. As discussed next, new management strategies and technologies are being developed to address problems of nutrient concentration and variability, product quality, and environmental restrictions. These changes, along with a strong focus on exports, may help increase overall consumption of distillers grains.

Managing Sulfur Content

Until technologies are developed that can economically reduce sulfur levels in distillers grains, managing total sulfur intake by cattle is generally the best course of action for producers. Managing for sulfur includes having distillers grains tested for sulfur content, determining sulfate levels in the water, determining sulfur levels in other feedstuffs the cattle ingest, and modifying rations as needed. Colorado State University provides an on-line calculator that can be used to estimate total sulfur ingestion from rations and water sulfate levels (http://www.dlab.colostate.edu/webdocs/special_cases/sulfurcalc.cfm). Concentrations are estimated at three temperatures (40°F, 70°F, and 90°F) to account for differences in water intake.

Crawford (2007a, p. 2) suggests that producers supplement copper and zinc beyond traditional recommendations or add oxytetracycline or chlortetracycline to rations when conditions favor PEM. For example, "when cattle are transitioning to high sulfate intake conditions, the ruminal sulfide concentration peaks one to three weeks after the change" and susceptibility to PEM can be higher (Iowa State University 2007). Supplementing these nutrients can help reduce the amount of sulfur that is converted to hydrogen sulfide in the rumen. Further, "[a]lthough it appears that thiamine level does not have an effect on Sinduced PEM, it may be useful to include in diets with distillers grains as a form of insurance against other S-related problems" (Crawford 2007a, p. 2).

In rations that blend co-products, lowering sulfur concentrations in co-products from wet milling may help increase use of distillers grains. Researchers are examining the use of enzymes during steeping and ozone aided steeping (OAS) to reduce or eliminate the need for sulfur dioxide (SO_2) in wet milling. According to Chen (n.d.), "Typically, 0.1% to 0.2% sulfur dioxide is added to the water for steeping," resulting in the need to reduce residual SO_2 in final products. Ruan et al. (2004) found that, compared to the SO_2-based process, OAS can be used at lower temperatures, for shorter steeping periods, at reasonable cost, and without residue and environmental and health hazards.

Managing Fat Content

Technologies have been developed to remove fat from dry grind co-products before or after fermentation. Among the front-end technologies, researchers at the University of Illinois are working on three modified dry grind processes that use wet fractionation to reduce fat and fiber and increase protein content in DDGS. The quick germ process recovers corn germ; the quick germ quick fiber process recovers germ and pericarp fiber; and the enzymatic milling process recovers germ, pericarp fiber, and endosperm fiber prior to starch fermentation. These modified fractionation processes separate components of the corn kernel prior to starch fermentation and use water and enzymes, rather than the sulfites commonly used in wet milling. Corn is soaked, incubated in enzymes, and lightly ground to allow separation of germ and fiber before starch fermentation (see Singh et al. 2001 and Singh 2006).

These modified dry grind methods have the multiple advantages of allowing recovery of additional co-products, using less energy to produce ethanol, improving ethanol yield by 8% to 27%, and reducing DDGS production by 45%. These methods also reduce fat and fiber and increase protein in the DDGS, making it more suitable as a feedstock for nonruminant animals (see Table 5) (Singh 2006).

Other oil extraction methods include a dry fractionation process (Singh 2006) and use of solvent extraction and nanofiltration membranes to recover corn oil from ethanol extracts (Kwiatkowskia and Cheryan 2005). An example of dry fractionation technology

TABLE 5. DDGS nutrient analysis from conventional and modified dry grind process, reported from research conducted at the University of Illinois

	Conventional	Quick Germ	Quick Germ Quick Fiber	E-Mill
		(percent)		
Crude protein	28.5	35.91	49.31	58.5
Crude fat	12.7	4.83	3.85	4.53
Ash	5.05	4.13	3.24	---
Acid Detergent Fiber	10.8	8.22	6.80	2.03

Source: Singh 2006, p. 22.

being used at a dry grind plant is the Renew Energy facility in Jefferson, Wisconsin. According to company literature distributed at a recent conference at Iowa State University, the plant's co-product will be a high-protein (minimum 45%) livestock feed that is free of corn oil and bran, low in phosphorous, and low in fat (maximum of 6% crude fat) (see http://www.zfsinc.com/re/index.htm).

Back-end processes include centrifuge technologies that extract corn oil from co-products prior to drying. The extracted oil is feed- or fuel-grade, rather than the food-grade oil harvested using fractionation. Costs of adding back-end centrifuges reportedly are lower for many existing plants than the costs of adding front-end extraction technologies (McElroy 2007).

Managing Phosphorus Content

As noted, increased phosphorous excretion by cattle fed distillers grains can be managed by appropriate manure application in some regions but may be a limiting factor in other areas. Rausch and Belyea found that the production stream for syrup in dry grind plants contains most of the phosphorus and concluded that "processing this stream (syrup) to remove a significant amount of the phosphorus would result in a modified (low phosphorus) DDGS." Further, "because phosphorus in syrup appears to be carried in the water phase, technologies that remove phosphorus also probably will remove water, solving two processing issues" (Rausch and Belyea 2005, p. 15).

New dry milling processes using pre-fermentation fractionation can reduce phosphorus in distillers grains. Kleinhans, Pritchard, and Holt report that producers who feed the resulting distillers dried grains as a crude protein (CP) source will lower phosphorus output relative to using conventional distillers grains. These distillers dried grains "will be used exclusively as a CP supplement as opposed to conventional DDGS being used as a protein and energy supplement" (Kleinhans, Pritchard, and Holt 2005, p. 55). Researchers at the University of Nebraska-Lincoln and the Nebraska Corn Board are collaborating on a four-year project to extract phosphorus at ethanol plants and to produce value-added products such as inositol, a compound used in medical products. The project also will examine new manure management strategies (Kotrba 2005). Other research has examined the use of membrane technology to remove phosphorus from thin stillage (Lucas 2003). The goals of these technologies are to produce more efficient feed rations and reduce environmental impacts.

Selecting corn varieties that are naturally lower in phosphorus can also help reduce phosphorus levels in DDGS. According to Owens (2007, p. 49), phosphorus concentrations in some commercial hybrid varieties (and resulting co-products) can be twice that of other varieties. The typical range of phosphorus concentration in DDGS is 0.60% to 0.95%, but can be as low as 0.52% and as high as 1.04% in the distillers grains produced from specific hybrid corn varieties (Owens 2007, p. 49).

Combining Co-products

High total inclusion levels of co-products in beef rations have been achieved by blending wet milling co-products with dry grind co-products. According to Erickson et al. (2005, p. 8), "In addition to their commercial availability, another reason for feeding a combination of WDGS and WCGF is due to their nutritional profiles. Synergistic effects in feeding a combination of these byproducts may be observed because of differences in fat, effective fiber, and protein components." Research has shown that producers may feed a 50:50 blend of WDGS and WCGF at inclusion levels "as high as 75% without negatively affecting performance," although "optimum inclusion levels of a byproduct blend would be between 25% and 50% DM" (Erickson et al. 2005, pp. 8-9). Buckner et al. (2006a, p. 26) found that "higher by-product inclusion levels can be fed to feedlot cattle in a combination blend [WCGF and WDGS] to achieve greater by-product use."

Blending co-products may also help reduce average nutrient content when one co-product is high in a limiting nutrient (e.g., sulfur) and one is lower.

Exports

Another way to market the future production of distillers grains is aggressive development of export markets, which would reduce volumes that would need to be consumed by the domestic livestock and poultry industries to avoid stockpiles. Under the conservative scenario in the CARD study, the U.S. ethanol industry will export 4% to 6% of its distillers grains production annually throughout the projection period (through 2016/17). In the aggressive scenario, exports increase to 28% by the end of the projection period. Current efforts to export distillers grains are being facilitated by the increases in prices of corn and other feed grains, and the percentage of distillers grains production being exported is already higher than projected for the baseline scenario. The National Corn Growers Association (2007, 2008) estimates that 10% of the distillers grains produced in 2006 were exported and 14% of production in 2007 was exported.
Table 6 shows the explosive growth in exports of distillers grains as livestock and poultry producers in other countries are reacting to high grain prices. During the past five years, U.S. exports have increased threefold, from 742,000 metric tons in 2003 to 2,357,000 metric tons. The same improvements in product availability, quality, and consistency that could help boost domestic use should also make distillers grains more attractive in foreign markets.

Conclusions

The U.S. beef industry has great potential to increase use of distillers grains in rations as corn-based ethanol production increases. Economics will drive producer decisions about adoption rates and inclusion levels for feeding distillers grains, but decisions will also be guided by product availability, nutritional considerations, and carcass and meat quality issues. Given appropriate economic incentives, beef producers have shown themselves to be adept at adjusting rations and adopting management strategies to accommodate changes in ration ingredients. Producers can manage some of

TABLE 6. U.S. distillers grains exports, 2003 - 2007 and 2007 value

	Volume					Value
	2003	2004	2005	2006	2007	2007
			(metric tons)			($1,000)
Mexico	45,721	66,894	128,271	367,386	708,216	118,247
Canada	30,898	83,984	105,929	123,022	317,580	42,024
Turkey	0	0	216	416	136,519	19,350
Taiwan	0	7,431	42,249	92,824	134,404	25,220
Korea	70	625	4,843	24,587	102,529	19,034
Cuba	0	0	10,043	0	84,646	13,579
Japan	15	0	2,824	45,248	83,586	15,363
United Kingdom	184,742	188,857	113,874	92,591	79,934	12,360
Philippines	0	958	11,758	62,465	79,153	15,747
Ireland	255,398	185,007	206,222	145,225	75,711	12,681
Indonesia	0	11,516	46,523	43,764	68,918	12,284
Spain	40,169	77,176	110,052	23,458	65,497	13,644
Israel	12,380	6,366	47,935	17,668	62,315	8,596
Thailand	61	10	12,802	38,140	59,346	11,343
Vietnam	0	633	19,869	17,979	58,260	11,831
Morocco	0	0	5,499	27,858	46,246	7,108
Malaysia	0	12,475	34,410	29,970	39,576	8,478
Chile	3,652	0	3,607	3,011	37,488	5,572
Netherlands	16,445	36,536	53,749	457	37,261	6,625
Costa Rica	1,779	6,600	0	10,432	15,149	2,513
Colombia	10,140	3,849	2,565	4,945	12,440	1,919
Peru	0	0	0	0	10,129	1,300
Total Other Countries	140,490	98,789	105,971	82,207	41,880	6,994
Total World	741,960	787,706	1,069,211	1,253,653	2,356,783	391,812

Source: USDA 2008.

the factors that may limit the use of distillers grains (e.g., sulfur, fat, and phosphorus concentrations) through ingredient testing, ration formulation, and modified manure application plans. However, achieving the full potential for using distillers grains in the beef industry will require changes in the co-products themselves.

More scientific feeding trials and quality and sensory evaluations are needed to fully understand the effects of feeding distillers grains on beef animal performance and meat quality. Data are also needed from real-life feeding situations. However, based on the body of research to date, 50% is generally recognized as the maximum inclusion rate for distillers grains in cattle rations in most feeding situations, and optimal rates are lower for many measures of animal performance and meat quality. In most cases, both management and product changes will be required to increase these rates.

Economics will also drive decisions at ethanol plants about whether to adopt the technologies that are being developed to improve co-products for use as feed ingredients. More consistent quality and reducing the concentrations of some nutrients in distillers grains would help increase adoption rates and inclusion levels by the beef industry. Technologies that reduce fiber and increase protein content have the potential to make distillers grains more suitable for use in non-ruminant livestock and poultry rations and increase overall use by those industries. As more plants come on-line and margins tighten, plants should have added incentive to increase the value of the co-products used in livestock and poultry rations. The same improvements that could help boost domestic use of distillers grains should also make them more attractive in foreign markets, and aggressive development of export markets will complement efforts to increase domestic consumption.

Appendix A. Selected Results for Feeding Trials Using Corn-based Ethanol Co-products in Beef Feedlot Rations

The following table presents selected results from several recent beef feeding trials using corn-based ethanol co-products. Refer to the original publications for full explication of methodologies, results, and conclusions for each study. The percentages for ration ingredients and co-product inclusion levels in the following table are expressed on a dry matter basis.

Table A1. Selected results for live animal performance, carcass characteristics, and meat characteristics for cattle produced with beef finishing rations using various corn-based co-products and inclusion levels (refer to the bottom of the table for definitions of the abbreviations used)

Source	Co-product Inclusion Levels and Feeding Trial Information	Selected Results and Conclusions
Al-Suwaiegh et al. 2002	*Control*: 84% DRC *Co-product inclusion:* 30% corn WDG + 54% DRC 30% sorghum WDG + 54% DRC 60 Red Angus yearling steers, 127-day finishing trial	*Performance* • Steers fed WDG gained 10.1% faster and were 8.5% more efficient than those fed the DRC control ration. • Calculated NE_g values for corn WDG and sorghum WDG estimated to be 33.3% and 24.7% greater than for DRC. *Carcass characteristics* • HCW, FT, and YG were higher from either WDG than the DRC control. • LMA, marbling score, and DP were similar among all treatments. • Choice carcasses: 95% for DRC control, 70% for corn WDG, 74% for sorghum WDG.
Benson, Tjardes, and Wright 2005 (synopsis only)	*Control:* 82% cracked corn *Co-product inclusion:* 15%, 25%, 35% DDGS 199 steers, 105-day finishing trial	*Performance* • Greatest DMI for 25% DDGS; similar final weights among treatments. *Carcass characteristics* • 35% DDGS tended to have highest DP and had highest CW. • No differences for marbling, FT, LMA, or YG. *Other conclusions* No differences in manure odor characteristics between treatments.
Bremer, Erickson, and Klopfenstein 2007	*Control:* Meta-analysis of various studies using DRC and/or HMC. All diets contained 5% to 7.5% roughage. *Co-product inclusion:* 10%, 20%, 30%, 40%, 50% WDGS 1,257 predominantly black crossbred steers, 99- to 168-day feeding trials	*Performance* • Up to 50% WDGS improved ADG compared to no WDGS; ADG highest for 30% WDGS. • DMI lowest for 50% WDGS, highest for 20% WDGS. • F:G highest for no WDGS; lowest for 50% WDGS. *Carcass characteristics* • Cattle fed WDGS had fatter carcasses and higher marbling scores – numerically highest 12th rib fat and marbling scores occurred at 20% WDGS and then declined. *Other conclusions* • In most cases, performance and carcass characteristics improved from feeding up to 30% to 40% WDGS, then gradually declined (p. 39). • The results suggest "a 30% improvement in feeding value when WDGS replaced 15% to 40%

		of the diet. The feeding value at low levels (less than 15%) was approximately 160% the feeding value of corn" (p. 40).
Buckner et al. 2006a	*Control:* 44% DRC and 44% HMC *Co-product inclusion:* - 30% WCGF - 30% WDGS - 15% WCGF + 15% WDGS (30Blend) - 30% WCGF + 30% WDGS (60Blend) 250 crossbred backgrounded steers, 124-day finishing trial	*Performance* • Steers fed all co-product treatments gained faster and more efficiently than control. • 30% WDGS had highest ADG and final BW, lowest DMI and F:G. • 60Blend had lower gain and efficiency than other co-product treatments, but higher than control. • No associative effects were found from blending WCGF and WDGS compared to feeding each co-product alone. *Carcass characteristics* • 30% WDGS had highest HCW and calculated YG; control had lowest. *Other conclusions* • Results from the 60Blend treatment indicate higher co-product inclusion levels can be fed in feedlot rations by blending co-products to achieve greater co-product use (p. 25).
Buckner et al. 2006b	*Control:* 79.5% DRC *Co-product inclusion:* 10%, 20%, 30%, 40% DDGS (50% DDGS removed from study) 250 crossbred backgrounded steer calves, 167-day trial (22-day step-up period, 145-day finishing period)	*Performance* • DDGS improved performance at all inclusion levels relative to control. • Quadratic response for final BW and ADG; most improved for 20% DDGS. • Numerically optimal F:G for 20% DDGS *Carcass characteristics* • No differences were observed although HCW, marbling score, ribeye area, and 12th rib fat thickness numerically highest for 20% DDGS *Other conclusions* • Relative NEg highest for 10% and 20% DDGS; NEg higher for all co-product inclusion relative to DRC. • 50% DDGS (0.6% sulfur) resulted in sulfur toxicity during step-up period.
Corrigan et al. 2006	*Control:* 82.5% DRC, HMC, or SFC *Corn processing method and co-product inclusion:* - DRC + 15%, 27.5%, or 40% WDGS - HMC + 15%, 27.5%, or 40% WDGS - SFC + 15%, 27.5%, or 40% WDGS 480 crossbred steer calves, 167- and 168-day feeding periods	*Performance* • For each corn processing method, optimal HCW, final BW, ADG, and F:G resulted from DRC + 40% WDGS, HMC + 27.5% WDGS, and SFC + 15% WDGS. • DMI responded quadratically to WDGS inclusion level. *Carcass characteristics* • FT and marbling score show quadratic effect to WDGS inclusion level. • Numerically highest marbling scores for DRC + 15% WDGS and DRC + 27.5% WDGS. • FT and YG greater for DRC and HMC than for SFC treatments. *Other conclusions* • ". . . greater performance response to WDGS inclusion in diets based on less intensely processed corn may render them an economically attractive alternative to diets based on more intensely processed corn" (p. 35).
Depenbusch et al. 2007a	*Control:* 83.9% SFC with no additive, with Rumensin®, or with Rumensin + Tylan®	*Performance* • 25% WDGS resulted in 8% less weight gain. • ADG and final BW similar among treatments, numerically highest for SFC alone.

	Co-product inclusion: 25% WDGS with no additive, with Rumensin, or with Rumensin + Tylan 371 crossbred yearling heifers, 150-day finishing trial	• No significant effect on performance from Tylan and/or Rumensin. *Carcass characteristics* • CW, ribeye area, and DP lower for heifers fed 25% WDGS; marbling score and percentage of carcasses grading Choice or better significantly lower for 25% WDGS. *Other conclusions* "Twenty-five percent corn wet DGS in steam-flaked diets reduced animal performance and carcass value" (p. 74).
Depenbusch et al. 2007b	*Control:* 81.1% SFC + 6% hay *Co-product inclusion:* - 15% sorghum DDGS + no hay - 15% sorghum DDGS + 6% hay - 15% sorghum WDGS + no hay - 15% sorghum WDGS + 6% hay - 15% corn DDGS + 6% hay - 15% corn WDGS + 6% hay 299 crossbred yearling steers, 101- and 132 day finishing trial	*Performance* • 15% DGS vs. Control: no significant difference in DMI, ADG, feed efficiency, or final BW. • Corn DGS vs. Sorghum DGS: similar growth performance; corn DGS somewhat more efficient. • Dry vs. Wet: DDGS resulted in lower DMI and lower feed efficiency than WDGS. ADG not significantly different. • No Hay vs. 6% Hay: DMI and ADG declined without hay, feed efficiency not affected. *Carcass characteristics* • 15% DGS vs. Control: significantly lower DP from DGS. No significant differences for ribeye area, marbling score, KP&H fat, FT, and USDA YG and quality grades. • Corn DGS vs. sorghum DGS: Little difference in carcass characteristics, although higher DP from corn DGS than from sorghum DGS. • Wet vs. Dry: carcass characteristics not significantly different, but higher DP from WDGS. • No Hay vs. 6% Hay: 6% hay resulted in lower DP; no differences in marbling score, percentage grading Choice or better, ribeye area, KP&H fat, and liver abscesses. *Other conclusions* • 15% DGS in flaked-corn finishing diets reduced overall diet digestibility (p. 65). • "Sorghum-based and corn-based DGS have comparable nutritional value when added to finishing diets at 15% of dry matter. Likewise, wet DGS and dry DGS are comparable feed ingredients" (p. 65).
Depenbusch et al. 2007c	*Control:* 80.9% SFC *Co-product inclusion:* - SFC + 13.0% DDGS - SFC + 13% partially degermed DDGS (DEGERM) 610 crossbred yearling heifers, 118-day finishing trial	*Performance* • ADG and feed efficiency statistically similar for all diets. • 13% DDGS ration resulted in numerically highest final BW, DMI, and ADG. *Carcass characteristics* • Carcass characteristics and quality were not significantly altered by DGS treatments. *Other conclusions* • DEGERM has feed value similar to traditional DDGS. • DDGS and DEGERM resulted in higher fecal excretion and higher manure phosphorus concentration than control; DEGERM had numerically less phosphorus than DDGS.
Depenbusch, Gordon, and Drouillard 2007	*Control:* SFC *Co-product inclusion:*	*Performance* • Performance maximized at 15% DDGS. • 30% DDGS and no DDGS resulted in similar ADG, feed efficiency, final BW, and CW.

	15%, 30%, 45%, 60%, 75% DDGS 345 crossbred yearling heifers, finishing trial	• Gain efficiency declined as DDGS increased from 0 to 75%. *Carcass and Meat Characteristics* • Linear decrease in FT but increase in KP&H fat as DDGS increased. • Percent Choice or better carcasses decreased with increasing DDGS; number of YG 4 and 5 carcasses from DDGS treatments double number from no DDGS. • Meat tenderness improved as DDGS level increased; juiciness and flavor intensity unchanged; redness not different for various DDGS levels. *Other conclusions* • Can feed up to 30% DDGS before performance declines. • ". . . meat tenderness appears to be improved when DG is fed without any adverse effects on juiciness, flavor, or retail display life."
Fanning et al 1999	*Control:* 84.0% DRC *Co-product inclusion:* DRC + 30% corn WDGS DRC + 30% sorghum WDGS 60 crossbred yearling steers, 127-day feeding trial	*Performance* • 30% corn WDGS or 30% sorghum WDGS had greater final BW, ADG, and F:G. *Carcass characteristics* • 30% corn or 30% sorghum WDGS resulted in greater HCW, FT, and YG. • DP, LMA, marbling score, and percent of carcasses grading USDA Choice were unaffected by treatment, although control (no WDGS) had numerically highest percentage grading Choice. *Other conclusions* • Steers fed 30% corn- or sorghum-based WDGS gained 9.8% faster and were 9.1% more efficient than those fed no WDGS.
Firkins, Berger, and Fahey 1985	*Trial 5* *Control:* 80.4% HMC *Co-product Inclusion*: 25%, 50% WDG 132 crossbred steers, 108-day finishing trial	*Performance* • Linear improvement in ADG and F:G as inclusion of WDG increased. *Carcass characteristics* • No significant differences in carcass characteristics. *Other conclusions* • WDG "can be fed at levels of at least 50% of diet DM and still maintain performance comparable with that of steers fed corn-based finishing diets" (p. 847).
Gordon et al. 2002a	*Control:* 76.62% SFC *Co-product inclusion:* 15%, 30%, 45%, 60%, 75% Dakota Gold® DDGS 345 crossbred heifers, 153-day finishing trial	*Performance* • DMI, ADG, final BW, and G:F highest with 15% DDGS, with gradual declines in each as DDGS inclusion increased. • Performance with 30% DDGS similar to performance with control ration. *Carcass characteristics* • 15% DDGS resulted in highest HCW and highest percentage (29%) of Prime carcasses. • 60% DDGS and 75% DDGS resulted in less Prime and Choice and more Select carcasses. • Overall, heifers were overfinished, with large percentages of Prime and Choice overall. *Other conclusions* • "Including DDGS at 45% or more tended to reduce performance and carcass grade" (p. 28).
Gordon et al. 2002b	*Co-product inclusion:* 15%, 30%, 45%, 60%, 75% Dakota Gold® DDGS	*Trained panel sensory analysis* • Myofibrillar and overall tenderness increased as DDGS inclusion increased.

	60 rib cuts, aged 2 weeks and cut into 1" steaks Heifers from 153-day feeding trial	• Other sensory attributes not affected. • TBARS showed no differences in fat oxidation. *Display analysis* • L* value (lightness) exhibited treatment by day interaction with a quadratic effect. *Other conclusions* • ". . . the small improvements we observed in sensory trains and display characteristics are too small to warrant feeding DDGS on that basis alone" (p. 73).
Huls et al. 2007	*Control:* DRC + HMC *Co-product inclusion:* HMC + DRC + 10% MDGS, 20% MDGS, 30% MDGS, 40% MDGS, or 50% MDGS 288 yearling crossbred steers, 176-day finishing trial	*Performance* • Carcass-adjusted final BW, DMI, ADG all showed quadratic response to increasing levels of MDGS; all were optimum at 20% MDGS inclusion. • Linear improvement in feed conversion, with optimum at 50% MDGS inclusion. • Marbling score not affected by treatment, but numerically highest with 20% MDGS and lowest with 50% MDGS. *Carcass characteristic*s • Calculated YG showed quadratic response, with 20% MDGS resulting in highest YG. *Other conclusions* "Finishing diets including MDGS may be fed up to 50% of diet DM; however, optimal performance is likely between 20% to 40% of diet DM" (p. 41).
Jenschke et al. 2007	*Control:* Equal parts HMC and DRC plus 30% WDGS *Treatments:* Low alfalfa (4%); high alfalfa (8%) Low corn stalks (3%); high corn stalks (6%) Low corn silage (6%); high corn silage (12%) 385 crossbred steers from South Dakota and Nebraska, 139-day feeding trial *Meat:* 1″ steaks from beef knuckles (n = 160)	*Sensory and Chemical Analysis:* • Roughage plus WDGS "had minimal effects on the sensory attributes of beef" (p. 119). • Low alfalfa ration and low corn stalk ration resulted in most tender and juiciest beef among treatments "and tended to have least amount of detectable connective tissue" (p. 119). • Beef from cattle from SD were significantly juicier than those from NE. • Low alfalfa resulted in the most frequent bloody off-flavor; beef from cattle from SD had greater frequency of bloody off-flavor than cattle from NE. • Feeding corn silage with WDGS "could increase the probability of oxidation due to increases in PUFA" (p. 119). • PUFA "played a significant role in the development of liver-like off flavor;" location did not (p. 119.
Loza et al. 2006	*Control:* 44% HMC + 44% DRC *Co-product inclusion:* 30% WCGF + 0% WDGS 30% WCGF + 10% WDGS 30% WCGF + 15% WDGS 30% WCGF + 20% WDGS 30% WCGF + 25% WDGS 30% WCGF + 30% WDGS	*Performance* • 30% WCGF alone improved DMI, ADG, and F:G compared to control; the difference for F:G was significant. • DMI and ADG showed quadratic responses to increasing levels of WDGS. • Optimum ADG and F:G for 30% WCGF + 15% or 20% WDGS • Inclusion of WDGS did not significantly improve F:G relative to WCGF alone. *Carcass characteristic*s • Higher calculated YG for 30% WCGF + 10%, 15%, and 20% WDGS due to higher FT. • No significant differences in marbling or LMA.

	504 yearling steers, 116-day finishing trial	*Other conclusions* "These results indicate that optimal cattle performance would be achieved with inclusion levels of WDGS ranging from 15 to 20% in diets containing 30% WCGF" (p. 28).
May et al. 2007	*Controls:* 83.75% DRC 83.75% SFC *Co-product Inclusion:* - DRC + 10%, 20% (results not reported), or 30% WDG - SFC + 10%, 20%, or 30% WDG 624 crossbred yearly steers, 119-day finishing trial	*Performance* • DMI lower for SFC control than for DRC control. • DMI decreased for SFC treatments as WDG increased and increased for DRC treatments as WDG increased. • F:G and ADG not significantly different among treatments; DRC + 30% WDG had highest numerical DMI and ADG and lowest numerical F:G. • Efficiencies for DRC + 10% WDG about the same as SFC control. *Carcass characteristics* • DRC + 30% WDG had highest HCW and DP. • DRC treatments had highest marbling scores and percentage of Choice carcasses. *Other conclusions* • "Cattle fed steam-flaked corn diets showed little improvement when wet distiller's grains were added to the diet" (p. 58). • Price of wet distillers grains is the most important factor to consider," and "marketing strategies should also be a consideration . . . [because] cattle showed trends to deposit more external fat" (p. 58).
Mello et al. 2007 (abstract only)	*Control:* type of corn not specified *Co-product inclusion:* 15% and 30% WDGS 94 crossbred steers, 133-day finishing diet	*Carcass characteristics* • "Treatment did not significantly influence marbling texture, marbling distribution, or fat content of the ribeye" (p. 278). • 62.5% Choice carcasses from steers fed 15% WDGS, 46.9% Choice carcasses from steers fed 30% WDGS, and 37.5% Choice carcasses from no WDGS in ration.
Mello, Jenschke, and Calkins 2007a 2007b 2007c	*Control:* type of corn not specified *Co-product inclusion:* 15% and 30% WDGS 94 crossbred steers, 133-day finishing diet (2007a) 1/4″ ribeye slices (n = 94) (2007b) 1/4″ ribeye slices (n = 94) (2007c) 1" steaks from strip loins, tenderloins, and top blades (n = 48)	*Conclusions* • 2007a – ". . . there appears to be no detrimental effects on fat and marbling from feeding WDGS to cattle" (p. 125). • 2007b – Significantly higher PUFA and 6 fatty acids in WDGS treatments. Higher PUFA "could support greater oxidation, reduction in color stability, and possibly impact flavor" (p. 120). • 2007c – " . . . including WDGS in finishing diets can compromise the color and oxidation capacity of beef steaks resulting in lower shelf life." The data also suggest that "individual cuts respond differently to WDGS finishing diets" (p. 122). • Further work is needed to clarify these effects and relationships.
Rincker and Berger 2003	*Control:* whole corn, corn silage, SBM to 14% CP *Co-product inclusion:* - 12.5% DDG and urea to 14% CP - 25% or 50% DDG - 25% or 50%WDG - 37.5% DDG to 750 lb., then 20% to harvest	*Performance* • For WDG, quadratic effect on DMI (drop at 50%) and linear increase in ADG. • "Feed efficiency was poorer for steers fed the DDG compared to the WDG" (p. 6). *Carcass characteristics* • "In general, carcass composition was not affected by diet" (p. 6). • All DG treatments except 50% DDG resulted in higher DP than the control ration.

	- 20% DDG to 750 lb., then 37.5% to harvest - 37.5% WDG to 750 lb., then 20% to harvest - 20 WDG to 750 lb., then 37.5% to harvest 320 Holstein steers, 270-day trial	*Other conclusions* • "Dairy-beef steers should be fed DG at 12.5% - 37.5% . . . for optimum performance, carcass composition, and profit margins without having high levels of P and S in the feces" (p. 7). • "Feeding up to 50% DG can decrease performance but may be profitable if DG is purchased at a low enough price" (p. 7).
Roeber, Gill, and DiCostanzo 2005 and Gill, Roeber, and DiCostanzo 2004	Strip loins from Holstein steers from two feeding trials (n = 16 per treatment group) <u>Exp. 1 - Univ. of Ill. feeding trial (Rincker and Berger 2003)</u> Control: whole corn, silage, SBM) 12.5% DDG + urea 25% or 50% WDG 25% or 50% DDG <u>Exp. 2 - Iowa State Univ. feeding trial (Trenkle 2004)</u> Control: cracked corn and urea Control: cracked corn and SBM 10%, 20%, or 40% WDGS 10%, 20%, or 40% DDGS	*Conclusions* • Increasing WDG or DDG had slight detrimental effect on redness values. • No differences in shear force measurements among the WDG treatments; quadratic trend in shear force for DDG treatments with optimal level about 21%. • Exp. 1 – Numerically, consumer taste panels gave steaks from 25% WDG highest scores tenderness and juiciness and steaks from 50% WDG lowest scores. No differences for flavor. • Exp. 2 – Consumer panel found no significant differences among treatments for tenderness, juiciness, or flavor. • "Feeding distillers grains at up to 50% of the dietary DM did not affect tenderness or sensory traits, and seems to be a viable feed alternative without negatively impacting sensory attributes" (p. 2455). • Using distiller's grains at "high (40% to 50% of dietary dry matter) inclusion rates may have a negative effect on color stability of strip loins during retail display" (p. 2460). • Conversely, using distiller's grains at low to moderate levels (10% to 25%) may "maintain, or even enhance, shelf life of steaks in a retail outlet, without affecting cooked beef palatability" (p. 2460).
Trenkle 2004	*Control 1:* cracked corn and urea *Control 2:* cracked corn and SBM *Co-product inclusion:* - 10%, 20%, 40% WDGS - 10%, 20%, 40% DDGS 192 Holstein steers, 299-day growing and finishing trial (91-day growing period)	*Performance (over entire period)* • Performance similar for controls, DDGS treatments, and 20% WDGS. • 10% WDGS improved feed conversion relative to controls, DDGS treatments, and 40% WDGS. • "During the entire feeding trial, feeding wet or dry DGS did not affect performance except steers fed 40% wet DGS consumed less feed and had less gain, and steers fed 10% wet DGS consumed less feed with the same gain and improved feed efficiency" (p. 1). • 40% WDGS reduced feed intake and rate of gain without affecting feed conversion. *Carcass characteristics* • DP increased linearly with increased WDGS and increased DDGS. • 40% WDGS resulted in numerically lowest carcass weight; otherwise DG inclusion level had no significant effect on carcass weight, marbling score, ribeye area, or FT. • No consistent trend in YG or quality grades. *Other conclusions* WDGS or DDGS "can be fed to growing and finishing Holstein steers at 10% or 20% of diet dry matter without affecting performance or value of the carcass in a value-based market" (p. 5).
Trenkle 2007	*Control:* DRC + corn silage + chopped cornstalks + SBM	*Performance* • 24.9% MWDGS did not affect DMI or performance; 47% MWDGS reduced DMI and

	*Co-product inclusion: (*MWDGS, average 53.6% DM) 24.9% MWDGS + 0.10% urea 47.0% MWDGS + 1.35% urea 108 preconditioned steers, 186-day feeding trial	improved feed conversion without affecting gain. *Carcass characteristics* • "There were no statistically significant effects on carcass measurements" (p. 2). • 47% MWDGS caused trend toward lower marbling scores, fewer Choice carcasses, more YG2 and fewer YG 4. • USDA Choice carcasses: 83.3% from control, 77.8 from 24.9% MWDGS, 71.7% from 47.0% MWDGS. • CAB carcasses: 19.4% from control, 22.2% from 24.9% MWDGS, 11.7% from 47.0% MWDGS. *Other conclusions* • On the grid, average value of carcasses from 24.9% MWDGS $7 higher than control; average carcass value from 47.0% MWDGS was $38 less than control carcass value.
Vander Pol et al. 2005	*Corn processing treatments:* - Whole corn + 30% WDGS - DRC+ 30% WDGS - HMC+ 30% WDGS - 50:50 DRC:HMC blend + 30% WDGS - SFC+ 30% WDGS - FGC+ 30% WDGS	*Performance* • ADG highest for DRC, HMC, and DRC:HMC blend. • DMI significantly higher for DRC or whole corn than other treatments. • F:G lowest for HMC, highest for FGC. *Carcass characteristics* • DRC treatment resulted in highest fat thickness and calculated yield grade. • HMC resulted in highest marbling scores, SFC and FGC resulted in lowest. • No significant difference in number of carcasses grading Choice or better, but number in Upper 2/3 Choice lowest for SFC and FGC. *Other conclusions* • Steam-flaking, fine grinding, or no processing are not as favorable as dry-rolling and HMC in diets with 30% WDGS (p. 50).

List of abbreviations used in Appendix

CS = corn silage.
ADG = average daily gain.
BW = body weight.
CP = crude protein.
DDG = distillers dried grains.
DDGS = distillers dried grains with solubles.
DMI = dry matter intake.
DP = dressing percentage.
DRC = dry-rolled corn.
F:G = feed:gain ratio.
FGC = fine-ground corn.
FT = fat thickness at 12^{th} rib.
HCW = hot carcass weight.
HMC = high-moisture corn.
KP&H = kidney, pelvic, and heart.
LMA = longissimus muscle (ribeye) area.
MDGS = modified distillers grains with solubles.
MWDGS = modified wet distillers grains with solubles.
NDF = neutral detergent fiber.
NE_g = net energy for gain
PEM = polioencephalomalacia.
PUFA = polyunsaturated fatty acids.
SBM = soybean meal
SFC = steam-flaked corn.
TBARS = thiobarbituric acid reactive substances.
WDG = wet distillers grains.
WDGS = wet distillers grains with solubles.
YG = yield grade.

References

Amaral-Phillips, D.M. 2004. "Pros and Cons of Feed Wet Byproducts." Kentucky Ruminant Nutrition Workshop, University of Kentucky, October (available at http://www.uky.edu/Ag/AnimalSciences/dairy/ruminantnutritionworkshop/rumnut026.pdf).

Benson, C., K. Tjardes, and C. Wright. 2005. "Effects of Feeding Varying Concentrations of Dry Distillers Grains with Solubles to Finishing Steers on Performance and Odorant Emissions." (2005 ASAS/ADSA Joint Annual Mtg. Abstract) *Journal of Animal Science* 83(Suppl. 1): 247 (available at http://www.ddgs.umn.edu/abstracts-beef/2005-Benson-%20Effects%20of%20feeding%20varying--.pdf).

Benson, C., C. Wright, J. McCarthick, and R. Pritchard. 2006. "Effect of Increasing Dietary Concentrations of Dried Distillers Grains plus Solubles on Phosphorus Balance in Finishing Steers." *2006 South Dakota State University Beef Report* (available at http://ars.sdstate.edu/extbeef/2006/BEEF_2006-01_Benson.pdf).

Blasi, D.A., M.J. Brouk, J. Drouillard, and S.P. Montgomery. 2001. *Corn Gluten Feed, Composition and Feeding Value for Beef and Dairy Cattle*. MF-2488, Kansas State University, Manhattan, February (available at http://www.oznet.ksu.edu/library/lvstk2/mf2488.pdf).

Boyles, S. 2007. "Distillers Grains with Solubles." *Beef Team Newsletter*. Issue 551, August 29 (available at http://fairfield.osu.edu/ag/beef/beefAgst29.html).

Bremer, V.R., G.E. Erickson, and T.J. Klopfenstein. 2007. "Meta-Analysis of UNL Feedlot Trials Replacing Corn with WDGS." *2008 Nebraska Beef Report*, University of Nebraska – Lincoln, pp. 39-40 (available at http://beef.unl.edu/reports.shtml).

Buckner, C.D., G.E. Erickson, T.J. Klopfenstein, R.A. Stock, K. J. Vander Pol, and J.R. Teichert. 2006a. "Effect of Feeding a By-product Combination on Two Levels or By-product Alone in Feedlot Diets." Nebraska Beef Report MP 90, University of Nebraska, Lincoln (available at http://beef.unl.edu/beefreports/200709.shtml).

Buckner, C.D., T.L. Mader, G.E. Erickson, S.L. Colgan, K.K. Karges, and M.L. Gibson. 2006b. "Optimum Levels of Dry Distillers Grains with Solubles for Finishing Beef Steers." 2007 Nebraska Beef Cattle Report. University of Nebraska, Lincoln (available at http://beef.unl.edu/beefreports/200713.shtml).

Chen, P.L. n.d. "Ozone Aided Corn Steeping Process." University of Minnesota, St. Paul (available at http://www.tc.umn.edu/~chenx088/research.php?topic=ozonecorn).

Corah, L., and M. McCully. n.d. "Declining Quality Grades: A Review of Factors Reducing Marbling Deposition in Beef Cattle." White paper, Certified Angus Beef (CAB Partners) (available at http://www.cabpartners.com/news/research/declining_quality_grades.pdf).

Corrigan, M.E., G.E. Erickson, T.J. Klopfenstein, K.J. Vander Pol, M.A. Greenquist, and M.K. Luebbe. 2006. "Effect of Corn Processing and Wet Distillers Grains Inclusion Level in Finishing Diets." *2007 Nebraska Beef Cattle Report*. University of Nebraska-Lincoln (available at http://beef.unl.edu/beefreports/200712.shtml).

Crawford, G. 2007a. "Managing High Sulfur Concentrations in Beef Cattle Feedlot Rations." University of Minnesota Beef Center, St. Paul (available at http://www.extension.umn.edu/beef/components/pdfs/Factsheet_HighSulfur.pdf).

———. 2007b. "Managing Sulfur Concentrations in Feed and Water." Presented at 68^{th} Minnesota Nutrition Conference, Minneapolis, September 18-19 (available at http://www.extension.umn.edu/beef/components/pdfs/ManagingSulfur_Crawford.pdf).

Depenbusch, B.E., J.S. Drouillard, E.R. Loe, and M.J. Quinn. 2007a. "Efficacy of Feed Grade Antibiotics in Finishing Diets Containing Distiller's Grains with Solubles." *Beef Cattle Research 2007*, Kansas State University, Manhattan (available at http://www.oznet.ksu.edu/library/lvstk2/srp978.pdf).

Depenbusch, B.E., J.S. Drouillard, E.R. Loe, M.J. Quinn, and M.E. Corrigan. 2007b. "Optimizing Use of Distiller's Grains with Solubles (DGS) in Finishing Cattle Diets." *Beef Cattle Research 2007*, Kansas State University, Manhattan (available at http://www.oznet.ksu.edu/library/lvstk2/srp978.pdf).

Depenbusch, B.E., J.S. Drouillard, E.R. Loe, M.J. Quinn, and M.E. Corrigan. 2007c. "Degermed Corn Distiller's Grains with Solubles (DGS) Have Feed Value Similar to Traditional Distiller's Grains." *Beef Cattle Research 2007*, Kansas State University, Manhattan (available at http://www.oznet.ksu.edu/library/lvstk2/srp978.pdf).

Depenbusch, B.E., C.M. Gordon, and J.S. Drouillard. 2007. "Dried Corn Distiller's Grains with Solubles: How Much Is Too Much?" Research Update in *2007 Plains Nutrition Council Spring Conference*, Publication No. AREC 07-20, Texas A&M University Agricultural Research and Extension Center, Amarillo, p. 91 (available at http://amarillo.tamu.edu/programs/beeftce/2007proceedingsFinal.pdf).

Erickson, G.E., T.J. Klopfenstein, K. Vander Pol, V. Bremer, and P. Loza. 2005. "Feeding of Wet Corn Milling Byproducts to Beef Cattle." University of Nebraska, Lincoln (available at http://www.ddgs.umn.edu/articles-beef/2005Erickson%20(MNC)%20Feeding%20wet%20corn.pdf).

Fanning, K., T. Milton, T. Klopfenstein, and M. Klemesrud. 1999. "Corn and Sorghum Distillers Grains for Finishing Cattle." *1999 Nebraska Beef Cattle Report*, University of Nebraska, Lincoln (available at http://beef.unl.edu/beefreports/199913.shtml).

Firkins, J.L., L.L. Berger, and G.C. Fahey, Jr. 1985. "Evaluation of Wet and Dry Distillers Grains and Wet and Dry Corn Gluten Feeds for Ruminants." *Journal of Animal Science* 60(3):847-60.

Gill, R., D.L. Roeber, and A. DiCostanzo. 2004. "Impact of Feeding Distillers Grains on Beef Tenderness and Sensory Traits." Presented to Iowa Corn Promotion Board, April 2004 (available at http://www.iowacorn.org/forms/UMStudy_FinalReport.pdf).

Gordon, C.M., J.S. Drouillard, J. Gosch, J.J. Sindt, S.P. Montgomery, J.N. Pike, T.J. Kessen, M.J. Sulpizio, M.F. Spire, and J.J. Higgins. 2002a. "Dakota Gold®-Brand Dried Distiller's Grains with Solubles: Effects on Finishing Performance and Carcass Characteristics." *Cattlemen's Day 20*02, Report of Progress 890. Kansas State University, pp. 27-29 (available at http://www.ddgs.umn.edu/articles-beef/2002-Gordon%20Dakota%20Gold%20brand%20ddgs%20%20Effects%20on%20finishing--.pdf).

Gordon, C.M., J.S. Drouillard, R.K Phebus, K.A. Hachmeister, M.E. Dikeman, J.J. Higgins, and A.L. Reicks. 2002b. "The Effect of Dakota Gold®-Brand Dried Distiller's Grains with Solubles of Varying Levels on Sensory and Color Characteristics of Ribeye Steaks." *Cattlemen's Day 20*02, Report of Progress 890. Kansas State University, pp. 72-74 (available at http://www.ddgs.umn.edu/articles-beef/2002-Gordon-%20The%20effect%20of%20Dakota%20Gold--.pdf).

Gould, K., and S. Rust. 2007. **"**Ration Formulation with Distiller Grains with Solubles." *Cattle Call* 12(1): 3-4.

Hicks, B. 2007. "Dried Distillers Grains with Solubles for Finishing Cattle." In *Beef Cattle Research Update*, Oklahoma Panhandle Research & Extension Center, Goodwell, OK, June (available at http://oaes.pss.okstate.edu/goodwell/Publications/Animal%20Science/OSU%20Beef%20Cattle%20Research%20Update%20June%202007.pdf).

Huls, T., M.K. Luebbe, G.E. Erickson, and T.J. Klopfenstein. 2007. "Effect of Inclusion Level of Modified Distillers Grains plus Solubles in Finishing Steers." *2008 Nebraska Beef Report*, University of Nebraska-Lincoln, pp. 41-42 (available at http://beef.unl.edu/reports.shtml).

Iowa Beef Center. 2007. "Co-products: Frequently Asked Questions." Iowa State University, Ames (available at http://www.iowabeefcenter.org/content/Feed_coproducts_cattlefaq.html).

Iowa State University. 2007. “Polio in Cattle Can Be Caused by Sulfur Toxicity.” College of Veterinary Medicine, Veterinary Diagnostic and Production Animal Medicine (available at http://www.vetmed.iastate.edu/departments/vdpam/vdl.aspx?id=2070).

Jenschke, B.E., J.R. Benton, C.R. Calkins, T.P. Carr, K.M. Eskridge, T.J. Klopfenstein, and G.E. Erickson. 2007. “Characteristics of Beef Finished on Wet Distillers Grains with Varying Types and Levels of Roughage.” *2008 Nebraska Beef Report*, University of Nebraska – Lincoln, pp. 124-125 (available at http://beef.unl.edu/reports.shtml).

Jones, C., G. Tonsor, R. Black, and S. Rust. 2007. “Economically Optimal Distiller Grain Inclusion in Beef Feedlot Rations: Recognition of Omitted Factors.” Paper presented at NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management, Chicago, IL, April 16-17 (available at http://www.farmdoc.uiuc.edu/nccc134/conf_2007/pdf/confp18-07.pdf).

Kleinhans, G.B., R.H. Pritchard, and S.M. Holt. 2005. “Composition and Nutritive Value of Corn Fractions and Ethanol Co-products Resulting from a New Dry-milling Process.” *2005 South Dakota State University Beef Report*, Beef 2005 - 12, Brookings (available at http://ars.sdstate.edu/extbeef/2005/Beef_2005-12_Kleinhans.pdf).

Klopfenstein, T. 2001. “Distillers Grains for Beef Cattle.” Presentation at the National Corn Growers Association Distillers Grain Workshop, Lincoln, NE, November (available at http://www.distillersgrains.com/pdf/Klopfenstein-DG%20for%20Beef%20Cattle-11-01.pdf).

Kononoff, P.J., and B. Janicek. 2005. “Understanding Milling Feed Byproducts for Dairy Cattle.” G1586 NebGuide. University of Nebraska, Lincoln, October (available at http://www.ianrpubs.unl.edu/epublic/live/g1586/build/g1586.pdf).

Kotrba, R. 2005. “Nebraska Researchers Aim to Lower Distillers Grains Phosphorous Levels.” *Grain Distillers Quarterly*, Fourth Quarter.

Kwiatkowski, J., and M. Cheryan. 2005. “Recovery of Corn Oil from Ethanol Extracts of Ground Corn Using Membrane Technology.” *Journal of the American Oil Chemists’ Society* 82 (3): 221-27.

Kwiatkowski, J.R., A.J. McAloon, F. Taylor, and D.B. Johnston. 2006. “Modeling the Process and Costs of Fuel Ethanol Production by the Corn Dry Grind Process.” *Industrial Crops and Products* 23: 288–296 (available at http://www.iit.edu/~ipro346s07/dryMilling2.pdf).

Lardy, G. 2007. “Feeding Coproducts of the Ethanol Industry to Beef Cattle.” AS-1242 (Revised), North Dakota State University, Fargo (available at http://www.ag.ndsu.edu/pubs/ansci/beef/as1242w.htm).

Lawrence, J.D. 2007. "Distillers Grains in Beef Cowherd and Feedlot Rations." PowerPoint presentation, Iowa State University, Ames (available at www.econ.iastate.edu/faculty/lawrence/PowerPoint/DGS_Livestock.ppt).

Loy, D. 2007. "How Much Distillers' Grains Can I Feed?" In *Ethanol Feeds: Feeding Distillers Grains to Beef Cattle*. Iowa Beef Center, Iowa State University, Ames, February (available at http://www.iowabeefcenter.org/content/Distillers_Newsletter_February_2007.pdf).

Loy, D., and W. Miller. 2002. "Ethanol Co-products for Cattle." IBC-18. Iowa Beef Center, Iowa State University, Ames, February, p. 4 (available at http://www.extension.iastate.edu/Publications/IBC18.pdf).

Loza, P.L., K.J. Vander Pol, M.A. Greenquist, G.E. Erickson, T.J. Klopenstein, R.A. Stock. 2006. "Effects of Different Inclusion Levels of Wet Distillers Grains In Feedlot Diets Containing Wet Corn Gluten Feed." In *2007 Nebraska Beef Cattle Report*, University of Nebraska, Lincoln (available at http://unl.edu/beefreports/200710.shtml).

Lucas, L.C. 2003. New Research May Reduce Phosphorus in Corn Processing Coproducts." *Illini DairyNET*, April 30 (available at http://www.livestocktrail.uiuc.edu/dairynet/paperDisplay.cfm?ContentID=1188).

Maguire, R.O., D.A. Crouse, and S.C. Hodges. 2007. "Diet Modification to Reduce Phosphorous Surpluses: A Mass Balance Approach." *Journal of Environmental Quality* 36 (September-October):1235-40 (available at http://jeq.scijournals.org/cgi/content/abstract/36/5/1235).

May, M.L., J.S. Drouillard, M.J. Quinn, and C.E. Walker. 2007. "Wet Distiller's Grains with Solubles in Beef Finishing Diets Comprised of Steam-Flaked or Dry-Rolled Corn." In *Beef Cattle Research 2007*, Report of Progress 978. Kansas State University, Manhattan (available at http://www.oznet.ksu.edu/library/lvstk2/srp978.pdf).

McElroy, A.K. 2007. "Corn Oil Extraction Opens New Markets." *Distillers Grains Quarterly*. First Quarter, pp. 7-8 (available at http://www.gs-cleantech.com/pdf/DGQ_Q1_2007.pdf).

Mello, de, A.S. Jr., C.R. Calkins, J.M. Hodgen, B.E. Jenschke, and G.E. Erickson. 2007. "Wet Distillers Grains Plus Solubles Do Not Alter the Relationship between Fat Content and Marbling Score In Calf-fed Steers." (Abstract) *Journal of Animal Science* 2007 85(Suppl. 1):278 (available at http://adsa.asas.org/meetings/2007/abstracts/0278.PDF).

Mello, de, A.S. Jr., B.E. Jenschke, and C.R. Calkins. 2007a. "Effects of Wet Distillers Grains Finishing Diets on Fat Content and Marbling Score in Steers." *2008 Nebraska*

Beef Report, University of Nebraska – Lincoln, pp. 124-125 (available at http://beef.unl.edu/reports.shtml).

_______. 2007b. "Influence of Feeding Wet Distillers Grains on Fatty Acid Composition of Beef." *2008 Nebraska Beef Report*, University of Nebraska – Lincoln, pp. 120-121 (available at http://beef.unl.edu/reports.shtml).

_______. 2007c. "Wet Distillers Grains Plus Solubles Affect Lipid Oxidation and Objective Color of Beef Steaks." *2008 Nebraska Beef Report*, University of Nebraska – Lincoln, pp. 122-123 (available at http://beef.unl.edu/reports.shtml).

Mosier, N.S., and K. Ileleji. 2006. "How Fuel Ethanol Is Made from Corn." ID-328 Purdue University Extension Bioenergy series, West Lafayette, IN, December (available at http://www.ces.purdue.edu/extmedia/ID/ID-328.pdf).

National Corn Growers Association. 2007. "Ethanol and Co-products" (available at http://www.ncga.com/ethanol/coproducts/index.asp).

_____. 2008. "Distiller Grains Exports Nearly Double in One Year." http://www.ncga.com/news/notd/2008/February/022008a.asp).

National Research Council. 2000. *Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000.* Washington, DC: The National Academies Press, 60-61 (available at http://www.nap.edu/openbook.php?isbn=0309069343&page=60).

Owens, F. 2007. "Corn Ethanol Byproducts: Effects on Carcass Merit and Meat Quality." Presented at ProBeef07, Iowa State University, Ames, September 5-7 (available at http://www.iowabeefcenter.org/content/News-Publications/2007/meetings/ProBeef%20presentations/Fred%20Owens.pdf).

Owens, F.N., and B.A. Gardner. 2000. "A Review of the Impact of Feedlot Management and Nutrition on Carcass Measurements of Feedlot Cattle". In *Proceedings of the American Society of Animal Science, 1999*, American Animal Science Society, pp. 1-18 (available at http://jas.fass.org/cgi/reprint/77/E-Suppl/1-ag).

Powers, W., D. Loy, A. Trenkle, and R.E. Martin. 2006. "Use of Distillers Grains in Feedlot Diets: Impact on Phosphous Excretion." IBC 29, Iowa Beef Center, Iowa State University, Ames, July (available at http://www.extension.iastate.edu/Publications/IBC29.pdf).

Pritchard, R.H. 2007. Corn By-Products: Considerations Involving Sulfur." In *Proceedings of the 2007 Plains Nutrition Council Spring Conference*, San Antonio, Texas, March 29-30. Publication No. AREC 07-20, Texas A&M University, Amarillo (available at http://amarillo.tamu.edu/programs/beeftce/2007proceedingsFinal.pdf).

Rausch, K.D., and R.L. Belyea. 2005. "Co-products from Bioprocessing of Corn." Paper No. 057041, 2005 ASAE Annual International Meeting, Tampa, FL, July 17-20 (available at http://www.ddgs.umn.edu/articles-proc-storage-quality/2005-Rausch-%20Co-products%20from%20bioprocessing--.pdf).

Rincker, C.B., and L.L. Berger. 2003. "Optimizing the Use of Distillers Grain for Dairy-Beef Production." Distiller Grain Trial, University of Illinois, Champaign, (available at http://www.livestocktrail.uiuc.edu/uploads/beefnet/papers/Optimizing%20D%20Grain.pdf).

Roeber, D.L., R.K. Gill, and A. DiCostanzo. 2005. "Meat Quality Response to Feeding Distillers Grains to Finishing Holstein Steers." *Journal of Animal Science* 83:2455-60.

Ruan, R., H.W. Lei, P.L. Chen, S.B. Deng, X. Lin, Y.H. Li, W. Wilcke, and G. Fulcher. 2004. "Ozone-aided Corn Steeping Process." *Cereal Chemistry* 81(2):182-87.

Singh, V. 2006. "Past, Present, and Future of Dry Grind Corn Processes." PowerPoint presentation at 2006 Bioenergy Symposium, Purdue University, West Lafayette, IN, February 23 (available at http://www.purdue.edu/dp/energy/centers/bioenergy/presentations/V.%20Singh%20-%20Powerpoint.pdf).

Singh, V., K.D. Rausch1, P. Yang, H. Shapouri, R.L. Belyea, and M.E. Tumbleson. 2001. "Modified Dry Grind Ethanol Process." Agricultural Engineering Department, University of Illinois at Urbana – Champaign, July 18 (available at http://www.age.uiuc.edu/faculty/krausch/Publications/Singh%20et%20al%20-%20Modified%20Dry%20Grind%20white%20paper.pdf).

Snider, T.A. 2004. "Distillers Grains and Sulfur White Paper." National Corn Growers Association, April (available at http://www.ddgs.umn.edu/articles-proc-storage-quality/2004-Snider-%20DG%20and%20sulfur--.pdf).

Tjardes, K., and C. Wright. 2002. "Feeding Corn Distiller's Co-products to Beef Cattle." ExEx2036 *Extension Extra*. South Dakota State University, Brookings, August (available at http://www.distillersgrains.com/pdf/Schingoethe-ExEx2036%20DDG%20for%20Beef%20Cattle.pdf).

Tokgoz, S., A. Elobeid, J. Fabiosa, D.J. Hayes, B.A. Babcock, T-H. Yu, F. Dong, C.E. Hart, and J.C. Beghin. 2007. "Emerging Biofuels: Outlook of Effects on U.S. Grain, Oilseed, and Livestock Markets." Staff Report 07-SR 101, Center for Agricultural and Rural Development, Iowa State University, Ames (available at http://www.card.iastate.edu/publications/DBS/PDFFiles/07sr101.pdf).

Trenkle, A. 2004. "Evaluation of Wet and Dry Distillers Grains with Solubles for Finishing Holstein Steers." A.S. Leaflet R1883. In *Iowa State University Animal*

Industry Report 2004, Iowa State University, Ames (available at http://www.ans.iastate.edu/report/air/2004pdf/AS1883.pdf).

_______. 2007. "With Increasing Availability of Distillers Grains Will Phosphorus Be a Problem for Iowa Livestock Producers?" Iowa State University Animal Industry Report 2006. A.S. Leaflet R2124 (available at http://www.ans.iastate.edu/report/air/2006pdf/R2124.pdf).

U.S. Department of Agriculture (USDA). 2002. "Water Quality in U.S. Feedlots." APHIS Info Sheet. USDA Animal and Plant Health Inspection Service, Washington, DC. December (available at http://www.aphis.usda.gov/vs/ceah/ncahs/nahms/feedlot/feedlot99/FD99water.pdf).

_______. 2007a. Agricultural Baseline Projections: U.S. Livestock, 2007-2016. Economic Research Service, last updated February 14 (available at http://www.ers.usda.gov/briefing/Baseline/livestock.htm).

_______. 2007b. "Ethanol Co-products Used for Livestock Feed." National Agricultural Statistics Service, Washington, DC (available at http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID= 1756).

_______. 2008. FAS Online – U.S. Trade Internet System. USDA Foreign Agricultural Service, Washington, DC (available at http://www.fas.usda.gov/ustrade).

Vander Pol, K.J., G.E. Erickson, M.A. Greenquist, T.J. Klopfenstein, and T. Robb. 2005. "Effect of Corn Processing in Finishing Diets Containing Wet Distiller Grains on Feedlot Performance and Carcass Characteristics of Finishing Steers." *2006 Nebraska Beef Report.* University of Nebraska-Lincoln, 48-50 (available at http://www.ddgs.umn.edu/articles-beef/2006-VanderPol%20Effect%20of%20corn%20processing%20in%20finishing--.pdf).

Vasconcelos, J.T., and M.L. Galyean. 2007. "Nutritional Recommendation of Feedlot Consulting Nutritionists: The 2007 Texas Tech University Survey." *Journal of Animal Science* 85: 2772-81 (available at http://jas.fass.org/cgi/content/abstract/85/10/2772).

Weiss, B., M. Eastridge, D. Shoemaker, and N. St-Pierre. 2007. "Fact Sheet: Distillers Grains." The Ohio State University, Columbus, June (available at http://ohioline.osu.edu/as-fact/pdf/distillers.pdf).

Westcott, P. 2007. *Ethanol Expansion in the United States: How Will the Agricultural Sector Adjust?* FDS-07D-01, U.S. Department of Agriculture, Economic Research Service, Washington, DC, May (available at http://www.ers.usda.gov/Publications/FDS/2007/05May/FDS07D01/).