United States Department of Agriculture

FDS-11-I-01

October 2011

Outlook

A Report from the Economic Research Service

www.ers.usda.gov

Estimating the Substitution of Distillers' Grains for Corn and Soybean Meal in the U.S. Feed Complex

Linwood A. Hoffman and **Allen Baker**[1]

Contents

Approved by USDA's World Agricultural Outlook Board

Abstract

Corn-based dry-mill ethanol production and that of its coproducts—notably distillers' dried grains with solubles (DDGS)—has surged in the past several years. The U.S. feed industry has focused on the size of this new feed source and its impact on the U.S. feed market, particularly the degree that DDGS substitute for corn and soybean meal in livestock/poultry diets and reduce ethanol's impact on the feed market. This study develops a method to estimate the potential use of U.S. DDGS and its substitutability for corn and soybean meal in U.S. feed rations. Findings demonstrate that, in aggregate (including major types of livestock/poultry), a metric ton of DDGS can replace, on average, 1.22 metric tons of feed consisting of corn and soybean meal in the United States. Over time, DDGS may substitute for less corn and more soybean meal as the share of beef cattle consumption of DDGS declines slightly (although increasing in absolute terms), with offsetting share increases in dairy cattle, swine, and poultry. Feed market impacts of increased corn use for ethanol are smaller than that indicated by the total amount of corn used for ethanol production because of DDGS.

Keywords: Distillers' grains, feed potential, substitution, corn, and soybean meal

Acknowledgments

The authors gratefully acknowledge the input and review comments of Paul Westcott, Ken Mathews, Don Blayney, Janet Perry, Erik Dohlman, Molly Garber, and Greg Pompelli of USDA's Economic Research Service (ERS); Jerry Norton of USDA's World Agricultural Outlook Board; Marina Denicoff of USDA's Agricultural Marketing Service; Michelle Wittenberger, Oliver Flake, Richard Omeara, and Mike Jewison of USDA's Foreign Agricultural Service; Kurt A. Rosentrater of USDA's Agricultural Research Service; Terry J. Klopfenstein of University of Nebraska; Gerald C. Shurson of University of Minnesota; Robert Wisner of Iowa State University at Ames; Frank J. Dooley of Purdue University; Charles Staff of the Distillers' Grain Technology Council at Louisville, Kentucky; and Maria Luther, Food and Drug Administration, Center for Veterinary Medicine, Division of Animal Feeds. Thanks to Angela Anderson and Cynthia A. Ray of ERS for editorial and design guidance.

[1] Allen Baker is a retired agricultural economist from USDA, Economic Research Service.

The use of commercial and trade names does not imply approval or constitute endorsement by USDA.

Introduction

U.S. ethanol production growth has been stimulated partly by higher energy prices and the influence of the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007 (Government Printing Office, 2006 and 2007).[1] The 2007 Energy Act mandates the use of as much as 15 billion gallons of starch-based ethanol (mostly from corn) in the United States by 2015. In 2005/06, 4.5 billion gallons of ethanol were produced. By 2008/09, production more than doubled to 10.2 billion gallons, and in 2009/10, it rose to 12.5 billion gallons.[2, 3] Accompanying this growth in ethanol production, distillers' grain production has expanded substantially, increasing from an estimated 10.4 million metric tons (mmt) in 2005/06 to an estimated 33.4 mmt in 2009/10.[4]

Distillers' dried grains with solubles (DDGS) have long been substituted for corn and soybean meal in livestock and poultry diets, supplying both energy and protein.[5] Incorporating DDGS into these diets, however, may be constrained by nutritional and/or price considerations. For example, DDGS may not provide some of the nutrients needed by a particular type of livestock or poultry to achieve its desired weight gain or maintain its body weight. Assuming DDGS provide the desired nutrients, the price of DDGS must be favorable for feeding. Hoffman and Baker (2010) show that DDGS prices relative to alternative feed ingredients have declined into a favorable feeding range for many different types of livestock and poultry.[6]

How does the continued market expansion of DDGS affect the U.S. feed complex (or processed feeds fed) and to what extent do DDGS substitute for corn and soybean meal, thereby reducing the grain market impact of using corn to produce ethanol? A bushel of corn used for dry-mill ethanol production yields DDGS equal to about a third of the corn's original weight. Researchers are less sure, however, how this coproduct substitutes for corn and soybean meal in the diets of different types of livestock and poultry. Understanding of the characteristics of DDGS may demonstrate more effectively how they can be substituted into different livestock/poultry diets and the impact this substitution may have on the U.S. feed complex. To compute the overall or aggregate DDGS substitution rate for corn and soybean meal, multiply each type of livestock/poultry's DDGS substitution rate for corn (energy) and soybean meal (protein) times the market share of DDGS consumption by type of livestock/poultry and then sum each of the products.

This report provides a transparent method to estimate the substitution potential of DDGS for corn (energy) and soybean meal (protein) and the corresponding impact this has upon the U.S. feed complex. First, the feeding characteristics of DDGS are reviewed along with potential inclusion rates for each type of livestock/poultry. Second, potential U.S. DDGS inclusion rates per livestock/poultry are determined. Third, substitution rates of DDGS for corn and soybean meal are determined by type of livestock/poultry. Fourth, DDGS consumption estimates (market share) by crop year are estimated by type of livestock/poultry. Fifth, the aggregate substitution of DDGS for corn and soybean meal is computed by multiplying the market share times the substitution rates between DDGS and corn and soybean meal by type of livestock/poultry. Lastly, impacts on the U.S. feed complex are determined from the substitution of DDGS for corn and soybean meal.

[1]In addition to Government policies and higher energy prices in the long run, ethanol production growth depends partly on feedstock costs and changes in technological advancements.

[2]Ethanol production numbers are expressed in terms of the corn crop year (September-August).

[3]Monthly ethanol production data were converted to corn crop years from the usual ethanol calendar year (U.S. Energy Information Administration, 2010).

[4]1 metric ton = 2,204.622 pounds.

[5]Distillers' grains refer to coproducts generated by dry-mill ethanol plants, including distillers' wet grains (DWG), distillers' dried grains (DDG), distillers' wet grains with solubles (DWGS), distillers' dried grains with solubles (DDGS), and condensed distillers' solubles (CDS). Unless otherwise specified, distillers' grains will refer to distillers' dried grains with solubles (DDGS). See Hoffman and Baker (2010) for additional details about the market for distillers' grains. The Renewable Fuels Association (2011) estimates that 61 percent of distillers' grains products were sold in dry form and 39 percent in wet form for calendar year 2010. The USDA report *Ethanol Co-Products Used in Livestock Feed*, summarizes the average annual quantities of these different coproducts fed by selected livestock producers (USDA/NASS, 2007). Since these statistics could not be used to compute the total amount of these feed products consumed by type of livestock/poultry and since there are no reliable statistics on the production of different ethanol coproducts, we had to simplify the estimation process for each coproduct's substitution potential for corn and soybean meal. We converted all coproducts into what we refer to throughout this report as DDGS. Dry matter basis is used to estimate the substitution of DDGS for corn and soybean meal.

[6]New technology will affect the composition of DDGS, and may change the substitution rates for corn and protein meal.

Feeding DDGS to Livestock/Poultry

Feeders that choose to include DDGS into the diets of livestock/poultry need to be aware of DDGS nutritional content and feeding issues related to the use of these nutrients. The amount of DDGS that can be included in the diet of a particular type of livestock/poultry varies by its nutrient requirements and the nutrient availability and cost of alternative diet ingredients.

DDGS Nutritional Content Issues

DDGS are used by the livestock and poultry industries as a source of protein and energy in feed rations. DDGS are considered a mid-protein feed that offers the same or greater energy as corn but contains less protein than soybean meal (table 1). Ruminant animals, such as beef and dairy cattle, can use distillers' grains nutrients more readily than monogastric animals, such as hogs and poultry.[7] Compared with corn, DDGS are higher in calcium, phosphorus, and sulfur (table 1) so that, depending on the inclusion rate, adding DDGS to an animal's diet may negate the need for supplemental phosphorus (Tjardes and Wright, 2002). Since DDGS go through a drying process, overheating may occur and potentially cause a chemical reaction detrimental to DDGS feeding quality. In such cases, some of the carbohydrates and protein in DDGS may become chemically bound, thus making the product indigestible to the animal. Consequently, a lighter colored DDGS may generally be preferable to a darker one that is associated with heat damage.[8]

DDGS can also contain more sulfur than corn, thereby adding significant amounts of sulfur to the diet (Berger and Good, 2007). Sulfuric acid may be used during fermentation of the ethanol feedstock mash for pH adjustment, but that process can increase the sulfur content of the distillers' grains. If cattle consume more than 0.4 percent sulfur (dry matter) from feed and water, they may contract polioencephalomalacia.[9, 10, 11] Some feeders add thiamine to reduce the risk of this disorder, but the proper inclusion level of thiamine and the likelihood of it completely eliminating the disorder is not certain. In addition, excessive sulfur interferes with an animal's ability to absorb copper and its metabolic rate. Thus, in geographic regions with high levels of sulfur in forages and water, feeders may need to reduce the levels of DDGS added to diets.

As mentioned previously, phosphorus levels in DDGS (0.89 percent) are greater than those in corn (0.25 percent) (see table 1), so adding DDGS to an animal's diet may negate the need for phosphorus supplements, which are costly. Phosphorus concentrations may determine inclusion rate in many diets where nutrient management of the waste is a problem.[12] Research is being conducted to develop methods for removing phosphorus from DDGS (Berger and Good, 2007).

The sodium content of DDGS may vary from 0.01 percent to 0.48 percent, averaging 0.11 percent (Shurson and Alghandi, 2008). In comparison, corn contains about 0.02 percent of sodium. Salt is formed as a result of pH adjustments during processing. Salt contains a large amount of sodium and, if poultry are fed sodium above required levels, the resulting increased water consumption may cause wet litter and dirty eggs. Wet litter can encourage

[7]A ruminant is an animal with a rumen compartment in its stomach (e.g., cattle, sheep, goats, deer, elk, and bison). Unlike animals with a single compartment stomach (monogastric), ruminants are able to convert cellulose in its various forms into starches and sugars, which can then be metabolized.

[8]The precise color preferred by some animal feeders may also depend on the livestock/poultry being fed. Also, color may be a function of type of feedstock used, not always an indicator of protein damage.

[9]Dry matter basis means an adjustment is made for the moisture content, compared with an "as fed" or "as is" basis, where no adjustment is made for moisture content.

[10]Polioencephalomalacia (PEM) is a neurologic disease of ruminants. The term PEM denotes a lesion with certain gross and microscopic features. Historically, PEM has been associated with a thiamine (Vitamin B1) deficiency but more recently has been associated with high sulfur intake.

[11]Recent feeding studies indicate that this limit in diets is 0.53 percent (Erickson et al., 2005).

[12]Excessive phosphorus released into the environment (e.g., through animal waste) may contribute to eutrophication in the Nation's lakes and streams (Rausch and Belyea, 2005). Regulations for disposal of animal wastes are becoming increasingly stringent depending on phosphorus content. Since phosphorus content from DDGS is high relative to corn and to requirements of most ruminants, high phosphorus levels in diets can increase phosphorus in animal wastes. Disposal of these wastes must comply with established regulations.

Table 1
Nutrient profiles of selected feedstuffs[1]

Nutrients	Distillers' dried grains with solubles (corn)	Corn (yellow grain)	Soybean meal (dehulled, solvent)	Corn gluten meal	Corn gluten feed	Hominy	Cotton-seed meal (41 percent solvent)	Wheat middlings
				Percent				
Dry matter[2]	92.00	87.00	88.00	90.00	88.00	89.00	90.00	89.00
Crude protein[3]	27.00	7.50	47.80	60.00	21.00	11.50	41.00	15.00
Ether extract[3]	9.00	3.50	1.00	2.00	2.00	6.50	2.10	3.60
Crude fiber[3]	8.50	1.90	3.00	2.50	10.00	5.00	11.30	8.50
Calcium[3]	0.14	0.01	0.20	0.02	0.20	0.05	0.16	0.15
Phosphorus[3]	0.89	0.25	0.65	0.50	0.90	0.50	1.00	0.91
Ruminant digestible protein[3]	21.10	5.80	46.60	47.40	19.30	8.00	29.50	12.20
Ruminant TDN[3]	82.00	80.00	79.00	86.00	75.00	86.00	72.00	81.00
Metabolizable energy for poultry								
Kcal/lb	1,270	1,540	1,115	1,700	795	1,390	915	950
Kcal/kg	2,800	3,390	2,458	3,740	1,750	3,060	2,010	2,090
Metabolizable energy for swine								
Kcal/lb	1,497	1,520	1,425	n/a	1,090	1,530	1,225	1,000
Kcal/kg	3,300	3,350	3,140	n/a	2,400	3,365	2,690	2,200
				Percent				
Methionine (percent)[3]	0.51	0.18	0.70	1.90	0.50	0.22	0.51	0.12
Lysine (percent)[3]	0.80	0.24	3.02	1.00	0.60	0.45	1.70	0.70
Sulfur (percent)[3]	0.30	0.19	0.43	0.50	0.16	[4]	0.30	0.16

Kcal/lb=Kilocalories per pound. Kcal/kg=Kilocalories per kilogram. n/a = Data not available.

[1]All data other than dry matter content are expressed in an "as fed" basis.
[2]Dry matter content of the unit of feed being examined.
[3]Nutrient content of the unit of feed being examined.
[4]Insignificant amount.

Source: Lundeen, p.16, 2011.

greater bacterial growth, increasing an animal's susceptibility to intestinal infections.

Mycotoxins—toxic chemical compounds produced by certain fungi—are also a concern for livestock/poultry feeders (USDA/GIPSA, 2006). Mycotoxins also may be associated with corn ear rot diseases and may be pathogenic for animals and humans (Siegel, 2010). If present in corn, mycotoxins become concentrated in DDGS approximately three-fold during the fermentation process. In addition, mycotoxins can be produced during storage if the distillers' grains are allowed to mold (Whitlow, 2008). The U.S. Food and Drug Administration (FDA) has been responsible for establishing and monitoring acceptable levels of mycotoxins and antibiotics in feedstuffs since 1965 (FDA, 2006). The FDA encourages livestock/poultry feeders to test their feed ingredients, ensuring that mycotoxins do not exceed acceptable levels.

Antibiotics also may be an issue when feeding DDGS (National Grain and Feed Association, 2009). Some U.S. ethanol plants may be using antibiotics as antimicrobials during the fermentation process to control bacterial contamination. The Food and Drug Administration's (FDA) Center for Veterinary Medicine (CVM) is concerned about the possibility of antibiotic residues in DDGS and potential animal and human health consequences (FDA, 2009a). FDA developed and made available a method for the screening, confirmation, and determination of thirteen antibiotics in DDGS (FDA, 2009b). When the distillers' grains are used as a feed or animal food ingredient, the antimicrobial is regulated by the FDA as a food additive (FDA, 2011) unless it is generally recognized as safe (GRAS) for that use (FDA, 2010). In the past, the Center for Veterinary Medicine (CVM) did not object to specific uses of antibiotics through enforcement discretion which was provided on a temporary basis. This enforcement discretion has expired and currently no antibiotic residues are allowed in distillers' grains intended for use as a feed ingredient.

Understanding DDGS Nutrient Variability Is Essential

Because DDGS's nutritional content varies, feeders are urged to use caution before adding them to their animals' diets (Tjardes and Wright, 2002). Actual nutrient analyses of the coproducts intended for use from the truck or railcar can vary widely for batches from the same plant and for batches from different plants. DDGS nutrient concentrations may vary due to changes in the nutrient content of the corn (a 1-percent difference in grain content results in approximately a 3-percent difference in DDGS content) being processed due, in part, to agronomic conditions or corn variety. Additional DDGS nutrient variation may be caused by fermentation and distillation efficiencies, drying processes and temperatures, and/or the amount of condensed distillers' solubles blended into co-products (Shurson and Alghandi, 2008).

Reducing nutrient variation in DDGS has become a higher priority for ethanol producers as margins tighten and producers count on revenue derived from coproducts (DDGS). Consequently, producers strive to provide more uniform quality DDGS. In addition to sampling the specific load of purchased DDGS, feeders can obtain an idea of the DDGS nutrient content from several different sources, such as ethanol plants (University of Minnesota) or from feed analyses (Dairy One).

In addition to issues of product variability, Mathews and McConnell (2009) discuss ethanol feed coproducts in the diets of cattle (beef and dairy) and hogs. The limitations of these coproducts, such as variable moisture content, product availability, and nutrient excesses or deficiencies, affect how they must be handled and stored, impacting costs to feed buyers.

Potential Inclusion Levels of DDGS, by Type of Livestock/Poultry

The amount of DDGS that can be included in the diet of a particular type of livestock/poultry varies by its nutrient requirements, nutrient availability, and cost of alternative diet ingredients. Nutritionists typically use energy, protein, amino acid, and mineral content in balancing livestock/poultry diets.[13] The optimal choice of commodities to supply these ingredients may change over time with the changing prices of competing feed ingredients, the age of the

[13]Diet formulation with specific nutrient requirements by livestock/poultry species along with a nutrient value for selected feed ingredients can be obtained from the National Research Council (1994, 1998, 2000, and 2001) for poultry, swine, beef, and dairy, respectively.

livestock/poultry, or whether the livestock/poultry is used for breeding or market stock.

Many studies that include DDGS in the diet of a particular type of livestock/poultry are conducted only on the basis of meeting nutrient requirements, but some may assume the cost of alternative ingredients. In this section we provide a brief review of the literature on potential inclusion levels of DDGS in diets by type of livestock and poultry.[14] Results may vary based on whether data came from university feeding trials, an experimental setting, or from actual feeding levels by industry. Potential inclusion levels are derived based on the following discussion and will be used later in this study's estimates of potential DDGS feeding by type of livestock/poultry.

[14]This brief review is intended to provide a basic understanding of feeding DDGS to different types of livestock/poultry and does not cover all possible references and information about this feeding. For more information about the physiology of each type of livestock/poultry or why they might consume different amounts of distillers' spent grains, see Tisch (2006).

Beef Cattle—DDGS are a good source of energy and protein for beef cattle in all phases of production (U.S. Grains Council, 2007). Since most of the starch in corn is converted to ethanol during the fermentation process, the fat and fiber concentrations in DDGS are increased by a factor of three compared with that in corn. DDGS contain high amounts of neutral detergent fiber (NDF) but low amounts of lignin, making DDGS a highly digestible fiber source for cattle that reduces digestive upsets compared with corn. The availability of highly digestible fiber in DDGS also allows them to serve as a partial replacement for forages and concentrates (Schingoethe, 2006).

DDGS in beef cattle diets supports inclusion for growing calves, supplementation of grazing and high-roughage diets or low phosphorus diets for beef cows, wintering cows or developing heifers, and fed cattle. DDGS can contribute to lower feed costs, fewer sub-acute acidosis occurrences than from a low-roughage diet, and improved fiber digestion in the rumen (National Corn Growers Association, 2008).[15] Growing and finishing cattle offer the largest potential use of DDGS. Feedlot diets that use DDGS at levels lower than 15-20 percent of diet dry matter serve as a protein source for the animal; at levels higher than 20 percent, DDGS serve as an energy source (Erickson et al., 2007).

[15]Acidosis can be an acute or subacute condition in rumen livestock. Acute acidosis occurs with rapid grain overload and may result in liver abscesses, severe illness, and even death. If these problems are prolonged, the low rumenal pH may damage the rumenal wall and reduce absorption capacity. Thus, even animals that survive may develop chronic conditions. A major symptom of subacute acidosis is reduced feed intake, making it difficult to diagnose and separate from other problems or events that reduce feed consumption, such as digestibility of the grain. Other symptoms include lethargy, diarrhea, panting, excessive salivation, kicking at the belly, and general signs of discomfort and stress.

Finishing cattle have been fed as much as 40 percent DDGS of diet dry matter as an energy source with excellent growth performance (table 2) (U.S. Grains Council, 2007; Klopfenstein, 2008). This inclusion rate, however, creates an excess of protein and phosphorus and may cause waste disposal issues that impact manure management plans. Feeding DDGS does not change the quality or yield of beef carcasses and has no effect on the taste or other sensory characteristics of beef (U.S. Grains Council, 2007).

Klopfenstein et al. (2008) reports on a meta-analysis where various levels of wet distillers' grains were fed to feedlot cattle. Results indicate that wet distillers' grains with solubles produced higher average daily gains and higher feed-to-gain values compared with cattle fed corn-based diets without DDGS. For example, the feeding value of wet distillers' grains with solubles at a 20-percent inclusion level was 142 percent with a decline to 131 percent at the 40-percent inclusion level. A similar analysis of dry distillers' grains with solubles showed a similar positive response but with less feeding value for dry versus wet distillers' grains. For example, the feeding value of DDGS at a 20-percent inclusion rate was 123 percent and at the 40-percent inclusion rate it declined to 100 percent. Erickson et al. (2007) reports that the biological optimum inclusion levels for dry distillers' grains with solubles (DDGS) is 20 percent for cattle on feed; however, higher levels of DDGS inclusion also provide positive feeding values. For wet distillers' grains with solubles, he reports biological optimal inclusion levels of 30 to 40 percent.

Erickson et al. (2005) suggests supplementing protein when finishing cattle diets contain less than 20 percent DDGS, as recommended by the National Research Council (2000). However, Vander Pol et al. (2005) reported that there was no benefit to supplementing finishing cattle diets with urea when diets contained 10-20 percent DDGS.

Forage diets usually maintain beef cows and replacement heifers but may require supplemental protein, energy, and phosphorus to achieve expected maintenance and growth levels. Most forage protein is degraded in the rumen, but cattle also need bypass protein (or protein not degraded in the rumen) (Stanton, 1998). DDGS provide a good source of bypass protein. DDGS fed to cattle grazing high-forage diets increases weight gains and reduces forage consumption, thereby, providing producers with an opportunity to extend the grazing period (U.S. Grains Council, 2007). The U.S. Grains Council (2007) reports that inclusion rates of 10-30 percent yielded

Table 2

Daily DDGS inclusion rates for livestock/poultry as a percent of daily dry matter intake

		Range of selected maximum potential inclusion rates	
Type of livestock/poultry	NASS actual[1]	Low	High
	Percent of dry matter intake		
Beef			
Cows	22	10	30[2]
Replacement heifers	N/A	10	30[2]
Cattle on feed	23	20	40[3]
Other	N/A	10	30[2, 4]
Dairy			
Cows	8	10	30[5]
Replacement heifers	N/A	10	30[5]
Hogs			
Breeding swine	10	10	50[2, 6]
Market swine	10	10	30[2, 6]
Poultry			
Layers	N/A	10	15[2, 7]
Pullets	N/A	10	15[2, 7]
Broilers	N/A	10	15[2, 7]
Turkeys	N/A	10	15[2, 7]

NASS=National Agricultural Statistics Service. N/A=Not applicable.
[1]USDA, NASS, 2007.
[2]U.S. Grains Council, 2007.
[3]Klopfenstein et al., 2008; Erickson et al., 2007.
[4]National Corn Growers Association, 2008.
[5]Schingoethe, 2008.
[6]Stein, 2008.
[7]Bregendahl, 2008.

beneficial results for beef cows and replacement heifers (table 2). Other potential uses of DDGS include feed for nursing and growing calves that require more protein. The National Corn Growers Association (2008) recommends a 10-20 percent inclusion rate for other cattle.

USDA's National Agricultural Statistics Service (NASS) survey, *Ethanol Co-Products Used for Livestock Feed*, provides a 2006 estimate of annual usage and inclusion rate of distillers' grains for cattle and hogs from Midwestern feeders (USDA/NASS, 2007).[16] This survey reported that beef cattle (cow/calf) were fed an average of 396 pounds of DDGS in 2006 at a 22-percent inclusion rate (see table 2). Cattle on feed consumed an average of 916 pounds in 2006 at a dry matter inclusion rate of 23 percent.

Dairy Cattle—DDGS provide a source of protein, fat, phosphorus, and energy for dairy cows. DDGS are a particularly good source of protein for cattle that is undegradable in the rumen (or by-pass protein). DDGS provide high amounts of neutral detergent fiber but offer low amounts of lignin, making them a highly digestible fiber source that reduce digestive upset more effectively than corn. Although they usually replace concentrate ingredients, the highly digestible fiber in DDGS also serves as a partial replacement for forages and concentrates in diets for dairy cattle although they usually replace concentrate ingredients (Shingoethe, 2008). The quality of protein in DDGS is fairly good, but lysine is the first limiting amino acid. (See Shcingoethe (2008) for further discussion of dairy cattle protein needs and amino acids.) Thus, milk production can sometimes be increased when cows are fed rations containing supplemental lysine and methionine that is protected in the rumen or when DDGS are blended with other high-lysine ingredients. Feeding DDGS to dairy cattle results in milk production as high or higher than when dairy cows are fed rations containing soybean meal as the protein source (U.S. Grains Council, 2007).

DDGS inclusion levels are not the only factor to consider when formulating the dairy cow diet. Other factors that could affect milk production and milk composition when DDGS are added to the diet include the type of forage, the ratio of forage to concentrate, the high oil content of DDGS, and the formulation of diets on an amino acid basis. In addition, the nutrient differences between DDGS and WDGS may affect the cow's ability to produce milk.

DDGS can also be used in diets of dairy calves, heifers, and dry cows. Dry cows were fed about 10 percent of dry matter and calves 28 percent. Different levels of DDGS have been fed to dairy heifers along with a blending of other feeds (Schingoethe, 2008).

Milk fat content may decrease if inadequate amounts of forage fiber are fed to dairy cattle. DDGS can be included in dairy cow diets at up to 20 percent of the ration without decreasing dry matter intake, milk production, and milk fat and protein percentage (see table 2). Inclusion of DDGS at 20-30 percent also supports milk production equal to or greater than diets with no DDGS; however, milk production from cows fed diets containing WDGS decreases when fed at more than 20 percent of the diet (U.S. Grains Council, 2007). Thus, dairy producers can feed more than the typical 5-10 percent that many have been feeding. When feeding DDGS at more than 20 percent of the ration, however, DDGS lacks a nutritional advantage because such diets may

[16]This study was a joint effort between USDA's National Agricultural Statistics Service and the Nebraska Corn Development, Utilization & Marketing Board (an agency of the State of Nebraska). Approximately 9,400 livestock operations in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin were contacted by mail in February 2007 with a second mailing 2 weeks later and telephone follow-up in March. Caution should be used while interpreting the results of the survey due to its regional nature.

contain excess protein and phosphorus, even though milk production performance is high with inclusion levels greater than 20 percent (Schingoethe, 2008).

NASS survey results suggest that Midwestern dairy cow feeders fed an average of 1,002 pounds of DDGS during 2006 at a dry matter inclusion rate of 8 percent (USDA/NASS, 2007) (see table 2).

Swine—DDGS can be used in the gestation, lactation, nursery, growing, and finishing diets for swine (Stein, 2008). DDGS can be an economical source of energy, amino acids, and phosphorus for swine. Swine, however, cannot efficiently digest the fiber in DDGS, and the corn oil present in DDGS can potentially affect meat quality. The amount of dicalcium phosphate normally fed can be reduced when feeding DDGS to swine because distillers' grains have a greater level of digestible phosphorus than corn. According to Stein (2008), DDGS included in the diet may have a positive effect on the health of the swine. For example, the incidence and severity of proliferative ileitis, an inflammation of the lower part of the small intestine common in young pigs, can be reduced by including 10 percent DDGS in feed rations.

Wilson et al. (2003) shows that DDGS can be fed to gestating sows at an inclusion rate of up to 50 percent with no negative effects on the animals. DDGS in the diets of gestating sows did not affect lactation feed intake, litter weight gain, and reproduction cycle. Negative effects were not seen in sow gestation weight gain, pigs born alive per litter, litter birth weight, or average pig birth weight for sows fed 0-50 percent of DDGS during gestation. Stein (2008) reports of research results that feeding DDGS to lactating sows at diet inclusion rates from 15 percent to 30 percent resulted in no negative effects. Thus, DDGS can be included in diets of gestating sows at inclusion rates of up to 50 percent and in diets of lactating sows at inclusion rates of up to 30 percent if diets are formulated based on concentrations of digestible energy, amino acids, and phosphorus (Stein, 2008).

Stein (2008) reports the results of eight experiments of DDGS inclusion in nursery pigs. From the day of weaning, a DDGS inclusion rate of 7.5 percent could be included in the diet without negative effects on the animals. Other findings suggest that an inclusion rate of up to 25 percent may be included in the diet during the initial 2 weeks after weaning and an inclusion rate of up to 30 percent may be used 2-3 weeks after weaning with no negative effects on pig performance.

Stein (2008) also reports on research results from feeding DDGS to grow-finish hogs. Generally, there was no change in performance by including DDGS in the diets of grow-finish hogs but there were experiments where reduced performance was observed. Stein (2008) reports of many experiments where DDGS can be included in diets to grow-finish hogs at up to 30 percent without negatively affecting hog performance. For experiments with reduced performance, a linear reduction in pig performance was reported when hogs were fed diets including 10, 20, and 30 percent DDGS. Reduced performance in these cases may have been due to reduced feed intake as a result of reduced DDGS quality or palatability. If DDGS had low lysine digestibility, pig performance could decline because lysine limits protein formation. Also, excessive protein intake could lead to reduced performance.

If this were the case, it is impossible to determine if the performance decline was due to DDGS in the diet or increased crude protein. Including crystalline lysine or tryptophan in hog diets may reduce the negative impact of increasing crude protein (Stein, 2007).

Effects of DDGS upon pig carcass composition and quality are mixed. Stein's (2008) summary of research results found a reduced dressing percentage from grow-finish hogs fed DDGS. These results may be due to increased fiber concentrations in DDGS-containing diets leading to increased intestinal tissue weight and reduced dressing percentage. While DDGS quality or diet formulation may account for these differences, further research is required to determine why the dressing percentage was reduced for some experiments. In approximately half of the experiments, however, the dressing percentage remained the same.

Stein's (2008) summary of research results also indicates that backfat thickness, lean meat percentage, and loin depth were not affected by the inclusion of corn DDGS in hog finishing diets. Some research results did show a decrease in swine belly thickness for some but not all experiments. Other findings showed that including DDGS in diets reduced swine belly firmness and increased iodine values of carcass fat (Stein, 2008). The increased iodine values of carcass fat may be due to the large quantities of unsaturated lipids present in corn DDGS, whereby the lipids are incorporated into carcass fat without hydrogenation. Increased unsaturated fatty acids reduce the firmness of the fat and increase the iodine values.

An experiment by White et al. (2007) demonstrated that the inclusion of 1 percent of conjugated linoleic acid in DDGS-containing diets during the 10 days prior to slaughter may reduce iodine values and could be used to mitigate soft fat in DDGS-fed hogs. Additional research shows that if DDGS are removed from diets in the 3-4 weeks prior to slaughter, acceptable iodine values are reported in pigs fed DDGS during early stages of growth (Hill et al., 2008; Xu et al., 2008).

The U.S. Grains Council (2007) recommends up to 30 percent inclusion of DDGS for nursery pigs. Due to concerns of reduced belly firmness and soft pork fat at higher levels of DDGS inclusion, however, the council recommends a 20-percent inclusion level for grower-finisher and developing gilts. For sows, feeders can include up to 50 percent of DDGS to gestation diets and 20 percent to lactation diets. We assumed that all diets were formulated on a digestible amino acid and available phosphorus basis.

Stein (2008) recommends that approximately 30 percent of DDGS can be included in diets fed to lactating sows, weanling pigs, and grow-finish pigs, and 50 percent can be included in gestating sow diets, assuming average or above-average-quality DDGS are used. USDA, NASS survey results from 2006 provide annual average DDGS consumption rates (60 pounds per head) and the dry matter inclusion percentage (10 percent) for hog diets (USDA/NASS, 2007).

Poultry—Corn DDGS can contribute energy, protein, and phosphorus to poultry diets (Bregendahl, 2008).[17] DDGS inclusion in poultry diets initially was set at a low level due to high fiber, poor amino acid quality, and low

[17]For more information about feeding DDGS to poultry, see Bregendahl (2008).

energy concentration. Bregendahl (2008) reports that energy and amino acid levels in DDGS, however, are higher than indicated by the National Research Council (1994). The phosphorus bioavailability found in DDGS, an economic asset, is higher than in corn and can be used to replace some supplemental phosphorus sources in the diet. Phosphorus is the third most expensive ingredient in poultry rations. Feeding DDGS to poultry may increase sodium intake, and overall sodium intake needs to be monitored in the diets for poultry. High sodium levels cause increased water consumption, potentially causing wet liter, dirty eggs, and susceptibility to intestinal infections (Bregendahl, 2008). Xanthophyll—a carotenoid pigment found in corn—is also found in corn DDGS and has been shown to improve desired egg yolk color (more yellow or red) when fed to laying hens and to increase the yellow skin color of broilers (U.S. Grains Council, 2007).

Layers—Lumpkins et al. (2005) reported that feeding 0-15 percent corn DDGS to laying hens did not affect egg production, egg weight, feed consumption, or feed utilization. Lumpkins et al. (2005) recommended feeding laying hens DDGS at no more than 10-12 percent. Roberson et al. (2005) conducted two experiments of diets that contained 0-15 percent of DDGS and focused on the effects on egg production or yolk color. Roberson et al. (2005) found that including 15 percent of DDGS in the diet did not affect egg production but, due to variable research results, recommended less than 15 percent in the laying hen diet. Both experiments used diets formulated using total amino acids.

Shurson et al. (2003b) conducted a commercial layer feeding trial in Jalisco, Mexico, to evaluate effects on egg production and egg quality by including 10 percent or more of DDGS into the layers' diet under practical feeding conditions. Shurson concluded that including 10 percent DDGS in the layers' diet can significantly improve egg production and egg yolk color.

Since these experiments, Bregendahl (2008) reported that the layer industry in the U.S. Midwest has used diets containing 5-20 percent DDGS with an average of 9 percent. These inclusion rates are affected by economics, as many commercial diets are based on a least-cost basis where the relative prices of all competing ingredients are considered. Furthermore, Bregendahl (2008) reported that the U.S. Midwest laying-hen industry fed DDGS to pullets at the same levels as routinely fed to laying hens, or up to about 15 percent.

Broilers—Lumpkins et al. (2004) focused on feeding inclusion rates of 0, 6, 12, and 18 percent DDGS to young broiler chicks. Body weight and feed utilization were not affected at up to 12 percent DDGS, but gain and feed utilization were reduced when broilers were fed at an inclusion rate of 18 percent, most likely due to an amino acid deficiency in the starter diet. Due to the high fiber content and low amino acid digestibility of DDGS, feeding high levels (25-30 percent) of DDGS to starter broilers is not recommended. Based on this study, researchers recommended a 6-percent inclusion rate of DDGS in starter diets, but grow-finish diets could contain 12-15 percent DDGS. Lumpkin's et al. (2004) study results were confirmed by feeding trials sponsored by the U.S. Grains Council (2007) and conducted in Taiwan. These feeding trials found that growth performance can be maintained when including 10 percent DDGS in the diets of starter, grower, and finisher broiler diets. Results from the Lumpkins et al. (2004) study were obtained from an experiment based on a total amino acid basis. The reduced growth performance found at high levels of DDGS inclusion may be due to amino acid deficiencies (such as lysine or arginine) because of the low amino acid digestibility of DGGS.

Wang et al. (2007a) evaluated the use of constant or increasing levels of DDGS in diets for broilers. Diets were formulated on digestible amino acid basis. Diets containing 15 percent DDGS could be fed throughout the feeding period with no adverse effects on live performance or carcass composition. Inclusion of 30 percent DDGS in the broiler diet during the starter and grower periods, however, reduced body weight, elevated feed conversion, and generally reduced breast meat yield, compared with results found for broilers fed 15 percent DDGS or broilers fed the control diet.

In another study, Wang et al. (2007b) evaluated the effects of moderate to high levels of DDGS in broiler diets and the effects of rapid and multiple changes in the level of DDGS inclusion in the diet during the growth period. Diets ranged from 0 to 30 percent DDGS inclusion and were formulated based on digestible amino acids. Broilers fed diets containing 15 percent DDGS did not differ from the control diet in terms of live performance or carcass characteristics, whether fed on a continuous basis or whether alternated weekly between a 0-15 percent inclusion rate of DDGS. Broilers fed a continuous diet with 30 percent DDGS inclusion experienced significant reductions in body weight, feed intake, and breast meat yield. Broilers fed 0-30 percent DDGS inclusion rates alternating on a weekly basis experienced live performance at about half that of broilers fed diets with inclusion rates of 0-30 percent DDGS continuously and similar to those fed 15-percent inclusion rate on a constant basis, although breast meat yield in the latter case tended to decline. Study results reflect the effective use of diets with 15 percent DDGS inclusion rates and showed that the abrupt removal of this level of DDGS did not adversely affect broiler performance.

Turkeys—Noll (2004) fed turkey toms diets up to 12 percent DDGS during the grower-finisher period and found no difference in body weight gain and feed conversion compared with turkeys fed the control corn-soybean meal diet. Also, the diets had no negative effects on breast meat yield. Roberson (2003) reported that DDGS could be included in turkey diets at the 10-percent level without affecting body weight gain or feed conversion of the turkeys, suggesting that DDGS can successfully be included at a 10-percent level for the grow-finish diets.

The U.S. Grains Council (2007) recommended maximum dietary inclusion levels for DDGS at 10 percent for broilers and turkeys and 15 percent for layers. The council added, however, that higher levels of DDGS can be used successfully with appropriate diet formulation adjustments for energy and amino acids. It further mentioned that diet formulation with DDGS should use digestible amino acid values, especially for lysine, methionine, cystine, and threonine, and minimum acceptable levels for tryptophan and arginine due to the second limiting nature of these amino acids in DDGS protein.

Bregendahl (2008) concludes that DDGS can be fed to broilers, turkeys, and laying hens at the 15-percent inclusion level or higher, when diets are formulated on a digestible-amino-acid basis. He recommends that younger broilers should receive lower inclusion levels, but inclusion levels should be increased as the broiler matures.

The USDA, NASS survey did not report on DDGS fed to poultry.

DDGS Feeding Information

Additional sources of information on feeding DDGS to livestock/poultry can also be obtained from the following references:

- *Journal of Animal Science*: http://jas.fass.org/
- *The Journal of Applied Poultry Research*: http://japr.fass.org/
- *Poultry Scienc*e: http://ps.fass.org/
- *International Journal of Poultry Sciences*: http://www.pjbs.org/ijps/ijps.htm
- *Journal of Dairy Science*: http://www.journalofdairyscience.org/
- Babcock et al. (2008): http://www.card.iastate.edu/books/distillers_grains/
- University of Minnesota: http://www.ddgs.umn.edu/
- University of Illinois: http://ilift.traill.uiuc.edu/distillers/
- University of Nebraska: http://beef.unl.edu/byproducts.shtml
- National Corn Growers Association: http://www.ncga.com/files/pdf/DistillersGrains9-08.pdf
- U.S. Grains Council: http://www.grains.org/ddgs-information/217-ddgs-user-handbook
- Distillers Grain Technology Council: http://www.distillersgrains.org/feedsource/

Furthermore, information may be found at other land grant universities not listed above.

Potential U.S. Feed Consumption of DDGS, by Type of Livestock/Poultry

After examining DDGS inclusion rates in livestock/poultry diets, we estimated the potential daily amount of DDGS fed (as fed basis) and multiplied it by the number of days fed and the number of head fed per crop year (a proxy for the number of head fed equals the inventory number or number slaughtered per year) to arrive at an annual estimate of potential U.S. DDGS feed consumption for a given crop year.[18] We used the low to mid-point range for maximum DDGS inclusion rates established by type of livestock/poultry as identified previously (see table 2).[19] The optimum set of ingredients may change over time depending on changes in the prices of competing feed ingredients, the age of the livestock/poultry, or the intended use of the livestock/poultry (i.e., breeding or market stock). Our estimates of DDGS inclusion in the diets of livestock/poultry are approximations based on literature from livestock/poultry scientists. Consequently, our estimates may not precisely match current feeding levels because higher grain prices tend to increase use of lower priced DDGS in diets of a particular group of livestock/poultry.

[18]See Appendix A for details on estimating daily potential consumption of DDGS by livestock/poultry.

[19]A least-cost feed ration model (Dahlke and Lawrence, 2008) is another method to compute potential DDGS consumption. However, this option and its massive data requirements for national estimates are beyond the scope of this study.

The estimates of potential U.S. DDGS feed consumption are useful in two ways.

- Estimates assist with the market share calculations of U.S. DDGS fed by livestock/poultry species which will be covered later in this report.
- Estimates of potential U.S. DDGS feed consumption provide information on whether rapidly rising levels of DDGS supply will exceed potential feed use.

We relied on a fairly uniform method to estimate potential DDGS consumption:

1. Daily intake of DDGS (on an "as fed" basis) is established for each species (see Appendix A for derivation of these estimates).[20]
2. Daily intake is then multiplied by the days fed per year to derive an annual intake.
3. The annual intake estimate is multiplied by the annual head (specified as an annual inventory number or an annual number produced) of selected beef cattle, dairy cattle, swine, and poultry taken from USDA/NASS (see tables 3 through 7 for all data sources).
4. Summing for each type of livestock/poultry provides an estimation of potential U.S. DDGS consumption levels for the respective crop year.
5. Potential consumption data are based on the assumption that DDGS prices will not be a barrier to feeding DDGS. Currently, higher grain prices may increase DDGS utilization in rations.

[20]We assume a potential inclusion rate that is recommended in the literature. This rate may be the low or mid-point of any suggested maximum potential inclusion rate. In doing so, we realize that actual inclusion in any given diet may be lower or higher than our assumed amounts due to local feed availability or relative prices of feed ingredients.

We estimated potential DDGS consumption by type of livestock/poultry for 5 crop years—2006/07 through 2010/11. Our DDGS estimates of U.S. potential feed use for the past 5 crop years averaged 61.8 million metric tons (mmt), with a range of 60.7-63.2 mmt. These estimates assume a near

Table 3

Potential consumption of U.S. distillers' dried grains with solubles, crop year 2006/07

Type of livestock/poultry	Potential intake of DDGS per day (as fed)[1]	Days fed per crop year	Consumption per head and per crop year[2]	Number of livestock/poultry fed per crop year	Potential DDGS consumption	Share
	-------------Pounds-------------			*1,000 head*	*1,000 metric tons*	*Percent of total*
Beef					**31,178**	**50.1**
Cows	3.55	90	319.8	32,644[3]	4,735	7.6
Replacement heifers	3.89	120	466.6	5,835[3]	1,235	2.0
Cattle on feed	8.51	365	3,105.6	14,647[3]	20,633	33.2
Other	2.80	120	336.5	29,977[3, 4]	4,576	7.4
Dairy					**16,154**	**26.0**
Cows	10.05	365	3,668.6	9,145[3]	15,218	24.5
Replacement heifers	3.98	120	477.5	4,325[3]	937	1.5
Hogs					**7,781**	**12.5**
Breeding swine	1.34	365	488.6	6,133[5]	1,359	2.2
Market swine	0.68	365	249.7	56,688[5]	6,421	10.3
Poultry					**7,063**	**11.4**
Layers	0.026	365	9.4	347,063[6]	1,479	2.4
Pullets	0.017	365	6.3	100,112[6]	287	0.5
Broilers	0.022	49	1.1	8,893,746[7]	4,284	6.9
Turkeys	0.057	147	8.4	265,373[7]	1,013	1.6
				Total	**62,177**	**100.0**

[1]See Appendix A for explanation of daily DDGS potential consumption.
[2]May not be the same animal due to turnover.
[3]Inventory as of January 1, 2007.
[4]Other cattle not in feedlots include other heifers, steers, bulls over 500 pounds, and calves under 500 pounds.
[5]Average quarterly inventory for corn crop year, September-August.
[6]Average monthly (number as of beginning of month) inventory for corn crop year, September-August.
[7]Number produced during crop year (.333 x calendar year number for 2006 + .667 x calendar year number for 2007).

Source: Cattle inventory numbers for 2007 are from *Cattle Final Estimates*, 2004-2008, http://usda.mannlib.cornell.edu/usda/nass/SB989/sb1019.pdf; Quarterly hogs and pigs data from *Hogs and Pigs Final Estimates*, 2004-2007, http://usda.mannlib.cornell.edu/usda/nass/SB986/sb1020.pdf; Layers and pullets data from *Chicken and Egg Annual Summary*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1509; Broilers and turkeys data from P*oultry Production and Value*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1130.

constant daily quantity of DDGS fed and a constant number of days fed for each of the crop years analyzed (first three columns are the same or nearly so in tables 3-7) and assume a variation among crop years due to different numbers of livestock/poultry fed each crop year based on changing inventory or slaughter numbers (column 4 and subsequent calculations in columns 5 and 6 may differ in tables 3 through 7).[21]

[21]These estimates assume a composition of DDGS from dry-mill corn ethanol plants without new technology applied to the production process. Co-products from new technology dry-mill plants are discussed by Hoffman and Baker (2010).

Table 4

Potential consumption of U.S. distillers' dried grains with solubles, crop year 2007/08

Type of livestock/poultry	Potential intake of DDGS per day (as fed)[1]	Days fed per crop year	Consumption per head and per crop year[2]	Number of livestock/ poultry fed per crop year	Potential DDGS consumption	Share
	-------------Pounds-------------			*1,000 head*	*1,000 metric tons*	*Percent of total*
Beef					**31,273**	**49.5**
Cows	3.55	90	319.8	32,435[3]	4,705	7.4
Replacement heifers	3.88	120	466.1	5,647[3]	1,194	1.9
Cattle on feed	8.51	365	3,105.6	14,827[3]	20,886	33.1
Other	2.80	120	336.0	29,454[3, 4]	4,488	7.1
Dairy					**16,362**	**25.9**
Cows	10.05	365	3,668.6	9,257[3]	15,404	24.4
Replacement heifers	3.99	120	478.3	4,415[3]	958	1.5
Hogs					**8,439**	**13.4**
Breeding swine	1.34	365	488.6	6,193[5]	1,373	2.2
Market swine	0.70	365	254.0	61,325[5]	7,067	11.2
Poultry					**7,109**	**11.3**
Layers	0.026	365	9.4	341,733[6]	1,456	2.3
Pullets	0.017	365	6.3	102,847[6]	295	0.5
Broilers	0.022	49	1.1	8,975,134[7]	4,323	6.8
Turkeys	0.057	147	8.4	271,003[7]	1,035	1.6
				Total	**63,184**	**100.0**

[1]See Appendix A for explanation of daily DDGS potential consumption.
[2]May not be the same animal due to turnover.
[3]Inventory as of January 1, 2008.
[4]Other cattle not in feedlots include other heifers, steers, bulls over 500 pounds, and calves under 500 pounds.
[5]Average quarterly inventory for corn crop year, September-August.
[6]Average monthly (number as of beginning of month) inventory for corn crop year, September-August.
[7]Number produced during crop year (.333 x calendar year number for 2006 + .667 x calendar year number for 2007).

Source: Cattle inventory numbers for 2008 are from *Cattle Final Estimates*, 2004-2008, http://usda.mannlib.cornell.edu/usda/nass/SB989/sb1019.pdf; Quarterly hogs and pigs data from *Hogs and Pigs Final Estimates*, 2004-2007, http://usda.mannlib.cornell.edu/usda/nass/SB986/sb1020.pdf; Layers and pullets data from *Chicken and Egg Annual Summary*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1509; Broilers and turkeys data from P*oultry Production and Value*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1130.

Table 5

Potential consumption of U.S. distillers' dried grains with solubles, crop year 2008/09

Type of livestock/poultry	Potential intake of DDGS per day (as fed)[1]	Days fed per crop year	Consumption per head and per crop year[2]	Number of livestock/ poultry fed per crop year	Potential DDGS consumption	Share
	-------------*Pounds*-------------			*1,000 head*	*1,000 metric tons*	*Percent of total*
Beef					**29,831**	**48.3**
Cows	3.55	90	319.8	31,712[3]	4,600	7.4
Replacement heifers	3.89	120	466.5	5,531[3]	1,170	1.9
Cattle on feed	8.51	365	3,105.6	13,856[3]	19,519	31.6
Other	2.81	120	337.4	29,680[3, 4]	4,542	7.3
Dairy					**16,487**	**26.7**
Cows	10.05	365	3,668.6	9,333[3]	15,531	25.1
Replacement heifers	3.98	120	478.0	4,410[3]	956	1.5
Hogs					**8,604**	**13.9**
Breeding swine	1.34	365	488.6	6,020[5]	1,334	2.2
Market swine	0.72	365	262.8	60,974[5]	7,269	11.8
Poultry					**6,898**	**11.2**
Layers	0.026	365	9.4	337,594[6]	1,438	2.3
Pullets	0.017	365	6.3	101,215[6]	290	0.5
Broilers	0.022	49	1.1	8,703,080[7]	4,192	6.8
Turkeys	0.057	147	8.4	255,927[7]	977	1.6
				Total	**61,819**	**100.0**

[1]See Appendix A for explanation of daily DDGS potential consumption.
[2]May not be the same animal due to turnover.
[3]Inventory as of January 1, 2009.
[4]Other cattle not in feedlots include other heifers, steers, bulls over 500 pounds, and calves under 500 pounds.
[5]Average quarterly inventory for corn crop year, September-August.
[6]Average monthly (number as of beginning of month) inventory for corn crop year, September-August.
[7]Number produced during crop year (.333 x calendar year number for 2006 + .667 x calendar year number for 2007).

Source: Cattle inventory numbers for 2009 are from *Cattle,* http://usda.mannlib.cornell.edu/usda/nass/Catt//2010s/2010/Catt-01-29-2010.pdf; Quarterly hogs and pigs data from *Quarterly Hogs and Pigs report*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1086; Layers and pullets data from *Chicken and Egg Annual Summary*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1509; Broilers and turkeys data from P*oultry Production and Value*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1130.

Table 6

Potential consumption of U.S. distillers' dried grains with solubles, crop year 2009/10

Type of livestock/poultry	Potential intake of DDGS per day (as fed)[1]	Days fed per crop year	Consumption per head and per crop year[2]	Number of livestock/ poultry fed per crop year	Potential DDGS consumption	Share
	-------------	*Pounds*	-------------	*1,000 head*	*1,000 metric tons*	*Percent of total*
Beef					**29,484**	**48.5**
Cows	3.55	90	319.8	31,371[3]	4,550	7.5
Replacement heifers	3.90	120	466.1	5,451[3]	1,156	1.9
Cattle on feed	8.51	365	3,105.6	13,642[3]	19,217	31.6
Other	2.81	120	336.0	29,806[3, 4]	4,560	7.5
Dairy					**16,099**	**26.5**
Cows	10.05	365	3,668.6	9,086[3]	15,119	24.9
Replacement heifers	3.98	120	477.3	4,526[3]	980	1.6
Hogs					**8,344**	**13.7**
Breeding swine	1.34	365	488.6	5,837[5]	1,294	2.1
Market swine	0.72	365	262.8	59,138[5]	7,050	11.6
Poultry					**6,820**	**11.2**
Layers	0.026	365	9.4	339,284[6]	1,446	2.4
Pullets	0.017	365	6.3	102,927[6]	295	0.5
Broilers	0.022	49	1.1	8,600,225[7]	4,143	6.8
Turkeys	0.057	147	8.4	245,244[7]	937	1.5
				Total	**60,748**	**100.0**

[1]See Appendix A for explanation of daily DDGS potential consumption.
[2]May not be the same animal due to turnover.
[3]Inventory as of January 1, 2010.
[4]Other cattle not in feedlots include other heifers, steers, bulls over 500 pounds, and calves under 500 pounds.
[5]Average quarterly inventory for corn crop year, September-August.
[6]Average monthly (number as of beginning of month) inventory for corn crop year, September-August.
[7]Number produced during crop year (.333 x calendar year number for 2006 + .667 x calendar year number for 2007).

Source: Cattle inventory numbers for 2010 are from *Cattle*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1017; Quarterly hogs and pigs data from *Hogs and Pigs report*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1086; Layers and pullets data from *Chicken and Egg Annual Summary*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1509; Broilers and turkeys data from P*oultry Production and Value*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1130.

Table 7

Potential consumption of U.S. distillers' dried grains with solubles, crop year 2010/11

Type of livestock/poultry	Potential intake of DDGS per day (as fed)[1]	Days fed per crop year	Consumption per head and per crop year[2]	Number of livestock/ poultry fed per crop year	Potential DDGS consumption	Share
	-------------Pounds-------------			*1,000 head*	*1,000 metric tons*	*Percent of total*
Beef					**29,736**	**48.7**
Cows	3.55	90	319.8	30,865[3]	4,477	7.3
Replacement heifers	3.89	120	466.9	5,158[3]	1,092	1.8
Cattle on feed	8.51	365	3,105.6	14,023[3]	19,754	32.3
Other	2.81	120	337.5	28,830[3, 4]	4,413	7.2
Dairy					**16,216**	**26.5**
Cows	10.05	365	3,668.6	9,150[3]	15,226	24.9
Replacement heifers	3.99	120	478.7	4,557[3]	990	1.6
Hogs					**8,324**	**13.6**
Breeding swine	1.34	365	488.6	5,781[5]	1,281	2.1
Market swine	0.72	365	262.8	59,075[5]	7,043	11.5
Poultry					**6,831**	**11.2**
Layers	0.026	365	9.4	339,073[6]	1,445	2.4
Pullets	0.017	365	6.3	104,204[6]	299	0.5
Broilers	0.022	49	1.1	8,625,200[7]	4,155	6.8
Turkeys	0.057	147	8.4	244,188[7]	933	1.5
				Total	**61,107**	**100.0**

[1]See Appendix A for explanation of daily DDGS potential consumption.
[2]May not be the same animal due to turnover.
[3]Inventory as of January 1, 2011.
[4]Other cattle not in feedlots include other heifers, steers, bulls over 500 pounds, and calves under 500 pounds.
[5]Average quarterly inventory for corn crop year, September-August.
[6]Average monthly (number as of beginning of month) inventory for corn crop year, September-August.
[7]Number produced during crop year (.333 x calendar year number for 2006 + .667 x calendar year number for 2007).

Source: Cattle inventory numbers for 2011 are from *Cattle*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1017; Quarterly hogs and pigs data from *Hogs and Pigs report*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1086; Layers and pullets data from *Chicken and Egg Annual Summary*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1509; Broilers and turkeys data from P*oultry Production and Value*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1130.

The estimated average market share of potential DDGS consumption by type of livestock/poultry for 2006/07 through 2010/11 was 49.0 percent for beef cattle, 26.3 percent for dairy cattle, 13.4 percent for swine, and 11.3 percent for poultry (table 8). In comparison, if we use livestock/poultry numbers from USDA (February 2011) projected for crop year 2020/21 and assume DDGS inclusion rates are similar to our current analysis, we estimate a potential 64 mmt feed consumption of DDGS with a potential set of market shares similar to our average for the past 5 crop years. For example, for 2020/21, we estimated a market share of 49 percent for beef cattle, 25 percent for dairy cattle, 14 percent for hogs, and 12 percent for poultry. Thus, this potential feed quantity and market shares are not much different than the average estimated for the past 5 crop years.

Table 8

Estimates of potential annual DDGS consumption, by selected crop year and type of livestock/poultry

Type of livestock/poultry	2006/07		2007/08		2008/09		2009/10		2010/11		Average of all estimates	
	1,000 metric tons	*Percent*	*1,000 metric tons*	*Percent*	*1,000 metric tons*	*Percent*	*1,000 metric tons*	*Percent*	*1,000 metric tons*	*Percent*	*1,000 metric tons*	*Percent*
Beef	31,178	50.1	31,273	49.5	29,831	48.3	29,484	48.5	29,736	48.7	30,301	49.0
Cows	4,735	7.6	4,705	7.4	4,600	7.4	4,550	7.5	4,477	7.3	4,613	7.5
Replacement heifers	1,235	2.0	1,194	1.9	1,170	1.9	1,156	1.9	1,092	1.8	1,170	1.9
Cattle on feed	20,633	33.2	20,886	33.1	19,519	31.6	19,217	31.6	19,754	32.3	20,002	32.4
Other cattle	4,576	7.4	4,488	7.1	4,542	7.3	4,560	7.5	4,413	7.2	4,516	7.3
Dairy	16,154	26.0	16,362	25.9	16,487	26.7	16,100	26.5	16,216	26.5	16,264	26.3
Cows	15,218	24.5	15,404	24.4	15,531	25.1	15,119	24.9	15,226	24.9	15,300	24.8
Replacement heifers	937	1.5	958	1.5	956	1.5	980	1.6	990	1.6	964	1.6
Hogs	7,781	12.5	8,439	13.4	8,604	13.9	8,344	13.7	8,324	13.6	8,298	13.4
Breeding swine	1,359	2.2	1,373	2.2	1,334	2.2	1,294	2.1	1,281	2.1	1,328	2.1
Market swine	6,421	10.3	7,067	11.2	7,269	11.8	7,050	11.6	7,043	11.5	6,970	11.3
Poultry	7,063	11.4	7,109	11.3	6,898	11.2	6,820	11.2	6,831	11.2	6,944	11.2
Layers	1,479	2.4	1,456	2.3	1,438	2.3	1,446	2.4	1,445	2.4	1,453	2.4
Pullets	287	0.5	295	0.5	290	0.5	295	0.5	299	0.5	293	0.5
Broilers	4,284	6.9	4,323	6.8	4,192	6.8	4,143	6.8	4,155	6.8	4,220	6.8
Turkeys	1,013	1.6	1,035	1.6	977	1.6	937	1.5	933	1.5	979	1.6
Total	62,177	100.0	63,184	100.0	61,819	100.0	60,748	100.0	61,107	100.0	61,807	100.0

Crop year: 2006/07 through 2010/11.

Note: Totals may not add due to rounding.

Sources: USDA, Economic Research Service calculations based on data from tables 3, 4, 5, 6, and 7.

Our estimates of U.S. DDGS potential consumption exceeded similar estimates found in the literature. For example, some recent estimates averaged 46.7 mmt, with a range of 35.2-55.3 mmt (table 9) (Dhuyvetter et al., 2005; Berger and Good, 2007; Dooley, 2008; Fox, 2008). These potential U.S. DDGS consumption estimates from the literature were for calendar years 2007 or 2008, or an average of earlier years, 2000-2004. Our analysis focused on the 5 different crop years—2006/07 through 2010/11—that represent a period of accelerating DDGS production. In addition to the effects of using different study periods, several other items account for differences between our study estimates and those found in the literature. First, the average potential consumption for dairy cattle and hogs from these selected studies was about half the estimated potential consumption for dairy cattle and hogs in our study, primarily due to a much lower DDGS inclusion rate for dairy cattle and hogs. Also, Dooley (2008) and Fox (2008) applied a DDGS usage adoption rate of less than 100 percent by type of livestock/poultry, which automatically would lower final estimates of potential DDGS consumption.[22] In contrast, our study did not use adoption rates due to lack of data but instead relied on DDGS potential inclusion rates that reflected the

[22]Dooley (2008) computed an adoption rate based on the livestock/poultry herd/flock size and its ability to consume a truckload of DDGS. While this is a plausible approach, it raises questions about smaller dairy or beef cow farms/ranches that consume DDGS in less than a truckload lot. For example, many smaller dairy farms can consume DDGS by having less than truckload quantities mixed and delivered with their typical concentrates. Fox (2008) used adoption rates derived from the 2007 USDA, NASS survey and applied these somewhat dated adoption rates to estimates of potential DDGS consumption for calendar year 2008.

Table 9

Selected studies from the literature that estimate potential annual DDGS consumption, by type of livestock/poultry

Livestock class	Dhuyvetter et al.		Berger and Good		Dooley		Fox		Average of all estimates	
	Calendar year									
	2000-04 average		2007		2008		2008			
	1,000 metric tons	*Percent*	*1,000 metric tons*	*Percent*	*1,000 metric tons*	*Percent*	*1,000 metric tons*	*Percent*	*1,000 metric tons*	*Percent*
Beef cattle	29,446	63.1	38,709	70.0	34,524	69.1	20,774	59.1	30,863	65.4
Beef cows	9,803	21.0	10,859	19.7	5,703	11.4	4,807	13.7	7,793	16.4
Cattle on feed	12,261	26.3	15,450	28.0	16,591	33.2	12,761	36.3	14,266	30.9
Other cattle	7,381	15.8	12,400	22.4	12,230	24.5	3,206	9.1	8,804	18.0
Dairy cattle	6,276	13.5	6,779	12.3	5,347	10.7	7,693	21.9	6,524	14.6
Dairy cows	6,276	13.5	6,779	12.3	5,347	10.7	7,693	21.9	6,524	14.6
Swine	3,663	7.9	3,824	6.9	3,842	7.7	3,677	10.5	3,752	8.2
Breeding swine	1,037	2.2	1,031	1.9	973	1.9	642	1.8	921	2.0
Market swine	2,626	5.6	2,793	5.1	2,869	5.7	3,035	8.6	2,831	6.3
Poultry	7,245	15.5	5,950	10.8	6,215	12.4	3,014	8.6	5,606	11.8
Broilers	4,486	9.6	4,263	7.7	3,709	7.4	1,809	5.1	3,567	7.5
Layers	1,818	3.9	1,686	3.1	1,644	3.3	683	1.9	1,458	3.0
Pullets	161	0.3			104	0.2			133	0.1
Turkeys	780	1.7			757	1.5	522	1.5	686	1.2
Total	46,630	100.0	55,261	100.0	49,929	100.0	35,158	100.0	46,744	100.0

Note: Totals may not add due to rounding.

Sources: Dhuyvetter et al., 2005; Berger and Good, 2007; Dooley, 2008; Fox, 2008.

low to mid-point range of maximum DDGS inclusion rates. Our approach also recognizes the DDGS feeding constraints as identified in USDA, NASS (2007). Furthermore, our study did not include DDGS usage in sheep, goats, fish, and horses for which DDGS feeding levels have been established, nor did the Berger and Good (2007) and Dooley (2008) studies, but the Dhuyvetter et al. (2007) and Fox (2008) studies included sheep and lambs.

Our estimated average potential U.S. DDGS feed consumption was 61.8 mmt for 2006/07 through 2010/11, an amount much higher than the estimated DDGS supply of 37.4 mmt for 2010/11 or a DDGS supply of 42.5 mmt from an assumed production of 15 billion gallons of corn-based ethanol.[23] These estimates also support Hoffman and Baker's (2010) findings that projected DDGS supplies would not exceed potential U.S. DDGS feed consumption. Furthermore, in addition to providing a measure of domestic feeding potential, their estimates identify a sizable export potential.

[23]If we assume 15 billion gallons of corn-based ethanol are produced, corn use for dry-mill fuel ethanol would total 5.17 billion bushels (2.7 gallons ethanol per bushel of corn and 93 percent of ethanol produced from dry-mill plants), or 41.0 mmt, 1 mmt from beverage distilleries, and .5 mmt from imports equal a total supply of about 42.5 mmt.

Substitution Rates of DDGS for Corn and Soybean Meal, by Type of Livestock/Poultry

One of the major variables needed to compute the aggregate substitution rate of DDGS for corn and soybean meal is the substitution rate by type of livestock/poultry. Substitution rates of DDGS for corn and soybean meal vary by type of livestock/poultry. This substitution calculation takes into consideration the nutrient requirements of each type of livestock/poultry. The estimates we used were taken from the literature.

Two alternative sets of estimates are provided. The first set of estimates (alternative #1) was developed based on conservative substitution assumptions. The second set (alternative #2) is considered the substitution potential for current conditions. For example, these substitution rates reflect improved beef cattle and dairy cattle performance from feeding DDGS, which led to faster weight gain for beef cattle and increased milk production for dairy cattle. Substitution rates may change in the future based on new research from the animal science community. Based on our findings, we formed a range of substitution rates (table 10) and later demonstrate the effect that such a range has on the aggregate substitution rate of DDGS for corn and soybean meal.

Alternative #1 Substitution Rates—Based on the substitution rates found in table 10, 1 pound of DDGS could replace mostly corn and soybean meal and some other items, depending on the type of livestock/poultry (table 10). For example, DDGS replaced some dicalcium phosphate but also required some additional limestone in swine diets. The substitution rate of DDGS for corn or soybean meal, however, differs by each type of livestock/poultry. Therefore,

Table 10

DDGS substitution rates for corn and soybean meal, by type of livestock/poultry

One pound of DDGS substitutes for how many pounds of corn and soybean meal?

Alternative substitution rates	Type of livestock/poultry			
	Beef cattle	Dairy cattle	Swine	Poultry[1]
	Pounds			
Alternative #1				
Corn	1.00	0.45	0.89	0.51
Soybean meal	0.00	0.55	0.10	0.50
Total	1.00	1.00	0.99	1.01
Alternative #2				
Corn	1.20	0.73	0.70	0.61
Soybean meal	0.00	0.63	0.30	0.44
Total	1.20	1.36	1.00	1.05

[1]Weighted average substitution rates based on layers, broilers, and turkeys. Weights based on inventory numbers or slaughter numbers for 2006/07.

Source: Alternative #1: Beef cattle data from Vander Pol et al., 2006; Trenkle, 2003. Dairy cattle data from Anderson et al., 2006. Swine data from Shurson et al., 2002 and 2003. Poultry data from Lumpkins et al., 2004 and 2005; Roberson, 2003. Alternative #2: Beef and dairy cattle data from Arora et al., 2008. Swine and poultry data from Shurson, March and August 2009.

to derive an aggregate substitution rate of DDGS for corn and soybean meal, substitution rates for each major type of livestock/poultry must be examined.

Beef Cattle–One pound of DDGS or WDGS can replace 1 pound of corn for 10-40 percent of diet dry matter intake and generally zero to minimal amounts of soybean meal or urea (Vander Pol et al., 2006; Trenkle, 2003).

Dairy Cattle—One pound of DDGS or WDGS can substitute for 0.45 pounds of corn and 0.55 pounds of soybean meal for up to 20 percent of the dry matter intake for dairy cattle diets (Anderson et al., 2006).[24]

[24]Feeding studies at South Dakota State University have also shown that DDGS and soy hulls can replace all soybean meal (Staff, 2011).

Swine—One pound of DDGS can generally substitute for 0.89 pounds of corn and 0.10 pounds of soybean meal for up to 20 percent of the swine diet (nursery, grow-finish, developing gilts, and lactating sows) (Shurson et al., 2002 and 2003a).

Poultry—For layers, 1 pound of DDGS can replace about 0.46 pounds of corn and 0.54 pounds of soybean meal for up to 12-15 percent of the diet (Lumpkins et al., 2005). We applied these same substitution rates to pullets. For broilers, 1 pound of DDGS can replace about 0.51 pounds of corn and 0.50 pounds of soybean meal for up to 15 percent of the diet during the grower and finisher periods (Lumpkins et al., 2004). For turkeys, 1 pound of DDGS can replace about 0.58 pounds of corn and 0.465 pounds of soybean meal for up to 10 percent of the grow-finish diet (Roberson, 2003). A weighted average (based on inventory numbers or numbers slaughtered for 2006/07) represents all poultry, and 1 pound of DDGS can replace 0.51 pounds of corn and 0.50 pounds of soybean meal.

Alternative #2 Substitution Rates—More recent estimates of the substitution rate of DDGS for corn and soybean meal reveal that 1 pound of DDGS replaces more than a pound of corn and soybean meal combined for beef and dairy cattle (see table 10). However, 1 pound of DDGS was found to continue to replace about a pound of corn and soybean meal combined for swine and poultry.

Arora et al. (2008) found that feeding distillers' grains to beef and dairy cattle leads to improved animal performance in terms of faster weight gain for beef cattle and increased milk production for dairy cattle. Earlier estimates did not account for this performance improvement. For beef cattle, researchers estimated that 1 pound of DDGS substitutes for 1.196 pounds of corn and 0.056 pounds of urea. For dairy cattle, they reported that 1 pound of DDGS substituted for 0.731 pounds of corn and 0.633 pounds of soybean meal. Both the beef and dairy cattle estimates were weighted for the feeding of both DDGS and WDGS. Arora et al. claimed that swine growth performance remains unchanged from earlier estimates, supporting substitution rates at 1 pound of DDGS for 0.89 pounds of corn and 0.10 pounds of soybean meal for up to 15 percent of the swine ration. Their data did not provide DDGS substitution rates for poultry.

More recently, Shurson (March 2009 and August 2009) provided updated substitution rates of DDGS for corn and soybean meal by type of livestock/poultry (see table 10). Shurson's substitution estimates for both beef and dairy cattle agree with Arora et al. (2008) when accounting for substantially higher energy values, undegradeable protein in the rumen, and improved performance when feeding DDGS to cattle. Shurson's findings show that 1 pound of DDGS substitutes for 1.196 pounds of corn and 0.056 pounds of urea (nonprotein nitrogen) in beef cattle diets. Similarly, 1 pound of DDGS substitutes for 0.731 pounds of corn and 0.633 pounds of soybean meal in dairy cow diets. Shurson provides a set of substitution rates for hogs and poultry that differ from earlier estimates found in the literature. Compared with cattle, the energy value and protein quality of DDGS is lower for swine and poultry, but this fact has not limited the use of DDGS in swine and poultry rations. One advantage of feeding DDGS to swine and poultry is the reduction in inorganic phosphate supplementation. In swine diets, Shurson (March 2009) calculated that 1 pound of DDGS substitutes for 0.699 pounds of corn, 0.295 pounds of soybean meal, and 0.03 pounds of inorganic phosphate, with small supplementation of synthetic amino acids and calcium necessary. For poultry, Shurson (March 2009) found that 1 pound of DDGS can replace 0.608 pounds of corn and 0.438 pounds of soybean meal for layers. For broilers, he found that 1 pound of DDGS can replace 0.612 pounds of corn and 0.44 pounds of soybean meal. For turkeys, Shurson (March 2009) found that 1 pound of DDGS can replace 0.547 pounds of corn and 0.460 pounds of soybean meal. He then computed a simple average for a composite set of substitution rates for poultry. For example, 1 pound of DDGS replaced 0.589 pounds of corn and 0.446 pounds of soybean meal and 0.02 lbs of inorganic phosphate, or up to 20 percent of the ration, with small supplementation of synthetic amino acids, fat, and calcium necessary. Instead, we have computed a weighted average (based on inventory numbers or numbers slaughtered for 2006/07) substitution rate for poultry with 1 pound of DDGS replacing 0.61 pounds of corn and 0.44 pounds of soybean meal (see table 10).

U.S. DDGS Feed Consumption (Market Share), by Type of Livestock/Poultry

The second major variable needed to compute the aggregate substitution rate of DDGS for corn and soybean meal is the market share of DDGS consumption for each type of livestock/poultry. These estimates must be computed since an official Government source does not provide these statistics.[25] Market share estimates of U.S. DDGS feed consumption by type of livestock/poultry for 2006/07 were estimated based on information contained in the 2007 USDA/NASS survey and information contained in table 11 (table 12). Market share estimates for the remaining crop years—2007/08 through 2010/11—were estimated based on the allocation of remaining potential consumption (potential minus actual consumption) by type of livestock/poultry multiplied by the annual increase of U.S. DDGS feed use (table 13).

[25]One survey provided DDGS consumption estimates for beef cattle, fed cattle, dairy cattle, and swine for selected States in calendar year 2006 (USDA/NASS, 2007). However, estimates for poultry were not made. This survey focused on a selected number of Midwestern States, but lacks a national scope.

Beef cattle were estimated to consume about 66 percent of the DDGS fed in 2006/07 followed by dairy cattle at 24 percent, hogs at 6 percent, and poultry at 4 percent (table 12). In 2010/11, we estimated that beef cattle continued to consume more DDGS than any other type of livestock/poultry in the 5-year analysis period. While the market share for beef cattle is estimated to have declined to 56 percent over the period, that for dairy cattle, hogs, and poultry increased. Dairy cattle ranked second in estimated consumption of U.S. DDGS during the study period and saw market share of DDGS consumption rise from 24 to 27 percent. Although DDGS were first fed to dairy cattle from beverage distilleries and now corn dry-mill ethanol plants, beef cattle show greater DDGS consumption potential than dairy cattle because beef cattle far outnumber dairy cattle. Hogs ranked third with a market share of 6 percent in 2006/07, increasing to 10 percent in 2010/11, as inclusion rates rose along with research demonstrating DDGS potential in swine diets. Poultry ranked fourth with an estimated market share of 5 percent in 2006/07, increasing to 7 percent in 2010/11. Continuing research demonstrates that DDGS inclusion rates for poultry could increase from around the 5-10 percent range to a range of 10-15 percent and above.

The growth potential for U.S. feed consumption of DDGS is expected to follow a similar trend, with beef cattle consuming the majority of DDGS, followed by dairy cattle, swine, and poultry (table 13).[26] Some in industry or other researchers believe that consumption of DDGS by dairy cattle is nearing maximum use levels (Deutscher, 2009; Dooley, 2008). We do not find such a constraint at this time. Dooley mentions that dairy cattle, beef cattle, hogs, and poultry will be constrained by smaller operations in their inability to use truckload lots. We would argue that smaller farms could find alternate solutions. For example, DDGS can be mixed in with the concentrate mix and delivered to the farm and stored in the working storage located on the farm. For some beef cow operations, DDGS can be fed in range cubes, stored in bunker silos as is, or mixed with other materials, such as straw or corn fodder.

[26]The greatest potential for increased DDGS feeding remains with beef cattle. For example, based on an assumed production level of 15 billion gallons of ethanol and estimated domestic consumption levels of 31.5 mmt, the market share by type of livestock/poultry is estimated to be 55.7 percent for beef cattle, 27.2 percent for dairy cattle, 10.5 percent for swine, and 6.6 percent for poultry (table 13).

Table 11

Supply and disappearance of corn-based distillers' grains

Marketing year	Supply: Production: Distillers' spent grains from beverage distilleries	Percent of total production	Supply: Production: Distillers' spent grains from dry-mill plants producing fuel ethanol[1]	Percent of total production	Supply: Production: Total	Percent of total supply	Supply: Imports: Brewers' and distillers' dregs and wastes[2,3]	Percent of total supply	Supply: Total	Disappearance: Feed and residual	Percent of total disappearance	Disappearance: Exports: Brewers' and distillers' dregs and wastes[2]	Percent of total disappearance	Disappearance: Total
	mmt	*Percent*	*mmt*	*Percent*	*mmt*	*Percent*	*mmt*	*Percent*	*mmt*	*mmt*	*Percent*	*mmt*	*Percent*	*mmt*
1992/93	0.8	40	1.2	60	2.0	97	0.1	3	2.1	2.1	100	0.0	0	2.1
1993/94	0.6	27	1.6	73	2.2	96	0.1	4	2.3	2.1	92	0.2	8	2.3
1994/95	0.5	35	1.0	65	1.5	94	0.1	6	1.6	0.9	55	0.7	45	1.6
1995/96	0.8	77	0.2	23	1.0	93	0.1	7	1.1	0.5	41	0.6	59	1.1
1996/97	0.8	64	0.5	36	1.3	91	0.1	9	1.4	0.8	53	0.7	47	1.4
1997/98	0.9	52	0.8	48	1.6	94	0.1	6	1.7	1.1	65	0.6	35	1.7
1998/99	0.8	47	1.0	53	1.8	93	0.1	7	1.9	1.2	62	0.7	38	1.9
1999/00	0.9	51	0.9	49	1.7	92	0.1	8	1.9	1.1	59	0.8	41	1.9
2000/01	0.9	36	1.6	64	2.5	95	0.1	5	2.6	1.8	70	0.8	30	2.6
2001/02	0.9	31	2.0	69	2.9	96	0.1	4	3.0	2.1	72	0.9	28	3.0
2002/03	0.9	17	4.3	83	5.2	98	0.1	2	5.3	4.6	86	0.8	14	5.3
2003/04	0.9	13	6.1	87	7.0	99	0.1	1	7.1	6.4	90	0.7	10	7.1
2004/05	0.9	11	7.3	89	8.2	99	0.1	1	8.3	7.4	88	1.0	12	8.3
2005/06	0.9	9	9.5	91	10.4	99	0.1	1	10.5	9.3	88	1.2	12	10.5
2006/07	0.9	7	13.2	93	14.1	99	0.2	1	14.3	12.5	88	1.8	12	14.3
2007/08	0.9	4	20.5	96	21.4	100	0.1	0	21.5	17.6	82	3.9	18	21.5
2008/09	0.9	3	25.6	97	26.5	99	0.3	1	26.8	21.8	81	5.0	19	26.8
2009/10	0.9	3	32.5	97	33.4	99	0.4	1	33.8	25.5	75	8.3	25	33.8
2010/11[4]	0.9	2	36.1	98	37.0	99	0.4	1	37.4	29.1	78	8.3	22	37.4

mmt=Million metric tons.

[1]Does not account for noncorn spent grains.

[2]Assumes brewers spent grains are minor.

[3]May contain noncorn brewers' and distillers' dregs and wastes.

[4]Estimates from the September 12, 2011 WASDE and Feed Grains Database.

Source: Update of Hoffman and Baker (table 1, p. 5, 2010)

Estimation Methodology

We used results from a survey that reported DDGS feeding by type of livestock to estimate consumption by type of livestock for crop year 2006/07 (USDA, NASS, 2007). We multiplied the reported amounts of DDGS fed per crop year per animal by the number of head per crop year (specified as an annual inventory number or an annual number produced) and by the adoption rate (table 12). Since this survey did not report DDGS usage by poultry, we computed it as the difference between the total DDGS consumed in 2006/07 less amounts consumed by beef cattle, dairy cattle, and swine in that crop year (table 12). We assumed inclusion amounts as listed in table 3 for each of the different types of poultry and the adoption rate (8 percent) was a residual figure required to equal the total amount fed to all types of poultry.

Table 12

Estimated actual consumption of U.S. distillers' dried grains with solubles, by type of livestock/poultry, 2006/07 crop year

Type of livestock/poultry	Annual DDGS consumption per head[1, 2]	Adoption rate[3]	Number of livestock/ poultry fed per crop year	2006/07 acutal DDGS consumption	Share
	Pounds	*Percent*	*1,000 head*	*1,000 metric tons*	*Percent of total*
Beef				**8,203**	**65.5**
Cows	396	43	32,644[4]	2,521	20.1
Replacement heifers	396	43	5,835[4]	451	3.6
Cattle on feed	916	70	14,647[4]	4,260	34.0
Other	166	43	29,977[4, 5]	971	7.7
Dairy				**2,960**	**23.6**
Cows	1002	60	9,145[4]	2,494	19.9
Replacement heifers	396	60	4,325[4]	466	3.7
Hogs				**804**	**6.4**
Breeding swine	60	47	6,133[6]	78	0.6
Market swine	60	47	56,688[6]	725	5.8
Poultry				**563**	**4.5**
Layers	9.4	8[7]	347,063[8]	115	0.9
Pullets	6.3	8[7]	100,112[8]	22	0.2
Broilers	1.1	8[7]	8,893,746[9]	346	2.8
Turkeys	8.4	8[7]	265,373[9]	79	0.6
			Total	**12,529**	**100.0**

[1]Numbers for beef, dairy, and hogs taken from USDA, NASS (2007). Poultry numbers (potential) taken from table 3.
[2]May not be the same animal due to turnover.
[3]Numbers for beef, dairy, and hogs taken from USDA, NASS (2007). Poultry adoption rate was computed (see text for method).
[4]Inventory as of January 1, 2007.
[5]Other cattle not in feedlots include other heifers, steers, bulls over 500 pounds, and calves under 500 pounds.
[6]Average quarterly inventory for corn crop year, September - August.
[7]Represents an adoption rate necessary for total consumption minus amounts consumed by beef, dairy, and hogs to equal the amount consumed by poultry.
[8]Average monthly (number as of beginning of month) inventory for corn crop year, September - August.
[9]Number produced during crop year (.333 x calendar year number for 2006 + .667 x calendar year number for 2007).

Source: Cattle inventory numbers for 2007 from Cattle Final Estimates, 2004-2008, http://usda.mannlib.cornell.edu/usda/nass/SB989/sb1019.pdf; Quarterly hogs and pigs data from Hogs and Pigs Final Estimates, 2004-2007, http://usda.mannlib.cornell.edu/usda/nass/SB986/sb1020.pdf; Layers and pullets data from Chicken and Egg Annual Summary, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1509; Broilers and turkeys data from Poultry Production and Value, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1130.

The resulting market share for each class of livestock/poultry for 2006/07 was then computed by dividing the amount of DDGS fed to each type of livestock/poultry by the estimated total U.S. DDGS feed consumption for that year (table 12).

DDGS feed use and market shares were computed for the remaining crop years 2007/08 through 2010/11 (table 13, column 1). We calculated these numbers for each crop year based on annual DDGS feed use per year (table 11) and each crop year's remaining adoption potential (potential consumption (table 13, column 2) - actual DDGS feed consumption (table 13, column 3) = remaining potential consumption) for each type of livestock/poultry

Table 13

Estimated quantity and market share of U.S. distillers grains fed, by type of livestock/poultry, crop years 2006/07 through 2010/11[1]

Crop year by type of livestock/poultry	Column 1		Column 2	Column 3	Column 4	Column 5	Column 6
	Estimated quantity and market share of DDGS fed[2]		Estimated potential DDGS to be fed	(-) Less: estimated DDGS fed[2]	(=) equals remaining DDGS feed potential[3]	Percent of remaining potential to be fed	Allocation of change in DDGS fed next year[4]
	mmt	*Percent*	*mmt*			*Percent*	*mmt*
2006/07							
(from table 12)			(from table 3)				
Beef	8.2	65.5	31.2	8.2	23.0	51.5	2.6
Dairy	2.9	23.6	16.1	2.9	13.2	29.5	1.5
Swine	0.8	6.4	7.8	0.8	5.3	11.7	0.6
Poultry	0.6	4.5	7.1	0.6	3.3	7.3	0.4
Total	12.5	100.0	62.2	12.5	44.7	100.0	5.1
2007/08			(from table 4)				
Beef	10.8	61.5	31.3	10.8	20.5	50.2	2.1
Dairy	4.4	25.0	16.4	4.4	12.0	29.4	1.2
Swine	1.4	7.9	8.4	1.4	5.3	12.9	0.5
Poultry	1.0	5.5	7.1	1.0	3.1	7.5	0.3
Total	17.6	100.0	63.2	17.6	40.8	100.0	4.2
2008/09			(from table 5)				
Beef	12.9	59.3	29.8	12.9	16.9	47.5	1.8
Dairy	5.6	25.9	16.5	5.6	10.9	30.6	1.1
Swine	1.9	8.9	8.6	1.9	5.0	14.1	0.5
Poultry	1.3	5.9	6.9	1.3	2.8	7.9	0.3
Total	21.8	100.0	61.8	21.8	35.5	100.0	3.7
2009/10			(from table 6)				
Beef	14.7	57.6	29.5	14.7	14.8	47.6	1.7
Dairy	6.8	26.6	16.1	6.8	9.3	30.0	1.1
Swine	2.5	9.6	8.3	2.5	4.4	14.1	0.5
Poultry	1.6	6.2	6.8	1.6	2.6	8.4	0.3
Total	25.5	100.0	60.7	25.5	31.1	100.0	3.6
2010/11			(from table 7)				
Beef	16.4	56.4	29.7	16.4	13.3	47.3	1.1
Dairy	7.9	27.0	16.2	7.9	8.3	29.7	0.7
Swine	3.0	10.2	8.3	3.0	4.0	14.2	0.3
Poultry	1.9	6.5	6.8	1.9	2.5	8.8	0.2
Total	29.1	100.0	61.1	29.1	28.1	100.0	2.4
15 billion gallon ethanol production level[5]							
Beef	17.5	55.7		17.5			
Dairy	8.6	27.2		8.6			
Swine	3.3	10.5		3.3			
Poultry	2.1	6.6		2.1			
Total	31.5	100.0		31.5			

mmt=Million metric tons.

[1]Some columns may not sum due to rounding.

[2]Estimates of total U.S. DDGS fed comes from table 11.

[3]Remaining potential to be fed = (estimated potential to be fed minus estimated quantity fed) for beef, dairy, swine, and poultry. Remaining potential was reduced for swine and poultry. Swine was reduced by 25 percent per year because of industry concern that excessive oil would cause soft meat. Poultry was reduced by 50 percent per year because of slow adoption reported by industry.

[4]The allocation of change in DDGS fed the next year was based on the proportion of the remaining potential to be fed for the current year.

[5]If one were to assume 15 billion gallons of corn-based ethanol would be produced, corn use for this dry-mill fuel ethanol could total 5.17 billion bushels (2.7 gallons ethanol per bushel of corn and 93 percent of ethanol produced from dry-mill plants) which would produce about 41.0 mmt plus 1 mmt from beverage distilleries and .5 mmt from imports = about 42.5 mmt supply. From this supply, we subtract an estimated 11 mmt of exports and arrive at an estimated 31.5 mmt of DDGS fed under these assumptions.

Source: Calculations by USDA's Economic Research Service.

(see table 13, column 4). The proportion of this remaining potential by type of livestock/poultry was used to allocate (see table 13, column 5) the change in DDGS feed consumption for the next year (see table 13, column 6).[27] Thus, the sum of the current year's estimated DDGS feed consumption (see table 13, column 3) and the allocated change in total consumption for the upcoming year (see table 13, column 6) was equal to the upcoming year's DDGS feed consumption (see table 13, column 1 and 3). Adoption rates were not assumed for this calculation since potential consumption by type of livestock/poultry could be greater than or less than the estimated amount. The DDGS inclusion rate used for potential DDGS consumption (see table 13, column 2) was on the low to mid-part of a range of maximum inclusion rates. Previous market experience has shown that both DDGS inclusion levels and adoption increased when grain prices are higher. [28]

The share of remaining potential to be fed by type of livestock/poultry is shown in table 13, column 5. These numbers tend to differ somewhat by crop year but were used to allocate the change in annual feed consumption of DDGS to the different types of livestock/poultry. For example, in 2010/11, the percentage of remaining potential to be fed for beef, dairy, swine, and poultry was 48, 30, 14, and 9 percent, respectively. These shares are then used to allocate, by type of livestock/poultry, the increase in DDGS feed consumption for 2011/12.

As seen in table 13, actual U.S. feed use of DDGS by type of livestock/poultry remains below U.S. potential feed use. We use this remaining potential feed consumption to allocate the annual increase in DDGS feed consumption by type of livestock/poultry. Others have allocated annual increases in domestic DDGS feed consumption by assuming a fixed percentage by type of livestock/poultry (see Westcott, 2008). In contrast, Dooley (2008) reduced his potential DDGS feed consumption numbers by assuming farms will require a minimum of a truckload, creating an adoption rate by type of livestock/poultry.

In addition to our estimates of DDGS consumption (market share) by type of livestock/poultry, other estimates are available in the literature. For example, one set of estimates is available from the Renewable Fuels Association, although it is generally produced in conjunction with CHS, Inc.[29] Annual calendar year estimates can usually be obtained from annual industry outlook reports (Renewable Fuels Association, various years). For comparability with corn supply and demand estimates, we converted these estimates from a calendar year to a corn crop year (table 14). Another set of estimates comes from Wisner (2011) and listed in table 14. Compared with the other market share estimates, we found that our calculations for beef cattle were highest in all years and those for dairy cattle were lowest for all years. For swine and poultry, our estimates tended to be in the middle of the other two estimates. The estimates from our study and Wisner's (2011) converged for the later 2 years. Despite the various methods employed to compute these estimates, each set of market shares trends toward the past 5-year average potential market share that was computed earlier in our study—beef cattle at 49 percent, dairy cattle at 26.3 percent, swine at 13.4 percent, and poultry at 11.3 percent.

[27]Beef and dairy cattle received their full remaining potential for each crop year, but swine was reduced by 25 percent and poultry by 50 percent for each crop year because of slower adoption as reported by the industry (see earlier discussion on DDGS inclusion in swine and poultry diets).

[28]For example, Shurson (March 2009) reported that some hogs were fed at a DDGS inclusion rate of over 30 percent during 2008 and 2009, when corn and soybean meal prices were high and prices of DDGS were relatively low. Furthermore, some turkeys were fed at a DDGS inclusion rate of 20-30 percent between 2008 and 2009. In both examples, the inclusion rates are higher than those used in our analysis.

[29]CHS Inc. (http://www.chsinc.com/) is a Fortune 500 company that is diversified in energy, grains, and food. It is owned by farmers, ranchers, cooperatives, and preferred stockholders covering a geographic area from the Great Lakes to the Pacific Northwest and from the Canadian border to Texas. CHS provides products and services ranging from grain marketing to food processing, operates petroleum refineries/pipelines and, through a broad range of working partnerships, markets and distributes Cenex® brand energy products and renewable fuels, along with agronomic inputs and livestock feed. CHS Inc. is a prominent marketer of DDGS in both the domestic and export market.

Table 14

Market share estimates of U.S. feed consumption of distillers' grains, by crop year and type of livestock/poultry

Crop year, by type of livestock/poultry	Renewable Fuels Association	Wisner (2011)	Current ERS study
2006/07		Percent	
Beef cattle	42.0	45.2	65.5
Dairy cattle	43.3	42.8	23.6
Swine	10.4	6.0	6.4
Poultry	4.3	6.0	4.5
Total	100.0	100.0	100.0
2007/08			
Beef cattle	39.3	47.6	61.5
Dairy cattle	42.0	40.4	25.0
Swine	13.0	6.0	7.9
Poultry	5.7	6.0	5.5
Total	100.0	100.0	100.0
2008/09			
Beef cattle	38.3	50.0	59.3
Dairy cattle	40.3	38.0	25.9
Swine	14.7	6.0	8.9
Poultry	6.7	6.0	5.9
Total	100.0	100.0	100.0
2009/10			
Beef cattle	40.4	52.4	57.6
Dairy cattle	39.4	35.6	26.6
Swine	11.8	6.0	9.6
Poultry	8.4	6.0	6.2
Total	100	100.0	100.0
2010/11[1]			
Beef cattle	41.4	53.4	56.4
Dairy cattle	39.4	34.1	27.0
Swine	10.1	6.9	10.2
Poultry	9.1	5.6	6.5
Total	100	100.0	100.0

[1]Renewable Fuels Association's estimates for 2010/11 are based on calendar year 2010.

Source: Renewable Fuels Association outlook reports, various years; Wisner (2011); table 13.

Aggregate Substitution of Distillers' Grains for Corn and Soybean Meal

How does the substitution of DDGS for corn and soybean meal affect the total U.S. feed supply? A bushel of corn used for dry-mill ethanol production results in a feed coproduct (DDGS) that is about equal to a third of the corn's original weight. What is less understood, however, is how this coproduct substitutes for corn and soybean meal differently for each type of livestock/poultry and also in aggregate across all types of livestock/poultry. Estimating this aggregate rate requires a summation of the weighted average of market share and substitution rate for each type of livestock/poultry. We provide a range of estimates for both sets of substitution rates—alternative #1 and alternative #2 (see table 10)—and for the three different sets of market share estimates (see table 14), since it is imperative to show how these different estimates affect aggregate substitution of DDGS for corn and soybean meal.

Using the substitution rates of DDGS for corn and soybean meal, by type of livestock/poultry and the estimated actual DDGS consumed (market share) by type of livestock/poultry, we computed the aggregate substitution rate for crop years 2006/07 through 20010/11 (tables 15-19). Our findings illustrate the effects of a range of substitution rates by type of livestock/poultry, but

Table 15

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2006/07

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	65.5	23.6	6.4	4.5	100.0
Consumption (mmt)	8.2	2.9	0.8	0.6	12.5
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.84
Alternative #2	1.20	0.73	0.70	0.61	1.03
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.16
Alternative #2	0.00	0.63	0.30	0.44	0.19
12.5 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	8.2	1.3	0.7	0.3	10.5
Alternative #2	9.8	2.1	0.6	0.4	12.8
12.5 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	1.6	0.1	0.3	2.0
Alternative #2	0.0	1.8	0.2	0.3	2.3

mmt=Million metric tons.

[1]Converting from pounds to metric tons, the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.84 metric ton of corn and 0.16 metric ton of soybean meal. Alternative #2: Substitution rate = 1 metric ton of DDGS substitutes for 1.22 metric ton of feed consisting of 1.03 metric ton of corn and 0.19 metric ton of soybean meal.

Source: Tables 10 and 13.

Table 16

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2007/08

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	61.5	25.0	7.9	5.5	100.0
Consumption (mmt)	10.8	4.4	1.4	1.0	17.6
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.83
Alternative #2	1.20	0.73	0.70	0.61	1.01
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.17
Alternative #2	0.00	0.63	0.30	0.44	0.21
17.6 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	10.8	2.0	1.3	0.5	14.5
Alternative #2	12.9	3.2	1.0	0.6	17.8
17.6 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	2.4	0.1	0.5	3.1
Alternative #2	0.0	2.8	0.4	0.4	3.6

mmt=Million metric tons.

[1]Converting from pounds to metric tons, the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.83 metric ton of corn and 0.17 metric ton of soybean meal. Alternative #2: Substitution rate = 1 metric ton of DDGS substitutes for 1.22 metric ton of feed consisting of 1.01 metric ton of corn and 0.21 metric ton of soybean meal.

Source: Tables 10 and 13.

our study results focus on substitution rates from alternative #2. These substitution rates are deemed to be the most current and have been verified by an animal scientist (Shurson, March 2009 and September 2009).[30] We also computed the aggregate substitution rate based on a set of market share estimates from the Renewable Fuels Association (appendix tables 1-5) and Wisner (2011) (appendix tables 6-10), multiplied by our range of substitution rates by type of livestock/poultry, but later in the study focus only on our study's results from alternative #2 set of substitution rates. We then derived some generalizations from the range of these estimates (table 20).

Based on our study's estimates, we find that, on average, for the past 5 crop years (2006/07-2010/11), 1 metric ton (mt) of DDGS can substitute for about 1.22 mt of corn and soybean meal combined in the United States (table 20).[31] We also find that not only does the aggregate substitution rate change over time but also the amount of corn and soybean meal that is substituted for by DDGS. For example, 12.5 mmt of U.S. DDGS substitutes for 12.8 mmt of corn and 2.3 mmt of soybean meal in 2006/07 (see table 15). Thus, each metric ton of DDGS substitutes for 1.22 mt of feed consisting of 1.03 mt of corn and 0.19 mt of soybean meal. For the current crop year, 2010/11, our estimates suggest that 29.1 mmt of U.S. DDGS substitutes for 28.6 mmt of corn and 6.7 mmt of soybean meal. Thus for 2010/11, our aggregate substitution rate drops slightly to 1.21 compared with 1.22 for 2006/07. One mt of

[30]Note that some commercial feeders are finding ways to use higher levels of DDGS that have not been tested by university feeding studies or peer reviewed publications. For example, there can be a complete replacement of corn with WDGS and a corn stalk or straw mixture for beef cattle.

[31]These finding apply to DDGS fed in the United States. DDGS exports may have the same substitution effect, assuming that all substitution rates and market shares by type of livestock/poultry were similar to the United States. However, this is probably not the case. Thus, substitution rates for each country would have to be analyzed to assess U.S. DDGS imports to substitute for corn and soybean meal in that country.

Table 17

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2008/09

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	59.3	25.9	8.9	5.9	100.0
Consumption (mmt)	12.9	5.6	1.9	1.3	21.8
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.82
Alternative #2	1.20	0.73	0.70	0.61	1.00
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.18
Alternative #2	0.00	0.63	0.30	0.44	0.22
21.8 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	12.9	2.6	1.7	0.7	17.9
Alternative #2	15.5	4.1	1.4	0.8	21.7
21.8 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	3.1	0.2	0.6	3.9
Alternative #2	0.0	3.6	0.6	0.6	4.7

mmt=Million metric tons.

[1]Converting from pounds to metric tons, the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.82 metric ton of corn and 0.18 metric ton of soybean meal. Alternative #2: Substitution rate = 1 metric ton of DDGS substitutes for 1.22 metric ton of feed consisting of 1.00 metric ton of corn and 0.22 metric ton of soybean meal.

Source: Tables 10 and 13.

DDGS substitutes for 1.21 mt of corn and soybean meal combined, but the composition of feed (corn and soybean meal) substituted for changes to 0.98 mt of corn and 0.23 mt of soybean meal (table 19).

As the use of U.S. DDGS increases in each crop year (2006/07-2010/11), the aggregate substitution rate of 1 mt of DDGS for combined corn and soybean meal declines slightly from 1.22 to 1.21 mt (see table 20). This slight decline in aggregate substitution rate occurs because of the shift in market shares from beef cattle to dairy cattle, hogs, and poultry (see tables 15 through 19). The composition of feed (corn and soybean meal) substituted for also changes. This change is due to the smaller share of DDGS going to beef cattle over time, but also an increasing share to dairy cattle, swine, and poultry (see tables 15-19). Beef cattle have the largest substitution rate for corn of any type of livestock/poultry, but the smallest substitution rate for soybean meal. Dairy cattle, swine, and poultry have a smaller substitution rate for corn than do beef cattle, but a larger substitution rate for soybean meal. This change in the aggregate substitution rate for both corn and soybean meal is expected to slow as changes in annual market shares by type of livestock/poultry stabilize.

An alternative set of aggregate substitution rates for corn and soybean meal were computed based on a different set of market share estimates provided by

Table 18

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2009/10

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	57.6	26.6	9.6	6.2	100.0
Consumption (mmt)	14.7	6.8	2.5	1.6	25.5
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.81
Alternative #2	1.20	0.73	0.70	0.61	0.99
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.19
Alternative #2	0.00	0.63	0.30	0.44	0.22
25.5 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	14.7	3.0	2.2	0.8	20.7
Alternative #2	17.6	4.9	1.7	0.9	25.2
25.5 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	3.7	0.2	0.8	4.8
Alternative #2	0.0	4.2	0.7	0.7	5.7

mmt=Million metric tons.

[1]Converting from pounds to metric tons, the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.81 metric ton of corn and 0.19 metric ton of soybean meal. Alternative #2: Substitution rate = 1 metric ton of DDGS substitutes for 1.21 metric ton of feed consisting of 0.99 metric ton of corn and 0.22 metric ton of soybean meal.

Source: Tables 10 and 13.

the Renewable Fuels Association (various outlook years) and Wisner (2011). Their market share estimates (appendix tables 1-10) suggest a larger market share of DDGS consumption for dairy, swine, and poultry, but a smaller market share for beef cattle, than do our study's estimates (tables 15-19). Consequently, their average aggregate substitution rate of 1.23 for crop years 2006/07 through 2010/11 is slightly higher than our study's average estimate of 1.22 (table 20). Their estimates suggest a smaller substitution of DDGS for corn, but a greater substitution of DDGS for soybean meal, than estimates from our analysis over the past 5 crop years. Again this is due to the larger market share of DDGS consumption for dairy, swine, and poultry, than estimates from our study. We present these alternative results to illustrate the effects of different market share estimates, but will focus on our study's estimates for the remainder of this report.

Elsewhere in the literature, other aggregate substitution rates of DDGS for corn and soybean meal were derived by various authors to estimate the impacts of ethanol production on feed use or land use. For example, Westcott (2007 and 2008) provided estimates based on 1 mt of DDGS replacing 1 mt of corn and soybean meal combined, comprised of 91.5 percent of corn and 8.5 percent of soybean meal. Shurson (March 2009 and September 2009) provided a critique for the Renewable Fuels Association of different studies that used DDGS substitution rates for corn and soybean meal relative to

Table 19

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2010/11

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	56.4	27.0	10.2	6.5	100.0
Consumption (mmt)	16.4	7.9	3.0	1.9	29.1
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.81
Alternative #2	1.20	0.73	0.70	0.61	0.98
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.19
Alternative #2	0.00	0.63	0.30	0.44	0.23
29.1 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	16.4	3.5	2.6	1.0	23.5
Alternative #2	19.6	5.7	2.1	1.1	28.6
29.1 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	4.3	0.3	0.9	5.6
Alternative #2	0.0	5.0	0.9	0.8	6.7

mmt=Million metric tons.

[1]Converting from pounds to metric tons, the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.81 metric ton of corn and 0.19 metric ton of soybean meal. Alternative #2: Substitution rate = 1 metric ton of DDGS substitutes for 1.21 metric ton of feed consisting of 0.98 metric ton of corn and 0.23 metric ton of soybean meal.

Source: Tables 10 and 13.

land-use credits associated with the low carbon fuel standard for ethanol. Compared with our analysis that estimated an average aggregate DDGS substitution rate of 1 mt of DDGS for 1.22 mt of corn and soybean meal combined, Shurson provided a discussion of why aggregate substitution rates from other studies that ranged from 1.0 to 1.28 should be closer to his estimate of 1.23. As discussed earlier, these alternative aggregate estimates are a function of assumed DDGS substitution rates for corn and soybean meal for different types of livestock/poultry and the assumed market shares of domestic DDGS consumption by the different types of livestock/poultry.

Table 20

Aggregate substitution rates of distillers' dried grains with solubles for corn and soybean meal, by crop year and alternative substitution rate

Alternative aggregate substitution rate, by crop year	Quantity of DDGS fed in the United States	One metric ton of DDGS replaces how many metric tons of corn and soybean meal combined?	Quantity of DDGS fed in U.S. replaces how many tons of corn and soybean meal? Corn: Quantity	Corn: Percent	Soybean meal: Quantity	Soybean meal: Percent	Total	
	mmt	*mt*	*mmt*	*Percent*	*mmt*	*Percent*	*mmt*	*Percent*
Crop year 2006/07	12.5							
Renewable Fuels Association								
Substitution rates, alternative #1		1.00	9.1	73	3.4	27	12.5	100
Substitution rates, alternative #2		1.24	11.5	92	4.0	32	15.5	124
Wisner (2011)								
Substitution rates, alternative #1		1.00	9.0	73	3.4	27	12.5	100
Substitution rates, alternative #2		1.24	11.6	93	3.9	31	15.5	124
This study's estimates								
Substitution rates, alternative #1		1.00	10.5	84	2.0	16	12.5	100
Substitution rates, alternative #2		1.22	12.8	103	2.3	19	15.1	122
Crop year 2007/08	17.6							
Renewable Fuels Association								
Substitution rates, alternative #1		1.00	12.8	73	4.8	27	17.6	100
Substitution rates, alternative #2		1.23	15.9	90	5.8	33	21.7	123
Wisner (2011)								
Substitution rates, alternative #1		1.00	13.1	74	4.5	26	17.6	100
Substitution rates, alternative #2		1.24	16.6	94	5.2	30	21.8	124
This study's estimates								
Substitution rates, alternative #1		1.00	14.5	83	3.1	17	17.6	100
Substitution rates, alternative #2		1.22	17.8	101	3.6	21	21.4	122
Crop year 2008/09	21.8							
Renewable Fuels Association								
Substitution rates, alternative #1		1.00	15.9	73	5.9	27	21.8	100
Substitution rates, alternative #2		1.22	19.6	89	7.1	33	26.7	122
Wisner (2011)								
Substitution rates, alternative #1		1.00	16.5	76	5.3	24	21.8	100
Substitution rates, alternative #2		1.23	20.8	95	6.2	28	27.0	123
This study's estimates								
Substitution rates, alternative #1		1.00	17.9	82	3.9	18	21.8	100
Substitution rates, alternative #2		1.22	21.7	100	4.7	22	26.4	122
Crop year 2009/10	25.5							
Renewable Fuels Association								
Substitution rates, alternative #1		1.00	18.6	73	6.9	27	25.5	100
Substitution rates, alternative #2		1.22	23.1	90	8.2	32	31.3	122
Wisner (2011)								
Substitution rates, alternative #1		1.00	19.6	77	5.9	23	25.5	100
Substitution rates, alternative #2		1.23	24.6	96	6.9	27	31.5	123
This study's estimates								
Substitution rates, alternative #1		1.00	20.7	81	4.8	19	25.5	100
Substitution rates, alternative #2		1.21	25.2	99	5.7	22	30.9	121

—continued

Table 20

Aggregate substitution rates of distillers' dried grains with solubles for corn and soybean meal, by crop year and alternative substitution rate—continued

Alternative aggregate substitution rate, by crop year	Quantity of DDGS fed in the United States	One metric ton of DDGS replaces how many metric tons of corn and soybean meal combined?	Quantity of DDGS fed in U.S. replaces how many tons of corn and soybean meal? Corn: Quantity	Corn: Percent	Soybean meal: Quantity	Soybean meal: Percent	Total	
	mmt	*mt*	*mmt*	*Percent*	*mmt*	*Percent*	*mmt*	*Percent*
Crop year 2010/11	29.1							
Renewable Fuels Association								
Substitution rates, alternative #1		1.00	21.2	73	7.9	27	29.1	100
Substitution rates, alternative #2		1.23	26.5	91	9.3	32	35.8	123
Wisner (2011)								
Substitution rates, alternative #1		1.00	22.6	78	6.5	22	29.1	100
Substitution rates, alternative #2		1.23	28.2	97	7.6	26	35.8	123
This study's estimates								
Substitution rates, alternative #1		1.00	23.5	81	5.6	19	29.1	100
Substitution rates, alternative #2		1.21	28.6	98	6.7	23	35.3	121
Average for crop year 2006/07 to 2010/11	21.3							
Renewable Fuels Association								
Substitution rates, alternative #1		1.00	15.5	73	5.8	27	21.3	100
Substitution rates, alternative #2		1.23	19.3	90	6.9	32	26.2	123
Wisner (2011)								
Substitution rates, alternative #1		1.00	16.2	76	5.1	24	21.3	100
Substitution rates, alternative #2		1.23	20.4	95	6.0	28	26.3	123
This study's estimates								
Substitution rates, alternative #1		1.00	17.4	82	3.9	18	21.3	100
Substitution rates, alternative #2		1.22	21.2	100	4.6	21	25.8	122

mt=Metric tons.
mmt=Million metric tons.

Note: Totals may not sum due to rounding.

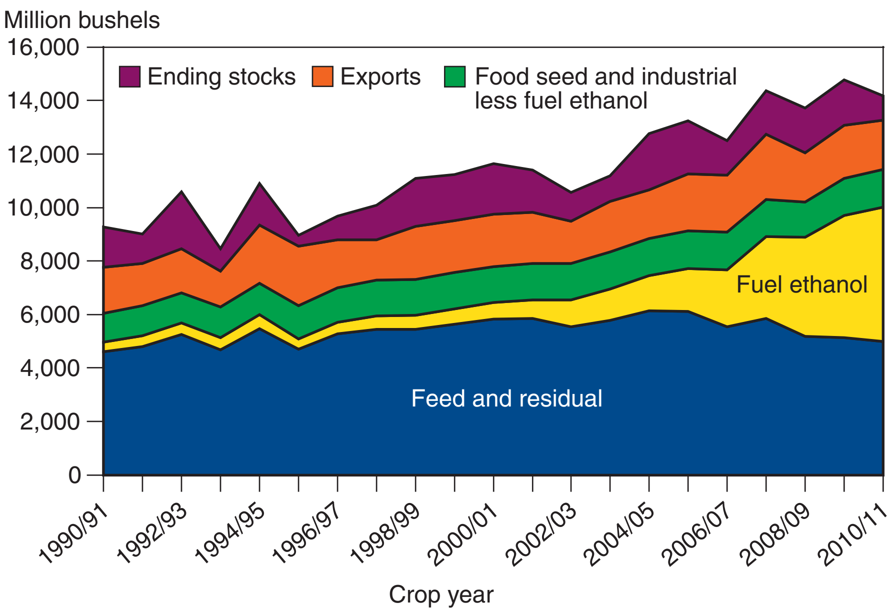
Source: USDA, Economic Research Service calculations based on tables 15-19 and appendix tables 1-10.

Effects of Dry-Mill Ethanol Production on U.S. Feed Supply[32]

Concerns among livestock/poultry feeders and other segments of the public arose over the use of corn for ethanol because of the shift away from corn used for other purposes (feed, food, seed, other nonethanol industrial uses, and exports) (fig. 1). While increased use of corn for ethanol production may be one reason that feed prices initially rose, its longer term impact on prices may be somewhat mitigated by the ethanol coproduct, DDGS, which can substitute for some of the corn used to produce ethanol but also for soybean meal. (See Trostle et al. (2011) for a longer explanation of feed and food commodity price increases.)

While ethanol expansion raised demand for corn, DDGS from the dry-mill production process provided some partially offsetting effects in the feed market. Consequently, the net effect in the domestic feed market of a bushel of corn being used for ethanol production is less than a bushel. For example, for crop year 2006/07, 1 mt of DDGS used in the domestic feed market substituted for an estimated 1.22 mt of corn and soybean meal combined, or the equivalent of about 37.8 percent (by weight) of the corn used in the associated ethanol production process.[33] We estimated that 12.5 mmt of DDGS were fed to U.S. livestock and poultry in 2006/07 and these DDGS substituted for 12.8 mmt of corn (103 percent of domestic DDGS fed) and 2.3 mmt of soybean meal (19 percent of domestic DDGS fed) (see table 15). Similarly, in 2010/11, we estimated that 29.1 mmt of DDGS were fed to U.S. livestock and poultry and these DDGS substituted for 28.6 mmt of corn (98 percent of domestic DDGS fed) and 6.7 mmt of soybean meal (23 percent of domestic DDGS fed) (see table 18).[34] Note that for either crop year 2006/07

Figure 1
U.S. corn use, crop years 1990/91 through 2010/11



Source: USDA, Economic Research Service, *Feed Grains Database*.

[32]Projections from the September 12, 2011WASDE report show that 5.02 billion bushels of corn will be used in the production of fuel ethanol for crop year 2010/11. Note that not all corn used to produce fuel ethanol is consumed by corn dry-mill plants. Based on an update of Hoffman and Baker's (2010) estimates, 444.0 million bushels, or 8.8 percent of this total, will be used for ethanol by corn wet-mill plants and 4,576 million bushels, or 91.2 percent of this total, will be used for ethanol by corn dry-mill plants.

[33]The amount of corn used to produce these DDGS in 2006/07 was 40 mmt ((12.5 mmt/0.3125) = 40 mmt)). A 17.5 pound yield of DDGS from a 56 pound bushel of corn used to produce ethanol from a dry-mill corn ethanol plant (17.5 pounds /56 pounds) equaled 31.25 percent of the corn's original weight. DDGS used in the 2006/07 domestic feed market (12.5 mmt (table 11)) substituted for an estimated 15.1 mmt of corn and soybean meal (see table 15), the equivalent of about 37.8 percent (by weight) of the corn used in the associated ethanol production process (15.1 mmt / 40 mmt) = 37.8 percent.

[34]The amount of corn used to produce these DDGS in 2010/11 was estimated to be 93.1 mmt ((29.1 mmt / .3125) = 93.1 mmt). DDGS estimated to be used in the 2010/11 domestic feed market, (29.1 mmt (table 13)), substituted for an estimated 35.3 mmt of corn and soybean meal or the equivalent of 37.8 percent (weight basis) of the corn used in the associated ethanol production process (35.3 mmt / 93.1 mmt) = 37.8 percent.

or 2010/11, the amount of feed (corn and soybean meal) substituted for by the DDGS represents, on a weight basis, the equivalent of about 37.8 percent of the corn used in the associated ethanol production process for the given crop year.[35]

The effects of DDGS substituting for corn and soybean meal can be seen in table 21. While there are other factors contributing to changes in the amount of U.S. corn and soybean meal fed annually, a clear increase can be seen in the amount of DDGS being fed while corn and soybean meal being fed is moderating or declining in recent years.[36] Overall, in the past several years, ethanol coproduct feeds (DDGS, corn gluten feed, and corn gluten meal) have gained market share in the market for U. S. feedstuffs fed, reaching an estimated 17.5 percent in 2010/11. Most of this increased market share can be attributed to the significant increase in domestic feed consumption of DDGS in recent years. As of 2010/11, DDGS replaced soybean meal as the number two feedstuff fed, and is second only to corn.

[35]Assuming production of corn-based ethanol equals 15 billion gallons, corn use for this dry-mill fuel ethanol production could total 5.17 billion bushels (2.7 gallons of ethanol per bushel of corn with 93 percent of ethanol produced from dry-mill plants) which would produce about 41.0 mmt plus 1 mmt from beverage distilleries and .5 mmt from imports = about 42.5 mmt supply. Assuming a 25-percent export share domestic consumption would equal 31.5 mmt. The amount of corn used to produce these DDGS (assuming 15 billion gallon ethanol production from corn) is 100.8 mmt ((31.5 mmt / .3125) = 100.8 mmt). DDGS estimated to be used in this domestic feed market, 31.5 mmt, substituted for an estimated 38.1 mmt of corn and soybean meal, or the equivalent of 37.8 percent (weight basis) of the corn used in the associated ethanol production process (38.1 mmt / 100.8 mmt) = 37.8 percent.

[36]Changing numbers of livestock/poultry being fed and the relative feed costs of the individual ingredients are contributing factors to changes in the amounts of feedstuffs being fed. For example, tables 3-7 reflect a general decline in the number of beef and dairy cattle being fed over the past 5 years (2006/07 through 2010/11). Also, the price of DDGS has generally been lower than prices for corn and soybean meal. A more detailed analysis of the factors explaining feed use is not part of this report.

Table 21

U.S. processed feeds fed, by crop year

Feed[1] (1,000 mt)	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02
Energy feeds										
Corn (September-August)	133,409	118,874	138,682	119,195	134,043	138,448	138,497	143,333	147,887	148,565
Sorghum (September-August)	11,614	11,178	9,577	7,495	13,106	9,270	6,652	7,230	5,652	5,843
Barley (September-August)	3,722	5,952	4,846	4,634	3,642	3,586	3,076	3,428	2,350	2,102
Oats (September-August)	3,625	3,924	3,432	2,773	2,880	3,088	3,036	2,809	2,946	2,250
Wheat (September-August)	3,908	9,585	7,440	6,155	7,681	8,798	6,379	8,943	5,999	3,500
Total energy feeds	156,279	149,512	163,976	140,252	161,352	163,191	157,641	165,744	164,833	162,259
Percent of total	82.5	80.0	80.8	78.3	80.0	77.6	75.5	76.4	75.8	75.0
Oilseed meals										
Soybean meal (October-September)[2]	22,000	22,936	24,079	24,141	24,784	26,213	27,812	27,529	28,706	30,001
Cottonseed meal (October-September)	1,045	2,393	2,965	2,685	2,824	2,682	2,298	2,638	2,590	3,030
Rapeseed (canola) meal (October-September)		1,002	952	1,172	1,102	1,552	1,470	1,565	1,519	1,247
Linseed meal (June-May)	92	99	92	117	135	168	153	171	178	112
Peanut meal (August-July)		103	175	164	128	86	85	125	100	131
Sunflower meal (October-September)		291	565	434	419	482	576	528	450	358
Total oilseed meals	23,138	26,824	28,827	28,713	29,392	31,183	32,394	32,556	33,543	34,879
Percent of total	12.2	14.3	14.2	16.0	14.6	14.8	15.5	15.0	15.4	16.1
Animal-protein feeds										
Meat and bone meal tankage (September-August)	2,166	2,204	2,456	2,394	2,369	2,253	2,439	2,069	1,925	1,750
Fishmeal and solubles (September-August)	422	649	338	255	282	260	296	249	214	255
Milk products (October-September)	421	426	420	381	388	373	248	277	275	227
Total animal-protein feeds	3,008	3,280	3,214	3,030	3,039	2,886	2,982	2,595	2,413	2,232
Percent of total	1.6	1.8	1.6	1.7	1.5	1.4	1.4	1.2	1.1	1.0
Other byproduct feeds										
Wheat millfeeds (September-August)	80	238	129	142	177	4,199	6,365	6,627	6,647	6,257
Rice millfeeds (August-July)	580	592	659	600	560	545	592	650	627	618
Fats and oils (September-August)	982	1,053	1,051	1,113	1,124	1,280	1,409	1,263	1,195	1,228
Miscellaneous byproduct feeds (September-August)[3]	1,376	1,390	1,404	1,418	1,432	1,446	1,461	1,476	1,490	1,506
Total other byproduct feeds[4]	3,018	3,273	3,243	3,274	3,293	7,470	9,827	10,015	9,959	9,609
Percent of total	1.6	1.8	1.6	1.8	1.6	3.6	4.7	4.6	4.6	4.4
Grain protein feeds										
Corn gluten feed (September – August)	1,200	1,400	2,000	2,500	3,100	3,600	3,700	4,000	4,200	4,400
Corn gluten meal (September – August)	700	700	1,000	800	800	900	1,100	1,100	900	1,000
Distillers' grains (DDGS) (September – August)	2,100	2,100	900	500	800	1,100	1,200	1,100	1,800	2,100
Total grain protein feeds[5] (September – August)	4,000	4,200	3,900	3,800	4,700	5,600	6,000	6,200	6,900	7,500
Percent of total	2.1	2.2	1.9	2.1	2.3	2.7	2.9	2.9	3.2	3.5
Total feeds fed	189,442.3	187,088.7	203,160.1	179,069.2	201,776.4	210,329.5	208,843.1	217,110.0	217,648.8	216,479.0

—continued

Table 21

U.S. processed feeds fed, by crop year—continued

Feed[1] (1,000 mt)	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
Energy feeds									
Corn (September-August)	140,934	146,850	155,838	155,330	140,726	148,793	131,625	130,174	127,006
Sorghum (September-August)	4,328	4,623	4,859	3,548	2,868	4,188	5,907	3,573	3,175
Barley (September-August)	1,999	1,723	1,428	1,041	1,360	911	990	931	1,178
Oats (September-August)	2,518	2,279	2,215	2,137	2,088	2,024	1,977	1,796	1,606
Wheat (September-August)	6,700	4,121	4,850	2,720	4,601	4,133	3,351	4,054	5,194
Total energy feeds	156,479	159,596	169,190	164,776	151,643	160,049	143,851	140,528	138,159
Percent of total	73.5	73.4	73.1	71.8	68.4	68.5	65.8	64.3	62.6
Oilseed meals									
Soybean meal (October-September)[2]	29,357	28,530	30,446	30,114	31,186	30,148	27,898	27,796	27,896
Cottonseed meal (October-September)	2,441	2,527	3,133	3,044	2,766	2,349	1,639	1,592	2,213
Rapeseed (canola) meal (October-September)	1,244	1,883	1,869	2,018	2,030	2,373	2,285	1,805	2,600
Linseed meal (June-May)	161	179	187	244	249	191	117	190	190
Peanut meal (August-July)	161	111	86	106	108	105	93	83	102
Sunflower meal (October-September)	232	317	133	278	323	311	327	368	373
Total oilseed meals	33,598	33,546	35,855	35,803	36,663	35,476	32,359	31,834	33,274
Percent of total	15.8	15.4	15.5	15.6	16.5	15.2	14.8	14.6	15.1
Animal-protein feeds									
Meat and bone meal tankage (September-August)	1,721	1,906	1,984	2,062	2,154	2,147	2,088	2,049	2,010
Fishmeal and solubles (September-August)	234	186	172	187	194	178	165	157	180
Milk products (October-September)	393	339	243	225	285	325	324	227	225
Total animal-protein feeds	2,349	2,431	2,399	2,475	2,634	2,651	2,577	2,433	2,415
Percent of total	1.1	1.1	1.0	1.1	1.2	1.1	1.2	1.1	1.1
Other byproduct feeds									
Wheat millfeeds (September-August)	6,287	6,155	6,131	6,203	6,218	6,119	5,928	5,795	5,128
Rice millfeeds (August-July)	628	543	558	592	497	511	560	608	525
Fats and oils (September-August)	1,222	1,310	1,448	1,427	1,354	1,301	1,081	878	905
Miscellaneous byproduct feeds (September-August)[3]	1,521	1,536	1,552	1,567	1,583	1,588	1,592	1,597	1,600
Total other byproduct feeds[4]	9,658	9,544	9,690	9,789	9,652	9,518	9,161	8,877	8,158
Percent of total	4.5	4.4	4.2	4.3	4.4	4.1	4.2	4.1	3.7
Grain protein feeds									
Corn gluten feed (September – August)	5,300	5,300	6,000	6,300	7,800	7,800	8,000	8,300	8,400
Corn gluten meal (September – August)	1,000	800	800	900	800	700	1,000	1,100	1,100
Distillers' grains (DDGS) (September – August)	4,600	6,400	7,400	9,300	12,500	17,600	21,800	25,500	29,100
Total grain protein feeds[5] (September – August)	10,900	12,500	14,200	16,500	21,100	26,100	30,800	34,900	38,600
Percent of total	5.1	5.7	6.1	7.2	9.5	11.2	14.1	16.0	17.5
Total feeds fed	212,983.1	217,617.2	231,333.5	229,342.9	221,691.5	233,794.3	218,748.0	218,572.4	220,606.0

mt=Metric tons.
[1]Adjusted for stocks, production, foreign trade, and nonfeed uses where applicable. Latest data may be preliminary or projected.
[2]Includes use in edible soy products and shipments to U.S. territories.
[3]Includes dried beet pulp and inedible molasses due to unavailability of production data.
[4]Excludes dried beet pulp, molasses beet pulp, and inedible molasses due to unavailability of production data.
[5]Excludes brewers' dried grains.

Source: Data for feeds fed from USDA, Economic Research Service, Feed Grains Database, Yearbook Tables, (http://www.ers.usda.gov/Data/FeedGrains/Table.asp?t=29); data for grain protein feeds from Hoffman and Baker, (2010, tables 1, 5, and 6) updated as of September 12, 2011 WASDE.

Conclusions

This report addressed the substitution effect of distillers' grains for corn and soybean meal on the U.S feed complex. The amount of corn and soybean meal that can be substituted in livestock/poultry diets by DDGS depends upon the actual amount (market share) of DDGS fed by type of livestock/poultry and the substitution rates of DDGS for corn and soybean meal by type of livestock/poultry ration. We found that, on average, for the past 5 crop years (2006/07-2010/11), 1 mt of distillers' grains substitutes for about 1.22 mt of corn and soybean meal combined in the United States.

As the market shares of U.S. distillers' grains consumed by the different types of livestock/poultry change, so do the aggregate substitution rates for corn and soybean meal. For example, in 2006/07, we estimated that 1 mt of DDGS substituted for 1.22 mt of corn and soybean meal feed. Of the estimated 12.5 mmt of U.S. DDGS fed in 2006/07, DDGS substituted for 12.8 mmt of corn (103 percent of the DDGS fed) and 2.3 mmt of soybean meal (19 percent of the DDGS fed). For 2010/11, we estimate an aggregate substitution rate of 1.21 mt, but the portion of substituted corn declines and the portion of soybean meal increases. For example, we estimate that 29.1 mmt of DDGS will be fed during 2010/11 and that it will substitute for 28.6 mmt of corn (98 percent of the DDGS fed) and 6.7 mmt of soybean meal (23 percent of the DDGS fed).

Thus, aggregate substitution rates declined slightly between 2006/07 and 2010/11 but the portion of corn declined and soybean meal increased. Substitution rates changed because, as greater amounts of DDGS were fed, a declining share was estimated to be consumed by beef cattle, so relatively less corn was replaced in the U.S. feed market than was replaced by soybean meal. Furthermore, our findings show that as the market share for beef cattle declined, market shares for dairy cattle, swine, and poultry increased. Beef cattle's DDGS substitution rate for corn is higher than any other type of livestock/poultry but is the lowest for soybean meal. Changes in aggregate substitution rates are expected to slow as annual market shares by type of livestock/poultry stabilize.

Corn and soybean meal quantities fed in the United States have moderated or declined in recent years, due partly to the substitution of DDGS or other ethanol coproducts (corn gluten feed or corn gluten meal) for corn and/or soybean meal. As of 2010/11, DDGS replaced soybean meal as the number two feedstuff fed, and is second only to corn. While ethanol expansion raised demand for corn, DDGS from the dry-mill production process partially offsets the impact on the feed market. Consequently, the net effect in the domestic feed market of a bushel of corn being used for ethanol production is less than a bushel. For example, the amount of feed (corn and soybean meal) replaced by the DDGS represents about 38 percent (weight basis) of the corn used in the associated ethanol production process for a given crop year.

Future industry surveys could provide additional information on DDGS substitution for corn and soybean meal, including information on the market share of DDGS consumed by type of livestock/poultry and the substitution rates of DDGS for corn and soybean meal by type of livestock/poultry. Furthermore, if information were available for each individual ethanol coproduct—DDG, DWG, DDGS, DWGS, CDS, corn gluten feed (CGF), wet corn gluten feed (WCGF), and corn gluten meal (CGM)—estimating the effects of ethanol coproducts on the U.S. feed complex could be more precise.

References

Anderson, J.L., D.J. Schingoethe, K.F. Kalscheur, and A.R. Hippen, "Evaluation of Dried and Wet Distillers Grains Included at Two Concentrations in the Diets of Lactating Dairy Cows," *Journal of Dairy Science* 89(8): pp. 3133–42, 2006, http://jds.fass.org/cgi/content/abstract/89/8/3133.

Arora, Salil, May Wu, and Michael Wang. *Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis*, Center for Transportation Research, Energy System Division, Argonne National Laboratory, September 2008, www.transportation.anl.gov/pdfs/AF/527.pdf.

Babcock, Bruce A., Dermot J. Hayes, and John D. Lawrence (eds). *Using Distillers Grains in the U.S. and International Livestock and Poultry Industries*, Midwest Agribusiness Trade Research and Information Center at the Center for Agricultural and Rural Development, Iowa State University, 2008, http://www.card.iastate.edu/books/distillers_grains/.

Berger, Larry L., and Darrel L. Good. "Distillers Dried Grains Plus Solubles Utilization by Livestock and Poultry," *Corn-Based Ethanol in Illinois and the U.S.: A Report from the Department of Agricultural and Consumer Economics*, University of Illinois, pp. 97-111, November 2007, http://www.farmdoc.illinois.edu/policy/research_reports/ethanol_report/Ethanol%20Report.pdf.

Bregendahl, Kristjan. "Use of Distillers Co-products in Diets Fed to Poultry," *Using Distillers Grains in the U.S. and International Livestock and Poultry Industries*, Midwest Agribusiness Trade Research and Information Center at the Center for Agricultural and Rural Development, Iowa State University, pp. 99-133, 2008, http://www.card.iastate.edu/books/distillers_grains/pdfs/chapter5.pdf.

Dahlke, Garland, and John D. Lawrence. "Ingredient Value and Cost Calculator For Livestock and Poultry Diets," *Using Distillers Grains in the U.S. and International Livestock and Poultry Industries*, Midwest Agribusiness Trade Research and Information Center at the Center for Agricultural and Rural Development, Iowa State University, pp. 179-98, 2008, http://www.card.iastate.edu/books/distillers_grains/pdfs/chapter8.pdf.

Dairy One. *Forage Feed Composition*. http://www.dairyone.com/Forage/FeedComp/MainLibrary.asp

Deutscher, Hope. "IDGC: Distillers Grains Products Markets Grow," *Ethanol Producer Magazine*, August 2009, http://www.ethanolproducer.com/articles/5816/idgc-distillers-grains-products-markets-grow.

Dhuyvetter, Kevin C., Terry L. Kastens, and Michael Boland. *The U.S. Ethanol Industry: Where will it be located in the future?* University of California, Agricultural Issues Center, November 2005, http://www.agmanager.info/agribus/energy/Ethanol%20Industry(AgMRC)—11.25.05.pdf.

Dooley, Frank J. *U.S. Market Potential for Dried Distillers Grains with Solubles*, working paper # 08-12, Department of Agricultural Economics, Purdue University, December 2008.

Ensminger, M.E., J.E. Oldfield, and W.W. Heinemann. *Feeds and Nutrition*, Second Edition, The Ensminger Publishing Company: Clovis, California, 1990.

Erickson, G.E., T.J. Klopfenstein, D.C. Adams, and R. J. Rasby. *Corn Processing Co-products Manual: A Review of Current Research on Distillers Grains and Corn Gluten*, Nebraska Corn Board and the University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources, Agricultural Research Division, Cooperative Extension Division, January 2005.

Erickson, G.E., Virgil R. Bremer, Terry J. Klopfenstein, Aaron Stalker, and Rick Rasby. "Feeding of Corn Milling Co-Products to Beef Cattle," *Utilization of Corn Co-Products in the Beef Industry*, Second Edition, Nebraska Corn Board and the University of Nebraska Lincoln, Institute of Agriculture and Natural Resources, Agricultural Research Division, University of Nebraska-Lincoln Extension, August 2007, http://beef.unl.edu/byprodfeeds/manual_01_01.shtml.

Fox, John A. "The Value of Distillers Dried Grains in Large International Markets," *Using Distillers Grains in the U.S. and International Livestock and Poultry Industries*, Midwest Agribusiness Trade Research and Information Center at the Center for Agricultural and Rural Development, Iowa State University, pp. 135-53, 2008, www.card.iastate.edu/books/distillers_grains/pdfs/chapter6.pdf.

Government Printing Office. *Energy Independence and Security Act of 2007*, December 19, 2007, http://www.gpo.gov/fdsys/pkg/PLAW-110publ140/html/PLAW-110publ140.htm.

Government Printing Office. *Energy Policy Act of 2005*, August 8, 2006, http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=109_cong_bills&docid=f:h6enr.txt.pdf.

Hill, G.M., J.E. Link, D.O.Liptrap, M.A. Giesemann, M.J. Dawes, J.A. Snedegar, N.M.Bello, and R. J. Tempelman. "Withdrawal of Distillers Dried Grains with Solubles (DDGS) Prior to Slaughter in Finishing Pigs," *Journal of Animal Science* 86(Supplement 2): p. 52 (Abstract), 2008.

Hoffman, Linwood A., and Allen Baker. *Market Issues and Prospects for U.S. Distillers' Grains Supply, Use, and Price Relationships*, FDS-10K-01, U.S. Department of Agriculture, Economic Research Service, December 2010, http://www.ers.usda.gov/Publications/FDS/2010/11Nov/FDS10K01/.

Hutjens, Mike. *Feeding Guide*, Third Edition, W.D. Hoard and Sons Company: Fort Atkinson, Wisconsin, 2008.

Klopfenstein, T.J. Personal communication, September 20, 2010.

Klopfenstein, Terry J., Galen E. Erickson, and Virgil R. Bremer. "Use of Distillers Co-Products in Diets Fed to Beef Cattle," *Using Distillers Grains in the U.S. and International Livestock and Poultry Industries*, Midwest Agribusiness Trade Research and Information Center at the Center for Agricultural and Rural Development, Iowa State University, pp. 6-55, 2008, www.card.iastate.edu/books/distillers_grains/pdfs/chapter2.pdf.

Lumpkins, B.S., A.B. Batal, and N.M. Dale. "Evaluation of Distillers Dried Grains with Solubles as a Feed Ingredient for Broilers," *Poultry Science* 83: pp. 1891-96, 2004, http://ps.fass.org/cgi/reprint/83/11/1891.

Lumpkins, B.S., A.B. Batal, and N.M. Dale. "Use of Distillers Dried Grains Plus Solubles in Laying Hen Diets," *The Journal of Applied Poultry Research* 14: pp. 25-31, 2005, http://japr.fass.org/cgi/content/abstract/14/1/25.

Lundeen, Tim (ed.). "Feedstuffs Ingredients Analysis Table 2011 Edition," *Feedstuffs 2011, Reference Issue and Buyers Guide*, Minnetonka, Minnesota, p. 16, September 15, 2011.

Mathews, Kenneth H. and Michael J. McConnell. *Ethanol Co-Product Use in U.S. Cattle Feeding: Lessons Learned and Considerations*, FDS-09D-01, U.S. Department of Agriculture, Economic Research Service, April 2009, http://www.ers.usda.gov/Publications/FDS/2009/04Apr/FDS09D01/.

National Corn Growers Association. *Corn Distillers Grain: Value-added Feed Source for Beef, Dairy Beef, Dairy, Poultry, Swine, and Sheep*, September 9, 2008, http://www.ncga.com/files/pdf/DistillersGrains9-08.pdf.

National Grain and Feed Association. "FDA Sampling Detects Antibiotic Residues in Ethanol Distillers Products," *NGFA Newsletter* Volume 61, Number 2, pp. 1 and 6, January 29, 2009, http://www.ngfa.org/files/misc/News1-29-09.pdf.

National Research Council. *Nutrient Requirements of Beef Cattle*, Seventh Revised Edition: Update 2000, National Academies Press: Washington, DC, 2000, http://www.nap.edu/openbook.php?isbn=0309069343.

National Research Council. *Nutrient Requirements of Dairy Cattle*, Seventh Revised Edition, National Academies Press: Washington, DC, 2001, http://www.nap.edu/openbook.php?isbn=0309069971.

National Research Council. *Nutrient Requirements of Poultry*, Ninth Revised Edition, National Academies Press: Washington, DC, 1994, http://www.nap.edu/openbook.php?isbn=0309048923.

National Research Council. *Nutrient Requirements of Swine*, Tenth Revised Edition, National Academies Press: Washington, DC, 1998, http://www.nap.edu/openbook.php?isbn=0309059933.

Noll, S.L., J. Brannon, and V. Stangeland. "Market Turkey Performance and Inclusion Level of Corn Distillers Dried Grains with Solubles," *Poultry Science* 82(Supplement 1): p. 321, 2004.

Rausch, Kent D., and Ronald L. Belyea. "Coproducts from Bioprocessing of Corn," paper presentation at annual meeting of the American Society of Agricultural Engineers, Tampa, Florida, July 17-20, 2005, http://www.ddgs.umn.edu/articles-proc-storage-quality/2005-Rausch-%20Coproducts%20from%20bioprocessing--.pdf.

Renewable Fuels Association. 2009 *Corn Quality Issues and Considerations for Ethanol Production*, November 2009, http://ethanolrfa.3cdn.net/ffe71cb4be159b0042_njm6iyb8p.pdf.

Renewable Fuels Association. *2009 Ethanol Industry Outlook: Growing Innovation*, p. 24. 2009, http://ethanolrfa.3cdn.net/9a54006afdf842b174_rlm626rio.pdf.

Renewable Fuels Association. 2010 *Ethanol Industry Outlook: Climate of Opportunity*, p. 7, 2010, http://ethanolrfa.org/page/-/objects/pdf/outlook/RFAoutlook2010_fin.pdf?nocdn=1.

Renewable Fuels Association. 2011 *Ethanol Industry Outlook; Building Bridges to a More Sustainable Future*, p. 7, 2011, http://www.ethanolrfa.org/page/-/2011%20RFA%20Ethanol%20Industry%20Outlook.pdf?nocdn=1.

Renewable Fuels Association. *Changing the Climate: Ethanol Industry Outlook 2008*, p. 14, 2008, http://www.ethanolrfa.org/page/-/objects/pdf/outlook/RFA_Outlook_2008.pdf?nocdn=1.

Renewable Fuels Association. *Ethanol Industry Outlook 2007: Building New Horizons*, p. 13, 2007, http://www.ethanolrfa.org/page/-/objects/pdf/outlook/RFA_Outlook_2007.pdf?nocdn=1.

Roberson, K.D. "Use of Dried Distillers' Grains with Solubles in Growing-finishing Diets of Turkey Hens," *International Journal of Poultry Science* 2 (6): pp. 389-93, 2003, http://scialert.net/qredirect.php?doi=ijps.2003.389.393&linkid=pdf.

Roberson, K.D., J.L. Kalbfleisch, W. Pan, and R.A. Charbeneau. "Effect of Corn Distillers' Dried Grains with Solubles at Various Levels on Performance of Laying Hens and Egg Yolk Color," *International Journal of Poultry Science* 2: pp. 389-93, 2005.

Schingoethe, David J. "Distillers Grains for Dairy Cattle," presentation at Iowa Regional Distillers Grains Workshops, Calmar, Waverly, and Cherokee, Iowa, February 2004. http://www.ddgs.umn.edu/articles-dairy/2001-Schingoethe-%20IA%20DDGS%20workshops.pdf.

Schingoethe, David J. "Use of Distillers Co-products in Diets Fed to Dairy Cattle," *Using Distillers Grains in the U.S. and International Livestock and Poultry Industries*, Midwest Agribusiness Trade Research and Information Center at the Center for Agricultural and Rural Development, Iowa State University, pp. 57-78, 2008, http://www.card.iastate.edu/books/distillers_grains/pdfs/chapter3.pdf.

Schingoethe, David J. "Utilization of DDGS by Cattle," presentation and paper at the 27th Western Nutrition Conference, Winnipeg, Manitoba, Canada, pp. 61-74, September 19-20, 2006, http://www.ddgs.umn.edu/articles-dairy/2006-Schingoethe-%20Utilization%20of%20DDGS%20by%20cattle.pdf.

Shurson, Jerry. "Analysis of Current Feeding Practices of Distiller's Grains with Solubles in Livestock and Poultry Feed Relative to Land Use Credits Associated with Determining the Low Carbon Fuels Standard for Ethanol," Renewable Fuel Association, March 25, 2009, http://www.ethanolrfa.org/page/-/objects/documents/2290/shurson.pdf?nocdn=1.

Shurson, Jerry, "A Scientific Assessment of the Role of Distiller's Grains (DGS) and Predictions of the Impact of Corn Co-Products Produced by Front-End Fractionation and Back-End Oil Extraction Technologies on Indirect Land Use Change," Renewable Fuels Association, September 10, 2009, http://www.ethanolrfa.org/page/-/rfa-association-site/studies/assessmentofdgs.pdf?nocdn=1.

Shurson, Jerry. *Impact of Distillers' Grains on Indirect Land Use*, presentation at the National Corn Grower Land Use Conference, St. Louis, MO, August 25-26, 2009, http://www.ddgs.umn.edu/ppt-swine/2009-Shurson-%20Impact%20of%20distillers%20grains%20on%20indirect%20land%20use%20change.pdf.

Shurson, Jerry, and Abdorrahman S. Alghandi. "Quality and New Technologies to Create Corn Co-Products from Ethanol Production," *Using Distillers Grains in the U.S. and International Livestock and Poultry Industries*, Midwest Agribusiness Trade Research and Information Center at the Center for Agricultural and Rural Development, Iowa State University, pp. 231-59, 2008, http://www.card.iastate.edu/books/distillers_grains/pdfs/chapter10.pdf.

Shurson, Jerry, and Mindy Spiehs. *Feeding Recommendations and Example Diets Containing Minnesota-South Dakota Produced DDGS for Swine*, Department of Animal Science, University of Minnesota, 2002, http://www.ddgs.umn.edu/feeding-swine/exampleswinediets-revised.pdf.

Shurson, Jerry, Mindy Spiehs, Jennifer Wilson, and Mark Whitney. "Value and use of "new generation" distillers' dried grains with solubles in swine diets," presented at the 19th International Alltech Conference, Lexington, KY, May 13, 2003a, http://www.ddgs.umn.edu/articles-swine/2003-Shurson-%2019th%20Internatl%20Alltech%20Conf.pdf.

Shurson, J., C. Santos, J. Aguirre, and S. Hernandez. "Effects of Feeding Babcock B300 Laying Hens Conventional Sanfandila Layer Diets Compared to Diets Containing 10 percent Norgold DDGS on Performance and Egg Quality," Minnesota Corn Research and Promotion Council and the Minnesota Department of Agriculture, 2003b.

Siegel, Victoria. "Corn Dried Distillers Grains and Mycotoxins," presentation made at the 14th Annual Distillers Grain Technology Council Symposium, Indianapolis, Indiana, May 12-13, 2010.

Staff, Charles, Executive Director, Distillers Grain Technology Council. Written communication, March 14, 2011.

Stanton, T.G. *Bypass Protein for Cattle no. 1.609*, Colorado State University, Fort Collins, Colorado, June 1998, http://docs.google.com/viewer?a=v&q=cache:g1Z8eXUzig8J:www.cheboygancoop.com/animalscience/beef/01609.pdf+bypass+protein+for+cattle,+no.+1.609.+colorado+state+extension,+t.l.+stanton&hl=en&gl=us&pid=bl&srcid=ADGEESgF1gNWlusRRGeec26TVPMDEQZfwmb7XO5Q7UDpBnK-Kxbe6Op5cZEdjeVv7CiCXYrefKTa3dZCEhReSDZ2tAJvupa1s-JzG2gPzyiJVllaDuvzqCmBwlyfxlA32IOjxnIodtpUNd&sig=AHIEtbSY_TsSfddwEN5k6qxwAcInldpzbA.

Stein, Hans H. "Distillers dried grains with solubles (DDGS) in diets fed to swine," Swine Focus #001, University of Illinois at Urbana-Champaign, Department of Animal Science, 2007, http://www.distillersgrains.org/files/feedsource/swine_brochure.pdf.

Stein, Hans H. "Use of Distillers Co-products in Diets Fed to Swine," *Using Distillers Grains in the U.S. and International Livestock and Poultry Industries*, Midwest Agribusiness Trade Research and Information Center at the Center for Agricultural and Rural Development, Iowa State University, pp. 79-97, 2008, www.card.iastate.edu/books/distillers_grains/pdfs/chapter4.pdf.

Tisch, David. *Animal Feeds, Feeding and Nutrition, and Ration Evaluation with CD-Rom*, Delmar Cengage Learning: Clifton Park, New York, 2006.

Tjardes, Kent, and Cody Wright. "Feeding Corn Distiller's Co-Products to Beef Cattle," ExEx 2036, South Dakota State University, College of Agriculture & Biological Sciences and USDA Cooperative Extension Service, 2002, http://pubstorage.sdstate.edu/AgBio_Publications/articles/ExEx2036.pdf.

Trenkle, Allen. "Evaluation of Wet and Dry Distillers Grains with Solubles for Finishing Holstein Steers," report to the Iowa Corn Promotion Board, November 2003, http://www.ddgs.umn.edu/articles-beef/2003-Trenkle-%20FINAL%20ISU12-03.pdf.

Trostle, Ronald, Daniel Marti, Stacey Rosen, and Paul Westcott. *Why Have Food Commodity Prices Risen Again?* WRS-1103, U.S. Department of Agriculture, Economic Research Service, June 2011, http://www.ers.usda.gov/Publications/WRS1103/.

University of Minnesota. *Distillers Grains By-products in Livestock and Poultry Feeds*, http://www.ddgs.umn.edu/.

University of Minnesota. *Nutrient Profiles: Archived Data (U.S.)*, http://www.ddgs.umn.edu/profiles-archived-us.htm.

U.S. Department of Agriculture, Economic Research Service. *Feed Grains Database*, http://www.ers.usda.gov/data/feedgrains/.

U.S. Department of Agriculture, Grain Inspection, Packers and Stockyards Administration. "What are Mycotoxins?" *Grain Fungal Diseases & Mycotoxin Reference*, pp. 7-12, September 2006, http://archive.gipsa.usda.gov/pubs/mycobook.pdf.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Cattle*. January 29, 2010, http://usda.mannlib.cornell.edu/usda/nass/Catt//2010s/2010/Catt-01-29-2010.pdf.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Cattle Final Estimates*, *2004-2008*, SB-1019, March 2009, http://usda.mannlib.cornell.edu/usda/nass/SB989/sb1019.pdf.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Chicken and Egg Annual Summary*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1509.

U.S. Department of Agriculture, National Agricultural Statistics Service, *Ethanol Co-Products Used for Livestock Feed, 2007*, http://usda.mannlib.cornell.edu/usda/current/EthFeed/EthFeed-06-29-2007_revision.pdf.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Hogs and Pigs: Final Estimates*, SB-1020, March 2009, http://usda.mannlib.cornell.edu/usda/nass/SB986/sb1020.pdf.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Poultry Production and Value*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1130.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Quarterly Hogs and Pigs*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1086.

U.S. Department of Agriculture, Office of the Chief Economist, World Agricultural Outlook Board (USDA, WAOB). *USDA Agricultural Projections to 2020*, OCE-111, February 2011, http://www.usda.gov/oce/commodity/archive_projections/USDAAgriculturalProjections2019.pdf.

U.S. Department of Agriculture, Office of the Chief Economist, World Agricultural Outlook Board (USDA, WAOB). *World Agricultural Supply and Demand Estimates*, WASDE-498, September 12, 2011, http://usda.mannlib.cornell.edu/usda/current/wasde/wasde-09-12-2011.pdf.

U.S. Energy Information Administration. *Petroleum Supply Monthly*, October 28, 2010, http://www.eia.doe.gov/oil_gas/petroleum/data_publications/petroleum_supply_monthly/psm.html.

U.S. Food and Drug Administration. *Analysis of Antibiotics in Distillers Grains Using Liquid Chromatography and Ion Trap Tandem Mass Spectrometry,* David N. Heller and G.K. Hemakanthi de Alwis, LIB-4438, Office of Research, Center for Veterinary Medicine, 2009b, http://www.fda.gov/downloads/AnimalVeterinary/ScienceResearch/ToolsResources/UCM182280.pdf.

U.S. Food and Drug Administration. *Animal Veterinary, Animal Food and Feeds Product Regulation,* February 16, 2011, http://www.fda.gov/AnimalVeterinary/Products/AnimalFoodFeeds/ucm050223.htm.

U.S. Food and Drug Administration. *FY 2010 Nationwide Survey of Distillers Grains for Antibiotic Residues*, memorandum from Director, Office of Surveillance and Compliance, September 30, 2009a, http://www.fda.gov/AnimalVeterinary/Products/AnimalFoodFeeds/Contaminants/ucm190907.htm.

U.S. Food and Drug Administration. "Mycotoxins in Feeds: CVM's Perspective," presentation made to Risk Management Agency by Michael Henry, Division of Animal Feeds, Center for Veterinary Medicine, Food and Drug Administration, August 23, 2006, http://www.fda.gov/AnimalVeterinary/Products/AnimalFoodFeeds/Contaminants/ucm050974.htm.

U.S. Food and Drug Administration, Animal Veterinary, Guidance, Compliance and Enforcement, Compliance and Enforcement. *Letter to Industry: Marketing of Animal Food Substances as Generally Recognized As Safe (GRAS)*, 2010, http://www.fda.gov/AnimalVeterinary/GuidanceComplianceEnforcement/ComplianceEnforcement/ucm229734.htm.

U.S. Grains Council. *DDGS User Handbook*, March 2007, http://www.grains.org/ddgs-information/217-ddgs-user-handbook.

Vander Pol, Kyle J., Galen E. Erickson, Matthew A. Greenquist, Terry J. Klopfenstein, and Thomas Robb. "Effect of Dietary Inclusion of Wet Distillers Grains on Feedlot Performance of Finishing Cattle and Energy Value Relative to Corn," *Nebraska Beef Cattle Reports*, University of Nebraska-Lincoln, Animal Science Department, pp. 51-3, 2006.

Vander Pol, Kyle J., Galen E. Erickson, and Terry J. Klopfenstein. "Degradable Intake Protein in Finishing Diets Containing Dried Distillers Grains," *Nebraska Beef Cattle Reports*, University of Nebraska-Lincoln, Animal Science Department, pp. 42-4, 2005.

Wang, Z., S. Cerrate, C. Coto, F. Yan, and P.W. Waldroup. "Use of Constant or Increasing Levels of Distillers Dried Grains with Solubles (DDGS) in Broiler Diets," *International Journal of Poultry Science* 6(7): pp. 501-7, 2007a.

--------, "Effect of Rapid and Multiple Changes in Level of Distillers Dried Grain with Solubles (DDGS) in Broiler Diets on Performance and Carcass Characteristics," *International Journal of Poultry Science* 6(7): pp. 725-31, 2007b.

Westcott, Paul. "Distillers Grains: Livestock Sector Uses and Implications for Feed Use of Corn and Soybean Meal," presented at World Commodity Outlook Conference, Washington, DC, May 2008.

Westcott, Paul. *Ethanol Expansion in the United States: How Will the Agricultural Sector Adjust?* FDS-07D-01, U.S. Department of Agriculture, Economic Research Service, May 2007, http://www.ers.usda.gov/publications/fds/2007/05may/fds07d01/fds07d01.pdf.

White, H., B. Richert, S. Radcliffe, A. Schnickel, and M. Latour. "Distillers Dried Grains Decreases Bacon Lean and Increases Fat Iodine Values (IV) and the Ratio of n6n:n3 but Conjugated Linoleic Acids Partially Recovers Fat Quality," *Journal of Animal Science* 85(Supplement 2): p. 78 (Abstract), 2007.

Whitlow, Lon. "Mycotoxins and Distillers Grains," *Know Mycotoxins*, North Carolina State University, http://www.knowmycotoxins.com/documents/WhitlowEnglish.pdf.

Wilson, J.A., M.H. Whitney, G.C. Shurson, and S.K. Baidoo. "Effects of Feeding Distillers Dried Grains with Solubles (DDGS) to Gestation and Lactation Diets on Reproductive Performance and Nutrient Balance in Sows," *Journal of Animal Science* 81(Supplement 2): pp. 47-8 (Abstract), 2003.

Wisner, Robert. *Estimated U.S. Dried Distillers Grains with Solubles (DDGS) Production and Use*, Iowa State University, University Extension, April 2011, http://www.extension.iastate.edu/agdm/crops/outlook/dgsbalancesheet.pdf.

Xu, G., S.K. Baidoo, L.J. Johnston, J.E. Cannon, D. Bibus, and G.C. Shurson. "Effects of Dietary Corn Dried Distillers Grains with Solubles (DDGS) and DDGS Withdrawal Intervals, on Pig Growth Performance, Carcass Traits, and Fat Quality," *Journal of Animal Science* 86 (Supplement 2): p. 52 (Abstract), 2008.

Appendix A: Estimating Potential DDGS Use by Livestock/Poultry Industry

We estimated the potential amounts of DDGS fed per corn crop year by computing the potential daily use of DDGS by livestock/poultry, multiplied by the number of days fed per year, multiplied by the number fed during the year, and then summed by type of livestock/poultry for the potential DDGS fed per year. Our potential daily inclusion levels of DDGS into the diets of livestock/poultry were taken from current literature (see table 2). Nutritionists typically use energy, protein, amino acid, and mineral content to balance livestock/poultry diets. The optimum set of ingredients may change over time depending on changing prices of competing feed ingredients, age of the livestock/poultry, or whether the livestock/poultry is used for breeding or market stock. Our estimates attempted to incorporate most of these variables. We assume that DDGS are priced so that they are economical to include in the diet of livestock/poultry. In most cases, we used a DDGS inclusion rate for the livestock/poultry diet that represented either the low end or mid-point range of maximum potential inclusion rates established in the literature (see table 2). We do not use the extreme maximum inclusion rate because we do not assume an adoption rate. Thus, we use a lower inclusion rate to compensate for the unknown adoption rate.

Beef Cattle

Cows—Our research was based on a 22.3 pound dry matter intake for a 1,175 pound beef cow in the last trimester of pregnancy (National Research Council, 2000). We assumed the cow was on a low quality grazing/high-roughage diet over the winter and in need of diet supplementation. A 20 percent DDGS inclusion rate was used for the cow on a high roughage diet (U.S. Grains Council, 2007). For the cow on a grazing diet, we assumed that 2 pounds per day of DDGS were fed (Klopfenstein, 2010). The daily potential amount of DDGS fed to beef cows (as fed) = a weighted average of 3.55 pounds (((22.3 pounds of dry matter per day x 20 percent DDGS inclusion rate (high-roughage diet)) + (2 pounds per day for the grazing diet)) x 110 percent to convert to an as fed basis. We assumed that these cows were fed over the winter for a period of 90 days. The cattle numbers fed were derived from a January 1st inventory number (USDA/NASS) (see tables 3 through 7).

Beef cow replacement heifers—We assumed that two classes of heifers were fed based on annual inventory numbers provided by the U.S. Department of Agriculture, annual cattle inventory report (USDA/NASS, 2009-11). NASS reported the number of heifers for beef cow replacement and the number expected to calve. Younger heifers not expected to calve equaled the difference between these two inventory numbers. Heifers expected to calve were assumed to be 900 pound animals with an average daily dry matter intake of 19.0 pounds during the last 4 months prior to calving (Ensminger et al., 1990). Heifers not expected to calve were assumed to be 650 pound animals with an average daily dry matter intake of 15.6 pounds (Ensminger et al., 1990). We assumed that both types of heifers were fed at a 20-percent DDGS inclusion rate (Klopfenstein et al., 2008; U.S. Grain Council, 2007). The daily potential amount of DDGS fed to heifers = a weighted average of 3.89

pounds ((19.0 pounds daily dry matter intake x 20 percent inclusion rate x percent of all beef cow replacement heifers expected to calf (3,563/5,835 = 60.7 percent as of January 1, 2007)) + (15.6 pounds daily dry matter intake x 20-percent inclusion rate x percent of all beef cow replacement heifers not expected to calf (2,272/5,835 = 39.3 percent as of January 1, 2007))) x 110 percent to convert to an as fed basis. These animals were assumed to be fed DDGS for 120 days.

Cattle on feed—We assumed that 950 pound steers consumed 22.1 pounds of dry matter per day with a 35-percent DDGS inclusion rate (Klopfenstien et al., 2008; Erickson et al., 2007). The daily amount of DDGS fed to cattle on feed = 8.51 pounds (22.1pounds of daily dry matter intake x 35-percent DDGS inclusion rate) x 110 percent to convert to an as fed basis. The 35-percent inclusion rate represents either wet or dry feeding of distillers' grains with solubles. We assumed that these animals were fed 365 days of the year. The number of cattle fed came from USDA, NASS, 2009-11.

Other cattle—This category included other heifers, steers, and bulls weighing more than 500 pounds not in a feedlot and calves weighing less than 500 pounds. For the heavier animals, we assumed that a 650 pound animal consumed 15.6 pounds of daily dry matter (National Research Council, 2000), and for the calves, we assumed that a 350 pound animal consumed 10 pounds of daily dry matter (Ensminger et al., 1990). The daily potential amount of DDGS fed to other cattle = a weighted average of 2.80 pounds ((15.6 pounds daily dry matter intake x 20-percent inclusion rate x percent of heifers, steers, and bulls over 500 pounds not in a feedlot (48.9 percent as of January 1, 2007)) + (10.0 pounds daily dry matter intake x 20-percent inclusion rate x percent of calves under 500 pounds and not in a feedlot (51.1 percent as of January 1, 2007))) x 110 percent to convert to an as fed basis. We assumed that these animals for both categories were fed 120 days of the year.

Dairy Cattle

Cows—We used a 52.0 pound mid-lactation daily dry matter intake times a 20-percent DDGS inclusion rate to arrive at the daily amount fed (Hutjens, 2008; Schingoethe, 2008). We computed a weighted daily average amount of DDGS fed to account for lactating and dry cows. For example, we assumed that the cows lactated for 305 days and were dry for 60 days per year. We assumed that a 1,500 pound dry cow was fed an average daily dry matter of 27 pounds (average during the dry period) (Hutjens, 2008) with a 10-percent DDGS inclusion rate (Schingoethe, 2008). Daily potential amount of DDGS fed to dairy cows = a weighted average of 10.05 pounds ((52.0 pounds daily dry matter intake x 20-percent inclusion rate x 305/365 days fed per year) + (27.0 pounds average daily dry matter intake x 10-percent inclusion rate x 60/365 days fed per year)) x 110 percent to covert to an as fed basis. The inclusion rates represent either WDGS or DDGS.

Milk cow replacement heifers—We made assumptions on two classes of heifers based on the annual inventory numbers provided by USDA's annual cattle inventory report (USDA/NASS, 2009-11). These findings included the number of heifers for milk cow replacement and the number expected to calve. Younger heifers not expected to calve equaled the difference between these two inventory numbers. Heifers expected to calve were assumed to be 880 pound animals with a daily dry matter intake of 19.4 pounds (Hutjens, 2008). Heifers not expected to calve were assumed to be 660 pound animals with a 15.6-daily dry matter intake. The daily potential amount of DDGS fed to heifers = a weighted average of 3.98 pounds ((19.4 pounds daily dry matter intake x 20-percent inclusion rate x percent of heifers expected to calve as a percent of all milk cow replacement heifers (2,831/4,325 = 65.8 percent as of January 1, 2007) x 110 percent to convert to an as fed basis.) + (15.6 pounds daily dry matter intake x 20-percent inclusion rate x percent of heifers not expected to calve as a percent of all milk cow replacement heifers(1,494/4,325 = 34.2 percent as of January 1, 2007) x 110 percent to convert to an as fed basis)). We assumed these animals were fed DDGS for 120 days per year.

Swine

To calculate the potential amount of DDGS fed to swine in a given crop year, we determined the average quarterly number of breeding swine per crop year and the average quarterly number of market hogs per weight group (USDA/NASS, *Quarterly Hogs and Pigs* report, various years and quarters). We determined the inventory numbers for each category and assumed that they were fed for 365 days of the year.

Breeding swine—We assumed that each hog in the breeding swine category had two production cycles per year. So we assumed an average weight of 358.3 pounds for a bred gilt, sow, and adult boar with a daily feed intake of 4.2 pounds per day and assumed that they were fed this diet for about 4 months per production cycle, or a total of 8 months per year (Ensminger et al., 1990). We also assumed an average 363.8 pound lactating gilt and sow consumed 11.7 pounds of feed per day for 2 months per production cycle, or 4 months per year (Ensminger et al., 1990). We used a 20-percent DDGS inclusion rate in our calculations. The daily quantity of DDGS fed to breeding swine = a weighted average of 1.34 pounds (4.2 pounds of feed per day x 20-percent DDGS inclusion x 8/12 months) + (11.7 pounds of feed per day x 20-percent DDGS inclusion rate per day x 4/12 months).

Market swine—We calculated the number of market hogs fed based on the average quarterly inventory of market hogs by weight category. For example, we considered the following weight groups:

1. Under 50 pounds market hogs were assumed to have been fed a ration of 2 pounds per day with a 10- percent DDGS inclusion rate.

2. The 50-119 pound market hogs were assumed to have been fed a ration of 4.2 pounds per day with a 20-percent DDGS inclusion rate.

3. The 120-179 pound market hogs were assumed to have been fed a ration of 6.9 pounds per day with a 20-percent DDGS inclusion rate.

4. The 180 pounds and over market hogs were assumed to have been fed a ration of 6.9 pounds per day with a DDGS inclusion rate of 10 percent (Ensminger et al., 1990).

The daily quantity of DDGS fed to market hogs during 2006/07 = a weighted average of 0.68 pounds per day (2 pounds of feed per day x 20- percent DDGS inclusion rate x portion of all market hogs in the under 50 pounds category (20,823/56,688 = 37 percent) + (4.2 pounds of feed fed per day x 20-percent DDGS inclusion rate x portion of all market hogs in the 50-119 pound category (13,958/56,688 = 25 percent) + (6.9 pounds of feed fed per day x 20-percent DDGS inclusion rate x portion of all market hogs in the 120-179 pound category (11,606/56,688 = 20 percent) + (6.9 pounds of feed fed per day x 10-percent DDGS inclusion rate x portion of all market hogs in the 180 pounds and over category (10,301/56,688 = 18 percent).

Poultry

To compute the potential amount of DDGS that poultry could be fed during the corn crop year, we calculated the amount of DDGS fed per day times the days fed per year times the number of birds fed. For the number of birds fed during the crop year, we used an average beginning-of-the-month inventory number for layers and pullets and the number of birds slaughtered for broilers and turkeys (see tables 3 through 7).

Layers—We assumed that layers were fed for 10 months of the year for egg production and 2 months of the year were allocated to molting. During the molting period, they receive nothing but water for 2 weeks, and for the remaining 6 weeks, they receive a maintenance ration (Ensminger et al., 1990). We assumed a DDGS inclusion rate of 12 percent. We assumed that a 60 week old layer consumed 1.65 pounds of feed per week while producing eggs and a maintenance diet of 1.01 pounds per week during molting (Ensminger et al., 1990). The daily amount of DDGS fed to layers = a weighted average of 0.026 pounds ((0.2357 pounds of feed consumption per day x 12-percent DDGS inclusion x 10/12 months) + (0 pounds of feed consumption per day for 2 weeks) + (0.1442 pounds of feed consumption per day x 12-percent DDGS inclusion x 1.5/12 months)).

Pullets—We assumed that pullets were fed a 12-percent DDGS inclusion rate from 2 to 25 weeks, receiving an average of 0.1442 pounds per day for 365 days (Ensminger et al., 1990). The daily amount of DDGS fed to pullets = 0.017 pounds (0.1442 pounds of feed per day x 12-percent DDGS inclusion rate).

Broilers—We assumed that broilers were fed for 8 weeks, but for the first week DDGS were not included in the ration. The grow-finish ration lasted 7 weeks, for which we assumed a 10- percent DDGS inclusion rate. We averaged the cumulative amount fed to male and female broilers for the 7 weeks and divided by 49 days for an average daily amount fed times the DDGS inclusion rate. The daily amount of DDGS fed to broilers = a weighted average of 0.022 pounds ((((11.49 total pounds for male broilers weeks 2-7) + (9.75 total pounds for female broilers weeks 2-7) / 2) / 49days) x 10-percent DDGS inclusion rate in daily feed intake) (Ensminger et al., 1990).

Turkeys—We assumed that turkeys were fed for 6 months (male) and 5 months (female). DDGS were not fed to turkeys for the first 3 weeks. Starting week 4 and each week thereafter, DDGS were included in the ration at a 10-percent inclusion rate. We assumed that during this period male turkeys consumed 114.09 pounds of feed and females consumed 54.3 pounds of feed. We summed and divided these numbers by 2 to get an average and then divided by 147 days (the number of days fed DDGS). The daily amount of DDGS fed to turkeys = a weighted average of 0.057 pounds ((((114.09 total pounds of feed for males turkeys weeks 4-24 + 54.3 total pounds of feed for female turkeys weeks 4-20) / 2) / 147 days) x 10-percent of DDGS inclusion in daily feed intake) (Ensminger et al., 1990).

Appendix B: Effects of Alternative Market Share Assumptions Upon DDGS Substitution for Corn and Soybean Meal, by Type of Livestock/Poultry

Appendix table 1

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2006/07

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	42.0	43.3	10.4	4.3	100.0
Consumption (mmt)	5.3	5.4	1.3	0.5	12.5
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.73
Alternative #2	1.20	0.73	0.70	0.61	0.92
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.27
Alternative #2	0.00	0.63	0.30	0.44	0.32
12.5 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	5.3	2.4	1.2	0.3	9.1
Alternative #2	6.3	4.0	0.9	0.3	11.5
12.5 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	3.0	0.1	0.3	3.4
Alternative #2	0.0	3.4	0.4	0.2	4.0

mmt=Million metric tons.

[1]Converting from pounds to metric tons the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.73 metric ton of corn and 0.27 metric ton soybean meal. Alternative #2: Substitution rate = 1 metric ton DDGS substitutes for 1.24 metric ton of feed consisting of 0.92 metric ton of corn and 0.32 metric ton of soybean meal.

Source: Renewable Fuels Association market share estimates and tables 10, 11, and 14 from this report.

Appendix table 2

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2007/08

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	39.3	42.0	13.0	5.7	100.0
Consumption (mmt)	6.9	7.4	2.3	1.0	17.6
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.73
Alternative #2	1.20	0.73	0.70	0.61	0.90
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.27
Alternative #2	0.00	0.63	0.30	0.44	0.33
17.6 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	6.9	3.3	2.0	0.5	12.8
Alternative #2	8.3	5.4	1.6	0.6	15.9
17.6 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	4.1	0.2	0.5	4.8
Alternative #2	0.0	4.7	0.7	0.4	5.8

mmt=Million metric tons.

[1]Converting from pounds to metric tons the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.73 metric ton of corn and 0.27 metric of soybean meal. Alternative #2: Substitution rate = 1 metric of DDGS substitutes for 1.23 metric ton of feed consisting of 0.90 metric ton of corn and 0.33 metric ton of soybean meal.

Source: Renewable Fuels Association market share estimates and tables 10, 11, and 14 from this report.

Appendix table 3

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2008/09

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	38.3	40.3	14.7	6.7	100.0
Consumption (mmt)	8.3	8.8	3.2	1.5	21.8
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.73
Alternative #2	1.20	0.73	0.70	0.61	0.89
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.27
Alternative #2	0.00	0.63	0.30	0.44	0.33
21.5 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	8.3	4.0	2.9	0.8	15.9
Alternative #2	10.0	6.4	2.3	0.9	19.6
21.5 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	4.8	0.3	0.7	5.9
Alternative #2	0.0	5.5	1.0	0.7	7.1

mmt=Million metric tons.

[1]Converting from pounds to metric tons the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.73 metric ton of corn and 0.27 metric of soybean meal. Alternative #2: Substitution rate = 1 metric of DDGS substitutes for 1.22 metric ton of feed consisting of 0.89 metric ton of corn and 0.33 metric ton of soybean meal.

Source: Renewable Fuels Association market share estimates and tables 10, 11, and 14 from this report.

Appendix table 4

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2009/10

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	40.4	39.4	11.8	8.4	100.0
Consumption (mmt)	10.3	10.0	3.0	2.1	25.5
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.73
Alternative #2	1.20	0.73	0.70	0.61	0.90
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.27
Alternative #2	0.00	0.63	0.30	0.44	0.32
25.5 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	10.3	4.5	2.7	1.1	18.6
Alternative #2	12.3	7.3	2.1	1.3	23.1
25.5 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	5.5	0.3	1.1	6.9
Alternative #2	0.0	6.3	0.9	0.9	8.2

mmt=Million metric tons.

[1]Converting from pounds to metric tons the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1.00 metric ton of feed consisting of 0.73 metric ton of corn and 0.27 metric ton of soybean meal. Alternative #2: Substitution rate = 1 metric ton of DDGS substitutes for 1.22 metric ton of feed consisting of 0.90 metric ton of corn and 0.32 metric ton of soybean meal.

Source: Renewable Fuels Association market share estimates and tables 10, 11, and 14 from this report.

Appendix table 5

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2010/11

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	41.4	39.4	10.1	9.1	100.0
Consumption (mmt)	12.0	11.5	2.9	2.6	29.1
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.73
Alternative #2	1.20	0.73	0.70	0.61	0.91
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.27
Alternative #2	0.00	0.63	0.30	0.44	0.32
29.1mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	12.0	5.2	2.6	1.4	21.2
Alternative #2	14.4	8.4	2.1	1.6	26.5
29.1 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	6.3	0.3	1.3	7.9
Alternative #2	0.0	7.2	0.9	1.2	9.3

mmt=Million metric tons.

[1]Converting from pounds to metric tons the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1.00 metric ton of feed consisting of 0.73 metric ton of corn and 0.27 metric ton of soybean meal. Alternative #2: Substitution rate = 1 metric ton of DDGS substitutes for 1.22 metric ton of feed consisting of 0.91 metric ton of corn and 0.32 metric ton of soybean meal.

Source: Renewable Fuels Association market share estimates and tables 10, 11, and 14 from this report.

Appendix table 6

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2006/07

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	45.2	42.8	6.0	6.0	100.0
Consumption (mmt)	5.6	5.3	0.8	0.8	12.5
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.73
Alternative #2	1.20	0.73	0.70	0.61	0.93
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.27
Alternative #2	0.00	0.63	0.30	0.44	0.31
12.5 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	5.6	2.4	0.7	0.4	9.0
Alternative #2	6.7	3.9	0.5	0.5	11.6
12.5 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	2.9	0.1	0.4	3.4
Alternative #2	0.0	3.3	0.2	0.3	3.9

mmt=Million metric tons.

[1]Converting from pounds to metric tons the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.73 metric ton of corn and 0.27 metric ton of soybean meal. Alternative #2: Substitution rate = 1 metric ton of DDGS substitutes for 1.24 metric ton of feed consisting of 0.93 metric ton of corn and 0.31 metric ton of soybean meal.

Source: Wisner (2011) market share estimates and tables 10, 11, and 14 from this report.

Appendix table 7

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2007/08

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	47.6	40.4	6.0	6.0	100.0
Consumption (mmt)	8.4	7.0	1.1	1.1	17.6
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.74
Alternative #2	1.20	0.73	0.70	0.61	0.94
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.26
Alternative #2	0.00	0.63	0.30	0.44	0.30
17.6 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	8.4	3.2	0.9	1.3	13.1
Alternative #2	10.0	5.1	0.7	1.6	16.6
17.6 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	3.9	0.1	1.3	4.5
Alternative #2	0.0	4.4	0.3	1.1	5.2

mmt=Million metric tons.

[1]Converting from pounds to metric tons the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.74 metric ton of corn and 0.26 metric ton of soybean meal. Alternative #2: Substitution rate = 1 metric ton of DDGS substitutes for 1.24 metric ton of feed consisting of 0.94 metric ton of corn and 0.30 metric ton of soybean meal.

Source: Wisner (2011) market share estimates and tables 10, 11, and 14 from this report.

Appendix table 8

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2008/09

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	50.0	38.0	6.0	6.0	100.0
Consumption (mmt)	10.9	8.3	1.3	1.3	21.8
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.76
Alternative #2	1.20	0.73	0.70	0.61	0.95
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.24
Alternative #2	0.00	0.63	0.30	0.44	0.28
21.8 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	10.9	3.7	1.2	0.7	16.5
Alternative #2	13.0	6.1	0.9	0.8	20.8
21.8 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	4.6	0.1	0.7	5.3
Alternative #2	0.0	5.2	0.4	0.6	6.2

mmt=Million metric tons.

[1]Converting from pounds to metric tons the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.76 metric ton of corn and 0.24 metric ton of soybean meal. Alternative #2: Substitution rate = 1 metric ton of DDGS substitutes for 1.23 metric ton of feed consisting of 0.95 metric ton of corn and 0.28 metric ton of soybean meal.

Source: Wisner (2011) market share estimates and tables 10, 11, and 14 from this report.

Appendix table 9

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2009/10

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	52.4	35.6	6.0	6.0	100.0
Consumption (mmt)	13.4	9.1	1.5	1.5	25.5
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.77
Alternative #2	1.20	0.73	0.70	0.61	0.96
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.23
Alternative #2	0.00	0.63	0.30	0.44	0.27
25.5 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	13.4	4.1	1.4	0.8	19.6
Alternative #2	16.0	6.6	1.1	0.9	24.6
25.5 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	5.0	0.2	0.8	5.9
Alternative #2	0.0	5.7	0.5	0.7	6.9

mmt=Million metric tons.

[1]Converting from pounds to metric tons the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.77 metric ton of corn and 0.23 metric ton of soybean meal. Alternative #2: Substitution rate = 1 metric ton of DDGS substitutes for 1.23 metric ton of feed consisting of 0.96 metric ton of corn and 0.27 metric ton of soybean meal.

Source: Wisner (2011) market share estimates and tables 10, 11, and 14 from this report.

Appendix table 10

Total U.S. DDGS substitution for corn and soybean meal, by livestock/poultry type, crop year 2010/11

	Type of livestock/poultry				
	Beef cattle	Dairy cattle	Swine	Poultry	Total
Estimated:					
Market share (percent)	53.4	34.1	6.9	5.6	100.0
Consumption (mmt)	15.5	9.9	2.0	1.6	29.1
Substitution rate for…[1]					
1 pound of DDGS substitutes for how many pounds of corn:			*Pounds*		
Alternative #1	1.00	0.45	0.89	0.51	0.78
Alternative #2	1.20	0.73	0.70	0.61	0.97
1 pound of DDGS substitutes for how many pounds of soybean meal:					
Alternative #1	0.00	0.55	0.10	0.50	0.22
Alternative #2	0.00	0.63	0.30	0.44	0.26
29.1 mmt of DDGS substitutes for how many mmt of corn:			*mmt*		
Alternative #1	15.5	4.5	1.8	0.8	22.6
Alternative #2	18.6	7.3	1.4	1.0	28.2
29.1 mmt of DDGS substitutes for how many mmt of soybean meal:					
Alternative #1	0.0	5.5	0.2	0.8	6.5
Alternative #2	0.0	6.3	0.6	0.7	7.6

mmt=Million metric tons.

[1]Converting from pounds to metric tons the substitution rate becomes—Alternative #1: Substitution rate = 1 metric ton of DDGS substitutes for 1 metric ton of feed consisting of 0.78 metric ton of corn and 0.22 metric ton of soybean meal. Alternative #2: Substitution rate = 1 metric ton of DDGS substitutes for 1.23 metric ton of feed consisting of .97 metric ton of corn and 0.26 metric ton of soybean meal.

Source: Wisner (2011) market share estimates and tables 10, 11, and 14 from this report.