Executive Summary

This 3rd Edition of the DDGS User Handbook updates our previous editions with information on recent research and experience on DDGS use. This edition also includes several new chapters discussing low fat DDGS now being produced in many U.S. ethanol plants.

The U.S. ethanol industry includes several different plant designs and production technologies, and uses several different grains as feedstocks for ethanol production – including a wide diversity of corn varieties and sources. With the evolving technology for corn fractionation and for oil extraction, the industry produces many different products as DDGS. As a result, no single DDGS commodity exists. This Handbook gives buyers tools they need in developing relationships with U.S. DDGS sellers, so that buyers can be confident of the value of the DDGS they purchase.

This version of the Handbook is divided into numerous short chapters, which enable readers to find quickly the specific information they are seeking. Those chapters are summarized below --

Introduction to U.S. DDGS – An Excellent Ingredient for Use in Animal Feeds – Recent record high feed ingredient prices around the world are causing animal nutritionists to search for lower cost alternative feed ingredients to minimize the cost of food animal production. U.S. dried distiller's grain with solubles (DDGS) is an excellent, lower cost alternative feed ingredient that continues to be produced in large quantities by the dry-grind fuel ethanol industry. The high energy, mid-protein, and high digestible phosphorus content of DDGS make it a very attractive, partial replacement for some of the more expensive, traditional energy (corn), protein (soybean meal), and phosphorus (mono- or dicalcium phosphate) used in animal feeds. When DDGS is added to properly formulated feeds, it results in excellent animal health, performance, and food product quality. These attributes, and others, have made DDGS one of the most popular feed ingredients for use in animal feeds around the world.

Ethanol Production and Its Co-Products – Dry-Grind and Wet Milling Processes – Most ethanol plants in the United States are dry-grind facilities which use starch from corn to produce ethanol and the remainder of the corn kernel is used to produce a variety of wet and dried distillers grains co-products including DDGS. In dry-grind ethanol production, each bushel of corn (25.4 kg) produces about 11.8 liters of ethanol, 7.7 kg of DDGS, and carbon dioxide. Wet mills represent a significant, but smaller proportion of the U.S. ethanol industry and produce corn gluten feed, corn gluten meal, and corn germ meal as the primary co-products.

Ethanol Production and Its Co-Products – Front-End Fractionation and Back-End Oil Extraction Technologies – Corn fractionation has been used for many years to produce specialized industrial and food grade products. A relatively small number of dry-grind ethanol plants implemented "front-end" fractionation technologies to separate the endosperm (starch rich fraction) from the non-fermentable fractions including the germ and bran. Several new corn co-products, including high-protein DDGS were produced using these technologies, but because of poor long-term economic viability of using these technologies, very, few U.S. dry-grind ethanol plants are using "front-end" fractionation technologies today. However, recently "back-end" oil extraction technologies have become widely adopted by the majority of U.S. dry-grind ethanol plants. In this process, approximately one-third of the corn oil is removed from thin stillage prior to producing a "reduced-oil" DDGS. The resulting DDGS from this process

contains 7 to 9 percent crude fat, and has slightly more crude protein and fiber than DDGS produced without oil extraction. Limited scientific information has been published evaluating the impact of reduced-oil on energy content, but all of the currently available information on this topic is summarized for beef, dairy, poultry, and swine in Chapters 15,18, 20, and 22 of this Handbook.

Nutrient Composition and Digestibility of DDGS: Variability and *In Vitro* Measurement – The variability in nutrient content and digestibility among DDGS sources can be a challenge when determining economic and feeding value for livestock and poultry. However, new nutritional "tools" have been developed, including metabolizable energy (ME) prediction equations for DDGS in swine and poultry diets and equations as well as chemical procedures for estimating digestible amino acid content for poultry and swine. Some commercial companies have developed nutritional "tools" to rapidly, accurately and inexpensively estimate total and digestible nutrient content of specific DDGS sources.

Recommended Laboratory Analytical Procedures for DDGS – Laboratory analysis of feed ingredients, including DDGS, is important to verify that guaranteed nutritional specifications are met, determine nutrient composition for accurate feed formulation, and to determine the presence and concentration of any potential contaminants. Chapter 5 of this Handbook describes recommended analytical procedures to use when verifying contract specifications for moisture, crude protein, crude fat and crude fiber in DDGS. Recommend laboratory analysis procedures are also described for use in determining concentrations of several nutrients of importance in diet formulations as well as methods for determining the presence of potential contaminants such as mycotoxins.

Comparison of Different Grain DDGS Sources – Nutrient Composition and Animal Performance – A variety of feedstocks are used to produce ethanol and DDGS around the world. Grains, such as corn, wheat, and barley vary in starch content, and those with the greatest amount of starch (e.g. corn) are used to a greater extent because they provide the greatest ethanol yield. Since the nutrient composition of grains used to produce ethanol varies, the nutrient composition of the resulting distiller's grains also varies and must be considered when using DDGS produced from different grains sources.

Physical and Chemical Characteristics Related to Handling and Storage of DDGS – Physical and chemical properties of DDGS vary among sources and can influence its feeding value, handling, and storage characteristics. These include color, smell, particle size, bulk density, pH, flowability, shelf-life stability, and hygroscopicity. Considerable research has been conducted during the past few years to measure various physical properties, particularly focused on flowability of DDGS. Moisture content of DDGS is important in order to minimize transportation costs, reduce flowability problems, and the risk of microbiological spoilage. Bulk density is an important factor in determining the storage volume of transport vehicles, vessels, containers, totes, and bags, as well as transport and storage costs.

Is Color the Only or Best Indicator of DDGS Quality? – Currently, there are no grading systems that define and regulate the quality standards for DDGS like those existing for corn and other grains exported from the U.S. Color of feed ingredients has historically been used as a

subjective indicator of the amount of heat damage, and consequently amino acid digestibility. As a result, color has become a quality assessment factor for some DDGS buyers in the export market. Although a darker colored DDGS sample may indicate reduced amino acid digestibility for poultry and swine, it is not always the case. Many factors influence the color of DDGS, and other measurements of quality should be used in order to obtain an accurate assessment of DDGS quality.

Antibiotic Use in DDGS Production – Antibiotics have been used in relatively small quantities to control bacterial infections during fermentation in ethanol production for many years, and virginiamycin and penicillin have been most commonly used. The U.S. FDA has approved the use of virginiamycin in ethanol production, and the scientific evidence available indicates that there are no concerns for residues or risks to animal and human health. A recent survey conducted by the University of Minnesota shows that less than 1 percent of distillers grains samples had penicillin or tetracycline residues, no samples had tylosin residues, and 1.3 percent had detectable levels of virginiamycin residues, which were below the 1 ppm level of being Generally Recognized as Safe. Erythromycin residues were found in 10 percent of the 159 samples, but concentrations were less than 0.8 ppm. Only one sample from this survey showed some inhibition to a sentinel strain of E. coli, but that sample had no detectable concentrations of the 5 antibiotics tested. These results indicate that the prevalence and concentrations of antibiotic residues are very low, and residues appear to be inactivated during the DDGS production process. Therefore, DDGS continues to be a safe feed ingredient for use in all animal feeds.

Mycotoxins in DDGS – Like many grain-based feed ingredients, DDGS may contain amounts of mycotoxins that can negatively affect animal performance or be produced and stored under conditions that cause mold growth and mycotoxin production. Mycotoxins can be present in DDGS if the grain delivered to an ethanol plant is contaminated with them. Mycotoxins are not destroyed during the ethanol production process, nor are they destroyed during the drying process used to produce DDGS. If mycotoxins are present in corn, their concentration in DDGS will be increased by 3 times. However, the risk of mycotoxins in DDGS is very low because it is uncommon for most of the major corn producing region in the U.S. to have adverse weather and climatic conditions that lead to mycotoxin production in corn. Furthermore, most ethanol plants monitor grain quality and reject corn sources that are contaminated with mycotoxins. Only approved mycotoxin testing procedures should be used when determining the presence and concentration of mycotoxins in DDGS.

Mycotoxin Situation with the 2011 U.S. Corn Crop and 2012 DDGS Production – In 2011, a few states (Ohio, Michigan, Indiana, and Nebraska) in the U.S. Corn Belt had corn growing and harvesting weather conditions conducive to vomitoxin production. Although DDGS produced in these states may have higher concentrations of vomitoxin than DDGS produced in other Midwestern U.S. states, the majority of DDGS produced in 2012 will contain less than 1 ppm vomitoxin. Some DDGS samples produced in 2012 may also contain zearalenone, aflatoxins, and T-2 toxin, but the frequency and concentrations will be low.

Sulfur Concerns and Benefits in DDGS – When excess sulfur (greater than 0.40 percent of diet dry matter) is present in ruminant diets neurological problems caused by polioencephalomalacia can occur. Sulfur is reduced to hydrogen sulfide by rumen bacteria and accumulates in the rumen causing toxicity. Some DDGS sources contain high concentrations of

sulfur, and if DDGS is fed at a high dietary inclusion rate, depending on the sulfur concentrations in other dietary ingredients and water, polioencephalomalacia can occur. Supplementation of ruminant diets with copper or thiamine may alleviate this problem if high sulfur diets are fed. However, recent research conducted at the University of Minnesota has shown that high sulfur content in DDGS fed to pigs protects against oxidized oil, found occasionally in DDGS sources, by increasing sulfur-containing antioxidants in pigs.

Use of DDGS in Beef Cattle Diets – Corn DDGS is an excellent energy and protein source for beef cattle in all phases of production. It has 102 percent to 127 percent the energy value of dry-rolled corn and can be effectively used as an energy source and fed up to 40 percent of ration dry matter intake for finishing cattle with excellent growth performance and carcass and meat quality. However, at this high DDGS feeding rate, cattle will consume excess protein and phosphorus. The best applications for using DDGS in beef cow diets are in situations where 1) supplemental protein is needed (especially when feeding low quality forages) to replace corn gluten feed or soybean meal, 2) a low starch, high fiber energy source is needed to replace corn gluten feed or soy hulls, and 3) when a source of supplemental fat is needed. For growing heifers, adding urea to meet the degradable protein intake requirement is not necessary when DDGS is used as an energy source in forage based diets. DDGS can be an effective forage supplement to increase growth at times when availability of forage may be limited for growing heifers.

Use of Reduced-Oil DDGS in Beef Cattle Diets – One study has been conducted at the University of Nebraska to evaluate feeding diets containing 35 percent (dry matter basis) reduced-oil wet distillers grains with solubles (6.7percent crude fat) compared to wet distillers grains containing 12.9 percent crude fat. Feeding the reduced-oil distillers grains reduced growth rate and feed conversion compared to cattle fed the 12.9 percent wet distillers grains diet. Although the energy value (NEg) is reduced by 1.3 percent for each 1 percent reduction in oil content, reduced-oil DDGS had an energy value equal to corn and is still an excellent energy source for beef feedlot cattle.

Is There a Connection Between Feeding DDGS and E. coli O157:H7 Shedding in Beef Cattle? – Consumption of ground beef is the most frequently implicated cause of E. coli O157:H7 outbreaks in humans and food products from cattle have been linked to 75 percent of these outbreaks. Some feedstuffs appear to alter the shedding levels of E. coli O157:H7, but these effects have not been consistently shown. Fasting and feeding poor quality forages have been shown to increase shedding of E. coli O157:H7 in cattle, but abruptly switching cattle from a high grain diet to a high quality hay-based diets has been shown to reduce E. coli O157:H7 populations. Currently, there is no scientific evidence that indicates that feeding DDGS causes E. coli O157:H7 contamination in ground beef. If there is a possible connection between feeding cattle DDGS and increased shedding of E. coli O157:H7, the mechanism has not been identified.

Use of DDGS in Dairy Cattle Diets – Corn DDGS can be included in dairy cow diets up to 20 percent of the diet without decreasing dry matter intake, milk production, and percentage milk fat and protein. Adding 20 to 30 percent DDGS to a lactating cow diet also results in milk production being equal to, or greater than when diets containing no DDGS are fed. Milk fat percentage varies among various studies, but was not significantly changed by the inclusion of

distiller's grains in the diet. Milk protein percentage is decreased when more than 30 percent DDGS is added to the diet. When formulating diets containing DDGS for lactating dairy cows, consideration should be given to type of forage, forage to concentrate ratio, crude fat content of DDGS, and the need for supplemental crystalline lysine to achieve optimal performance. Corn DDGS can be effectively used in a total mixed ration by lactating dairy cows under heat-stressed climatic conditions making it a valuable feed ingredient for use in dairy rations in sub-tropical and tropical regions of the world. Although there has been limited research to evaluate feeding DDGS to growing dairy heifers, diets containing up to 40 percent DDGS have been used to achieve excellent growth rate and feed conversion in growing beef cattle rations.

Use of Reduced-Oil DDGS in Dairy Cattle Diets – One study has been conducted to evaluate the effects of feeding reduced-oil DDGS (3.5 percent crude fat) on milk production and composition of lactating dairy cows. Researchers at South Dakota State University fed diets containing 0, 10, 20, or 30 percent reduced-oil DDGS (replacing soybean meal) to cows and found no effect of increasing levels of reduced-oil DDGS on dry matter intake, crude protein intake, or milk production. Milk production efficiency, milk fat percentage, milk fat yield, and total milk solids increased linearly. Milk protein percentage responded quadratically and no effects were observed for efficiency of nitrogen utilization and milk protein yield when increasing levels of reduced-oil DDGS were fed. These results indicated that feeding a very low oil DDGS source had some positive effects with no negative effects on lactation performance of dairy cows.

Use of DDGS in Poultry Diets – Corn DDGS is an excellent feed ingredient for use in layer, broiler, duck, and turkey diets and contains approximately 85 percent of the energy value of corn for poultry. Conservatively, DDGS can be added at 5 to 8 percent of starter diets for broilers and turkeys, and 12 to 15 percent of diets for layers and growing-finishing diets for broilers, ducks, and turkeys when diets are not formulated on a digestible amino acid basis, and achieve excellent performance and egg and meat quality. Recent research studies have shown that DDGS can be added to poultry diets at even higher dietary inclusion rates (25 percent for layers and broilers) to achieve excellent performance and egg and meat quality provided that accurate nutrient profiles specific to the DDGS source are used, and diets are formulated on a digestible amino acid basis.

Use of Reduced-Oil DDGS in Poultry Diets – One study has been conducted at Auburn University to estimate the AME_n content of a variety of corn co-products with variable nutrient content including crude fat concentrations. The following energy prediction equation can be used to estimate the energy content of reduced-oil DDGS for broilers: AMEn (kcal/kg of dry matter) = 3,517 – (33.27 x % hemicellulose, dry matter basis) + (46.02 x % crude fat, DM basis) – (82.47 x % ash, DM basis). No performance, egg, or meat quality studies have been published related to feeding reduced-oil DDGS to poultry.

Use of DDGS in Swine Diets – Corn DDGS is an excellent for use in swine diets in all phases of production. Maximum recommended dietary DDGS inclusion rates to support excellent performance are up to 30 percent for nursery pigs weighing more than 7 kg, growing-finishing pigs, and lactating sows, and levels of up to 50 percent of the diet for gestating sows. These recommendations are based on the assumption that diets are formulated on a digestible amino acid basis. Feeding diets containing more than 20 percent DDGS causes pork fat to become less firm. Therefore, depending on pork fat quality standards in a given country, some markets may require feeding no more than 20 percent DDGS throughout the grower-finisher

phase, or withdrawing it from the diet 3 to 4 weeks before harvest to achieve desired pork fat quality.

Use of Reduced-Oil DDGS in Swine Diets – One study has been conducted at the University of Minnesota to determine the relationship between crude fat and metabolizable energy (ME) content of DDGS, as well as develop prediction equations to estimate ME content using key nutrient fractions from chemical analysis. Results from this study showed a very poor relationship between crude fat and ME content of DDGS ranging from 5 to 13 percent crude fat (dry matter basis). Fiber content (measured as neutral detergent fiber-NDF, acid detergent fiber-ADF, or total dietary fiber-TDF) and gross energy (GE) content of reduced-oil DDGS are more important factors that determine ME content. The following equations can be used to accurately estimate ME content in DDGS regardless of crude fat content:
ME kcal/kg DM = 1,352 + (0.757 x GE kcal/kg) – (51.4 x % TDF)
ME kcal/kg DM = 4,440 – (68.3 x % ADF)
ME kcal/kg DM = 3,711 – (21.9 x % NDF) + (48.7 x % Crude fat)

Managing Pork Fat Quality When Feeding High Amounts of DDGS to Growing-Finishing Pigs – It is well established that the amount and composition of fatty acids in a grower-finisher swine diet directly affects the fatty acid composition and firmness of pork fat. Pork fat firmness is an important overall characteristic of pork quality and affects shelf-life, flavor, processing characteristics, and consumer acceptance. Feeding corn-soybean meal diets containing increasing dietary levels of DDGS linearly reduces pork fat firmness because of the high concentration of polyunsaturated fatty acids in the corn oil present in DDGS. In countries where pork fat quality is a concern, no more than 20 percent DDGS should be included in grower-finisher swine diets. Alternatively, higher (> 20 percent) dietary DDGS inclusion rates can be used if 1) DDGS is removed from the diet 3 to 4 weeks before harvest, 2) reduced-oil DDGS is used, 3) diets are formulated based on iodine value product, and 4) barley and/or wheat are used as the predominant grain sources in grower-finisher diets containing DDGS.

Use of Enzymes in DDGS Diets for Poultry and Swine – Most of the starch is removed from corn during ethanol production resulting in concentrated levels of protein, oil, fiber, and minerals in DDGS. Poultry and swine can only utilize moderate amounts of dietary fiber for energy, but DDGS contains more gross energy than corn. Therefore, there is considerable interest in using carbohydrase enzymes to improve the energy value of DDGS for poultry and swine. Most commercial enzyme products have been targeted toward poultry and swine and can be effective in diets containing small grains other than corn. However, in corn-based diets, the addition of commercial carbohydrases and proteases has resulted in inconsistent or no improvements in energy and nutrient digestibility. Poultry tend to derive more consistent benefits from carbohydrases than swine, presumably because of differences in digesta viscosity between the two different types of gastrointestinal tracts. Addition of phytase enzymes to DDGS diets have little added benefit of improving phosphorus digestibility in DDGS, but dramatically improve phosphorus digestibility in other ingredients such as corn and soybean meal.

Use of DDGS in Aquaculture Diets – Aquaculture is one of the fastest growing food producing industries in the world. Traditionally, fish meal has been used as the predominant protein source in most aquaculture diets, but high cost and reduced supply availability have caused fish nutritionists to use less expensive plant-based protein sources like DDGS. As a

result, there is increasing interest in using DDGS in aquaculture diets around the world due to its moderately high protein content, relatively low phosphorus content, and low cost compared to fish meal. Furthermore, DDGS does not contain anti-nutritional factors found in other protein sources such as soybean meal (trypsin inhibitors) or cottonseed meal (gossypol). Limited studies have been conducted to evaluate the addition of DDGS to catfish, rainbow trout, tilapia, sunshine bass, Pacific white shrimp, and freshwater prawns. Adding 10 percent DDGS to all aquaculture feeds can result in excellent performance, and DDGS levels up to 20 to 30 percent can also result in excellent performance if adequate additions of some crystalline amino acids (e.g. lysine, methionine, tryptophan) are added, or other complementary protein sources containing higher levels of amino acids are included in fish feeds.

Use of DDGS in Sheep and Goat Diets – While limited studies have been conducted to evaluate the effects of feeding DDGS to sheep and goats compared with other species, DDGS is an economical and excellent feed ingredient in diets for sheep and goats. The high fiber and low starch content of DDGS provides diet formulation flexibility and allows it to safely partially replace a portion of the forage or grain in diets with reduced risk of rumen acidosis compared to feeding grain-based diets. Dried distillers grains with solubles can be an excellent protein and energy supplement for ewes and growing-finishing lambs to replace a portion of the corn and soybean meal in the diet. Like cattle, sulfur content of the diet should be monitored and managed, especially when feeding high levels of DDGS with moderate to high sulfur levels. Conservatively, adding DDGS at a level of 20 percent of growing-finishing lamb diets and 25 percent of lactating ewe diets will provide good performance results, although some studies have shown that DDGS can be added at levels up to 50 percent of the ration of growing-finishing lambs without affecting growth performance or carcass quality.

Use of DDGS in Horse and Companion Animal Diets – Very little research has been conducted related to feeding diets containing DDGS to horses and other companion animals. However, because of the increasing supply and availability of high quality and relatively low cost U.S. DDGS produced today, it is becoming a more popular ingredient for use in horse feeds and commercial pet foods. Based upon the limited research information available, it appears DDGS is a very suitable ingredient at inclusion rates up to 20 percent of the diet for horses, rabbits, and dogs.

Impact of Diet Formulation Methods and Tools on Assessing Value of DDGS – One of the challenges of obtaining the best economic and nutritional value from U.S. DDGS is to know actual nutrient content and digestibility of the DDGS source being used. Several DDGS value calculator tools have been developed to determine DDGS feeding value for livestock and poultry. These tools are extremely useful for determining the actual economic value of DDGS in specific livestock and poultry diets. They should be used when evaluating whether the current price for DDGS is economical relative to its nutrient contributions and price relative to other competing ingredients. Depending on the nutrient composition of the DDGS source being used, and the diet formulation methods chosen, the relative economic and nutritional value of DDGS can vary substantially. Using accurate energy, amino acid, and phosphorus digestibility values for DDGS can reduce excessive feeding of nutrients, avoid nutrient deficiencies, and reduce diet costs while supporting optimal animal performance.

Factors that Affect DDGS Pricing and Transportation Logistics – One of the biggest factors for determining whether DDGS is an economical animal feed ingredient in the international market is the cost of transportation and logistics to import DDGS. A number of factors can affect DDGS pricing including: 1) U.S. demand for DDGS, 2) price of corn and soybean meal, 3) availability of supply for export, 4) seasonality of domestic DDGS consumption, 5) fluctuating transportation costs, and 5) import tariffs imposed by many countries. DDGS price follows the corn market more closely than the soybean meal market. Overall trends in both the corn and soybean meal markets affect the DDGS price, but daily volatility in the corn or soybean meal market on the Chicago Board of Trade does not always translate into daily volatility in the DDGS market. Ocean freight rates have varied dramatically over the past 5 years. The high volatility in charter vessel freight has a major impact on the cost of obtaining DDGS for international customers. The United States is currently the world's largest container importer, and shipping DDGS via containers is an excellent option for the discriminating buyer who is looking to purchase DDGS from a limited number of sources or ethanol plants. It is essential that DDGS importers know and trust their supplier. Importers should understand the exporting company's logistical and transportation capabilities. Freight spreads change. Exporters that have facilities and capabilities via multiple transit ways (Great Lakes, major rivers, Gulf of Mexico, Pacific Northwest) have a better ability to serve the export market around the globe. Purchasing DDGS at the lowest freight costs will require working with companies that have multiple transportation and loading options and flexibility.

Summary of U.S. Grains Council Sponsored International DDGS Feeding Trials – The effects of feeding U.S. DDGS to livestock, poultry, and fish have been evaluated by feed industry leaders and animal production companies from many countries. Feeding trials sponsored by the U.S. Grains Council have been conducted in Australia, Indonesia, Japan, Korea, Mexico, Taiwan, Thailand, and Vietnam. Results from these feeding trials involving various food animal species, using common diets found in these countries, have consistently shown positive performance and cost savings benefits of adding DDGS to animal feeds.

U.S. Suppliers of DDGS – There are over 36 experienced U.S. DDGS exporters listed in Chapter 32 of this Handbook who have DDGS supply available, transportation and logistics capabilities, and are eager to provide pricing information to current and potential DDGS customers around the world. Contact anyone of them for current prices and information about their capabilities to meet your DDGS supply needs.