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

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Introduction

The purpose of this report is to provide the Renewable Fuels Association an independent, scientific evaluation of the assumptions used in the Texas A&M "**FASOM**" model and the Iowa State University "**FAPRI/CARD**" system of models, involving the impact of distillers grains (DGS) on the Indirect Land Use Change analysis being conducted by the U.S. Environmental Protection Agency (EPA). In addition, the EPA lifecycle assessments of biofuels are based on 2022-era assumptions involving the level of new fractionation and corn oil separation technology adoption in the corn ethanol industry, and the impact of the resulting corn ethanol co-products in animal feeds on indirect land use change. The EPA is assuming that 20% of dry grind corn ethanol plants will be employing "front end" fractionation processes in 2022, with an additional 22% of corn ethanol plants employing "back end" corn oil separation technologies. Unfortunately, up to this point in time, the EPA has not considered the impact of these assumptions on the feed markets and land use, and has not adjusted the FASOM and FAPRI/CARD model assumptions to account for this significant level of production and market penetration of these distinctly different corn co-products. Therefore, another key section of this report involves estimating displacement ratios of new fractionated corn co-products in livestock and poultry feeds, based upon the limited scientific information available.

Review of "Agricultural Impacts of the Energy Independence and Security Act: FASOM Results and Model Description" (Beach et al., 2008)

This report accurately acknowledges that increased biofuels production results in increased production of co-products for use in animal feeds, which help mitigate environmental impacts of biofuels production by reducing land conversion and chemical inputs. However, the assumption that 1 lb. of DGS replaces 0.915 lbs. of corn and 0.085 lbs. of soybean meal is inaccurate. It is unclear how these assumptions were determined.

At least four factors must be used to determine DGS displacement ratios. These include percentage of market share by species, actual dietary inclusion rates by species, any changes in feed conversion when DGS is fed, and substitution rates of DGS for various competing ingredients. Currently, the dairy cattle and beef cattle sectors are the largest consumers of DGS (42% and 38% of total domestic consumption, respectively). It is likely that the dairy and beef industries will continue to be the largest consumers of DGS for the foreseeable future. However, rapid adoption of DGS in swine (14%) and poultry (6%) diets has occurred, and will likely continue, which will change the market share distribution among the four major livestock and poultry sectors. Currently, DGS feeding levels are 10 to 20% for dairy, 30 to 40% for feedlot beef cattle, 20 to 30% for growing-finishing pigs, and 7 to 15% for poultry.

The three most expensive nutrients provided in animal feeds are energy, protein (amino acids), and phosphorus. Several studies have been summarized by Erickson et al. (2006) that show that the energy value of wet distiller's grains is between 120 to 150% the value of dry rolled corn for cattle, and dried distiller's grains has lower energy value (120 to 127% the value of dry rolled corn), but each form of DGS is substantially higher in energy than corn. As a result of the substantially higher energy value of DGS compared to corn, feed conversion is substantially improved in cattle resulting in less feed required to get the same amount of weight gain or milk production than with corn alone. Distiller's grains are also high in ruminally undegradable protein making it an excellent protein source for cattle, which allows it to be a significant partial replacement for soybean meal and urea (non-protein nitrogen) in cattle feeds. Since the energy value of DGS for swine is about equal to corn, and for poultry, lower than corn, feeding DGS diets generally result in no improvement or change in feed conversion. All of these factors appear not to have been considered when establishing the FASOM model assumptions.

When accounting for the substantially higher energy value, high ruminally undegradable protein content, and improved performance when feeding DGS to cattle, a recent report by Shurson (2009) showed that the calculated displacement ratios are 1.36 and 1.25 for dairy and beef cattle, respectively (see **Appendix A**). This means that 1 pound of DGS replaces 0.73 lbs of corn and 0.63 lbs of soybean meal in dairy cow diets. Similarly, 1 pound of DGS replaces 1.20 lbs of corn and 0.05 lbs of urea (non-protein nitrogen) in beef cattle diets.

Compared to cattle, the energy value and protein quality of DGS is lower for swine and poultry, but has not limited the use of DGS in these food animal sectors. One advantage of feeding DGS to swine and poultry is the reduction in use of inorganic phosphate supplementation. In swine diets, Shurson (2009) calculated that the 1 pound of DGS replaces 0.70 lbs of corn, 0.30 lbs of soybean meal, and 0.03 lbs of inorganic phosphate, with the addition of small amounts of synthetic amino acids and calcium supplement, resulting in an overall ratio of 1.00. For poultry (composite of broilers, layers, and turkeys), 1 pound of DGS replaces 0.59 lbs of corn, 0.45 lbs of soybean meal, and 0.02 lbs of inorganic phosphate, with small additions of synthetic amino acids, fat and calcium supplement, resulting in an overall ratio of approximately 1.00 as well (Shurson, 2009).

When considering the current distribution of DGS use in these livestock and poultry sectors, along with the DGS displacement ratios by species, the overall aggregated displacement ratio for DGS is 1.25. The corn displacement of 0.895 reported by Shurson (2009) is similar to the 0.915 used in the FASOM model, but lower than the displacement ratio (0.955) in the Argonne National Laboratory (2008) report. However, Shurson (2009) calculated a much higher displacement for soybean meal (0.334) than used in the FASOM model (0.085) and in the Argonne (2008) report (0.291). Most of the reason for the higher soybean meal displacement in the Shurson (2009) report compared to the Argonne (2008) report can be explained by the greater proportion of soybean meal displaced (and less corn) in swine and poultry diets, with the remaining contribution coming mostly from savings in phosphate supplementation. The Argonne (2008) report did not consider use of DGS in the poultry industry, and used a lower swine dietary inclusion rate (10%) than the current level of 20%, used in the Shurson (2009) report.

On page 2-22 of the FASOM report, it is unclear what is meant by "This analysis assumes that DDG technology improves to pelletize and distribute DDG to a wider market. At the renewable fuel volumes analyzed in this rule, the amount of DDG in feed is unlikely to reach the maximum inclusion levels (30% to 40% for cattle), particularly if the ethanol industry continues to make progress in being able to improve the quality of DDG and adjust the nutritional content so that it is better suited for pork and poultry production."

Pelleting DGS has been a challenge using conventional pelleting equipment and processes in commercial feed mills, but it has not been a significant issue limiting market penetration. However, when DGS is added to typical corn-soybean meal based diets, the throughput of pelleted complete feeds in commercial feed mills is reduced. This has somewhat limited dietary inclusion rates of DGS in geographical locations where complete swine diets are pelleted. Flowability of dried DGS is a more significant problem that has limited its use. However, flowability issues have not substantially constrained the use of DGS in domestic and international feed markets.

Beef cattle, depending on a number of factors, have been fed DGS at dietary inclusion rates of 30% to 40% with good results. However, feeding these high DGS levels results in increased excretion of nitrogen and phosphorus in manure, and lower dietary inclusion rates may need to be used to meet best manure management practices. The impact of feeding DGS diets on increased manure nitrogen and phosphorus content has not been considered in the FASOM model. This is an important consideration related to the reduction in synthetic fertilizer inputs for crop production when livestock manure is applied to crop land. Contributions of manure nutrients, especially nitrogen and phosphorus, from all animal species must be considered in estimating the impact of the ethanol industry on greenhouse gas emissions, chemical inputs for crop production, and indirect land use change. Lactating dairy cattle are generally fed lower levels of DGS (10% to 20%) because of potential concerns with decreased milk fat levels.

The ethanol industry has not done much to adjust the nutritional content of DGS so that it is better suited to pork and poultry production, nor has it implemented industry wide programs to standardize quality and nutrient content. It has been well documented that the nutrient content and digestibility varies substantially among DDG sources (Spiehs et al., 2002;

Urriola, 2007). As a result, nutritional tools have been recently developed and are being implemented to estimate total and digestible nutrient content of individual DGS sources for more accurate diet formulation in order to manage this variability and increase DGS use in the livestock and poultry industries. The implementation of front-end fractionation and back-end oil extraction in ethanol plants is resulting in an increased variety of corn co-products that may or may not be as well suited for some feeding applications for various food animal species.

Review of "Technical Report: An Analysis of EPA Biofuel Scenarios with the CARD International Models" (CARD Staff, 2008)

On page 11 of the CARD Technical Report on "An Analysis of EPA Biofuel Scenarios with the CARD International Models", the authors indicate that DGS use by species is 61% in the beef cattle sector, 21% in the dairy industry, 9% in the pork industry, and 9% in the poultry sector. Although it is difficult to get accurate data on DGS usage by the various livestock and poultry sectors, these percentage usage rates are considerably different than those used in a recent technical review by Shurson (2009) that estimated DGS usage rates to be 38% for beef, 42% for dairy, 14% for swine, and 6% for poultry, and are substantially different than those from the 2008 Renewable Fuels Association Ethanol Industry Outlook (42% beef, 42% dairy, 11% swine, 5% poultry). Usage rates of DGS affect displacement ratios and the calculation of indirect land use changes because of differences in feeding value of DGS among species. However, when using the DGS displacement ratios in the Shurson (2009) report, and applying the species usage distribution in the CARD report, the overall displacement ratio would be 1.23, which is similar to 1.249 calculated in the Shurson (2009) report and slightly lower than the value (1.27) in the Argonne National Laboratory (2008) report. The high displacement ratio for dairy is minimized and the relative impact of the low displacement ratio for poultry is increased using the CARD assumptions for distribution of DGS.

The authors of the CARD report recognize that the differences in DGS usage by the various livestock and poultry sectors is related to producers accepting it as a viable alternative feed ingredient, as well as the dietary inclusion rates used. Three factors affecting the rate of adoption of DGS use were identified and include variability in nutrient content, storage stability, and ease of transport. I agree that these factors have affected the rate of adoption in the swine and poultry industries, but have had less impact in the rate adoption in the dairy and beef sectors. However, variability in nutrient content among DGS sources can be managed by knowing the source and its nutrient profile when formulating diets. It is well established that variability in nutrient content within a single DGS source is much more consistent than among sources (Spiehs et al., 2002). Furthermore, nutritional value assessment tools, such as Reveal (Cargill) and Illuminate (Value Added Science and Technology), are now beginning to be used to provide more accurate estimates of nutrient loading values for DGS sources in feed formulations.

Regarding DGS storage stability, there is very little published information on the need for adding antioxidants to DGS to minimize fat rancidity. However, results from field trials conducted in some countries in the DGS export market have shown no fat rancidity when stored for 10 weeks in hot humid conditions. Typically, DGS is stored for less than one month and often less than two weeks in commercial feed mills, which minimizes the risk of fat rancidity problems. The perception that DGS contains mycotoxins has slowed the rate of adoption of DGS in swine and poultry feeds, particularly in international markets. However, recent surveys (Zhang et al., 2009) have shown that the percentage of DGS samples containing mycotoxins is minimal, and if they are present, they are at levels below the FDA concern levels. Mold growth, and potential production of mycotoxins, occurs when the moisture content exceeds 15%. Almost all dried DGS is well below this moisture level, and typically ranges from 9 to 12% moisture, which prevents mold growth from occurring during storage.

No references were provided in the CARD report for the extent of DGS adoption in various livestock and poultry sectors. However, the reasons for relatively higher adoption rates in the beef and dairy sectors are accurate in recognition of the fact that DGS has higher economic and feeding value for ruminants compared to non-ruminants.

The CARD staff acknowledged that a considerable amount of research has been conducted to establish maximum dietary inclusion rates for all livestock and poultry species, but did not discuss the increase in feed conversion that occurs when feeding DGS to cattle (which impacts displacement ratios), and indicated higher feeding levels than are currently being used in beef, dairy, and poultry production. It is unclear if these high maximum dietary inclusion rates were used in the CARD model, or if they were simply discussed to provide information regarding the possible feeding levels that can be used for various species. Dietary inclusion rate assumptions do affect displacement ratios and indirect land use changes because disproportionate amounts of feed ingredient substitutions change as DGS levels increase in the diet.

The assumptions for corn displacement in the CARD/FAPRI model were 0.97 for beef and dairy, 0.89 for swine, and 0.79 for poultry. These values are substantially different than those used in the Shurson (2009) report, where corn displacement ratios were 1.20 for beef, 0.73 for dairy, 0.70 for swine, and 0.59 for poultry. Therefore, assuming that the CARD/FAPRI ratios were used in the CARD model calculations, corn displacement would be underestimated in the beef industry, and overestimated in the dairy, swine, and poultry industries compared to values in the Shurson (2009) and Argonne National Laboratory (2008) reports. Furthermore, soybean meal displacement values were underestimated in the CARD system of models (0.03 for beef and dairy cattle vs. 0.63 for dairy; 0.11 vs. 0.30 for swine; and 0.21 vs. 0.45 for poultry in the CARD and Shurson, 2009 reports, respectively). Because of the wide discrepancies in soybean meal displacement ratios between those used in the CARD system of models and those calculated in the Shurson (2009) report, the underestimated soybean meal displacement ratios used in the CARD model have less of a positive impact on the true value of DGS on reducing soybean production and soybean meal use than those determined by Shurson (2009).

As briefly mentioned in the FASOM model review, the CARD/FAPRI model does not appear to account for the fertilizer benefits of applying manure from livestock and poultry fed diets containing high DGS levels. Generally, depending on diet formulation methods and dietary DGS inclusion rates, the concentration of nitrogen and phosphorus can be significantly increased in variable types of animal manure. Increases in manure nitrogen and phosphorus content need to be considered in the model related to reduced synthetic fertilizer inputs for crop production.

Comments on EPA Draft Regulatory Impact Analysis

Although the EPA correctly acknowledges that DGS will substitute for different alternative feed ingredients in different animal diets, they incorrectly assume (based on information used in the FASOM and CARD models) that 1 pound of DGS would replace roughly 1 pound of "feed." I disagree with this "1 pound for 1 pound" assumption, because it doesn't accurately reflect feed ingredient displacement (substitution) rates in practical livestock and poultry diets, and significantly undervalues the actual feeding value of DGS. In my previous report for the Renewable Fuels Association for discussion on the impact of DGS on indirect land use change with the California Air Resource Board (Shurson, 2009), I described, in detail, the improvement in feed conversion when feeding DGS to cattle, actual diet composition changes when DGS is added to typical diets being fed, at conservative, but realistic maximum dietary inclusion rates. When accurately accounting for all of these factors across all animal species, the displacement ratio is 1.249 to 1.0, and the amount of actual soybean meal displaced is significantly higher than being credited in the FASOM and CARD models. In fact, the displacement ratios I calculated are similar to those obtained by Argonne National Laboratory (Arora et al., 2008).

On page 352 of the EPA DRIA (2009) report, the authors criticize the Argonne National Laboratory displacement ratios, suggesting that they do not take into account the "dynamic least cost feed decisions faced by livestock producers". It appears that the EPA authors do not fully understand least cost feed formulation decisions. When DGS is priced favorably (which it has been and continues to be) relative to other competing feed ingredients such as corn and soybean meal, it is generally added to livestock and poultry feeds at the highest dietary inclusion rate possible in order to minimize feed costs without compromising animal performance. In other words, as long as DGS is priced favorably relative to the ingredients it replaces, an analysis of DGS replacement based on a least-cost formulation method would likely produce results that are very similar to the simpler mass displacement method discussed in this paper. Rather, the deficiencies of the Argonne report were that it did not account for DGS use in the poultry industry, and the dietary inclusion rate for swine used in the calculations of displacement ratios was below current industry feeding practices. In my report (Shurson, 2009), I included poultry estimates and calculated a more realistic overall DGS displacement ratio. **Table 1** compares the conventional DGS "credits" as calculated recently by several sources.

Table 1. Comparison of DG mass displacement ratios for conventional DG from recent reports.

	DGS Mass Replacement Ratio (1 lb. DGS: conventional feed)			
	Corn	**Soybean meal**	**Other**	**Total**
Shurson (2009)	0.895	0.334	0.02	**1.249**
Argonne (2008)	0.955	0.291	0.025	**1.271**
O'Connor [IEA] (2009)	0.680	0.600	0.0	**1.280**
CARB, GTAP	1.0	0.0	0.0	**1.0**
FASOM	0.915	0.085	0.0	**1.0**
FAPRI	0.950	0.050	0.0	**1.0**

The authors of the EPA DRIA report recognize that fractionation technologies are being used to a limited extent in the ethanol industry, which substantially alters the nutrient composition and feeding value of resulting corn co-products. However, the extent to which these technologies will be adopted in the ethanol industry is extremely difficult to predict. Furthermore, quantities of resulting co-products, nutrient composition and digestibility by animal species, maximum dietary inclusion rates and animal performance responses are also difficult to predict because of lack of research data. However, using a number of assumptions, I have attempted to calculate displacement ratios for four fractionated corn co-products: corn bran, corn germ, high-protein DGS, and de-oiled DGS. The following estimated displacement ratio analysis may provide some value, along with the displacement ratios calculated in my previous analysis of DGS (Shurson, 2009), in establishing more realistic values for indirect land use changes resulting from both DGS and new fractionated corn co-products.

Finally, animal manure nutrient value is another significant factor that has not been considered in any of the models used to estimate indirect land use changes. Proper land application of animal manure significantly reduces the need for expensive synthetic fertilizer and significantly reduces crop input costs. In some animal species, feeding corn co-products can increase the nitrogen and phosphorus content of manure compared to feeding conventional diets. All livestock and poultry producers are required to determine nutrient content of manure and properly apply it to crop land to achieve its maximum value while minimizing any negative environmental impacts by using comprehensive nutrient management plans. The impact of animal manure must be considered in determining the overall impact of the ethanol industry on chemical, and therefore, energy inputs and indirect land use changes.

Estimated Displacement Ratios of New Dry Mill Fractionated Corn Co-products and Their Relative Value in Livestock and Poultry Diets

At least four factors must be used to determine corn co-product displacement ratios. These include percentage of market share by species (dairy, beef, swine, and poultry), actual dietary inclusion rates by species, any changes in feed conversion when corn co-products are fed, and substitution rates of corn co-products for various competing ingredients. Corn fractionation technologies are being implemented by some ethanol plants in an attempt to remove non-fermentable components of the corn kernel and improve ethanol yield. Because fractionation is a new and emerging technology in fuel ethanol production, there is limited published scientific information on nutrient composition, nutrient digestibility, and recommended maximum dietary inclusion levels for livestock and poultry.

Market share of fractionated co-product production and estimated potential use by species

Estimates of fractionated co-product production

There are no published data on the current level of production and diet usage rates of fractionated corn co-products. The EPA assumes that current wet mill capacity is 1.216 billion gallons/year and that capacity will remain constant between now and the year 2022. In addition, the EPA assumes that the total corn starch ethanol capacity will be 15 billion gallons/year by 2022. Using these assumptions, the dry grind ethanol production capacity will be 13.784 billion gallons/year. If we assume that 2.85 gallons of ethanol is produced per bushel of corn, this level of dry grind capacity would represent 4,836 million bushels of corn. Furthermore, the EPA assumes that 20% of dry grind ethanol plants will implement front-end fractionation, and 22% will implement back-end oil extraction by the year 2022. This leaves 58% of total co-product production devoted to producing conventional DGS. I believe that the extent to which front-end fractionation technologies will be implemented is being overestimated by the EPA. Rather, I predict that approximately 3 to 5% of ethanol plants will utilize front-end fractionation by the year 2022. The reasons for the lower level of adoption of fractionation technology in ethanol production are:

1. High capital investment required during current times of low or negative profits in ethanol production.

2. Difficulty starting up and keeping the technology functional in ethanol plants.

3. Greater emphasis on back-end oil extraction due to more favorable economic return on investment.

4. Undeveloped and uncertain market for co-products. The demand for fractionated corn co-products is minimal with the exception of high-protein DGS in some export markets.

Therefore, I believe that the EPA should reduce its estimates especially for the level of "front end" fractionation technology implemented in the dry-grind ethanol industry. The levels I have proposed are more reflective of the challenges the ethanol industry is facing with implementing these technologies and the extent of adoption of these technologies by 2022. However, I recognize that cost-reducing breakthroughs in fractionation technologies and improved economic conditions for ethanol producers could encourage wider adoption of the technologies that would be more closely in line with EPA estimates. But based on current knowledge and economic conditions, I believe EPA is overestimating the penetration of front-end technology, and slightly overestimating the extent of back-end oil extraction.

Nonetheless, if we assume the yields/bushel of corn of the major fractionated corn co-products (**Table 2**), and apply them to the EPA estimates of market share of fractionated co-products (**Table 3**), this would suggest that the U.S. ethanol industry would produce 21.64 million metric tonnes (MMT) of conventional DGS (wet and dried) which would represent 59.55% of total co-product production (excluding crude corn oil), followed by 7.24 MMT of de-oiled DDG (19.92%), 4.39 MMT of high-protein DDG (12.08%), 1.75 MMT of corn germ (4.82%), and 1.32 MMT of corn bran (3.63%). Additionally, the industry would produce approximately 0.48 MMT of crude corn oil. Using my proposed estimates for discussion and comparison purposes, the percentage of total corn co-product production resulting from a 5% adoption rate of front-end fractionation technology, and a 15% adoption rate of back-end oil extraction would result in 80% conventional DGS, 2.94% high-protein DDG, 0.88% corn bran, 1.17% corn germ, and 15% de-oiled DDG.

Table 2. Co-product yield (lbs. yielded per bushel of corn processed)

	Fractionation	Oil Extraction	Conventional
High protein DDG (1)	10		
De-oiled DDG (2)		15	
Corn bran	3		
Corn germ	4		
Crude corn oil		1	
Conventional DGS (3)			17

Estimated composition of crude protein, crude fat, and crude fiber

(1) Approx. 45% crude protein, 4% crude fat, 6% crude fiber

(2) Approx. 36% crude protein, 2.5% crude fat

(3) Approx. 29% crude protein, 10% crude fat, 7% crude fiber

Table 3. Estimated production and market distribution of fractionated co-products in 2022 using EPA estimates (million metric tonnes, unless noted otherwise).

	Fractionation	Oil Extraction	Conventional
Share of 2022 dry grind production (EPA)	20%	22%	58%
Bu. processed 2022 (millions)	967	1064	2805
Gross co-product yield	*million metric tonnes 2022*		
High protein(HP) DDG	4.39 (12.08%)[a]		
De-oiled DDG		7.24 (19.92%)	
Corn bran	1.32 (3.63%)		
Corn germ	1.75 (4.82%)		
Crude corn oil		0.48	
Conventional DGS			21.64 (59.6%)

[a]Numbers in ( ) are the percentages of total corn co-product production not including crude corn oil.

It is important to realize that fractionation and corn oil separation technologies decrease the volume of co-products that require drying, thus reducing the ethanol plant's fossil energy usage and GHG emissions. This energy "credit" is outside the scope of this analysis.

Estimates of fractionated co-product use by species

Because the availability of these co-products is limited, very little information is known about them, and the market has yet to be developed. Therefore, it is difficult to determine their future market share distribution by species. Using the estimated DGS distribution for 2008 (CHS, personal communication) as a starting point, the nutrient characteristics relative to the nutrient requirements of different animal species, and the limited information on nutrient digestibility and animal performance summarized in the following sections, I estimate the market share of each of these four co-products being consumed in 2022 in **Table 4**.

Table 4. Estimated % of consumption of total production by species of conventional DDG, high-protein DDG, de-oiled DDG, corn germ, and corn bran in 2022.

	Conventional DDG	HP DDG	De-oiled DDG	Corn Germ	Corn Bran
Dairy	36	30	20	10	40
Beef	34	30	30	5	58
Swine	20	25	30	20	2
Poultry	10	15	20	65	0

Dietary inclusion rates of fractionated co-products by species

References for scientific publications with results from feeding new, fractionated corn co-products to various livestock and poultry species are summarized in **Table 5**. The majority of these studies have evaluated nutrient content and digestibility, but not maximum dietary inclusion rates or determined their effects on animal performance. **Table 6** shows a summary of the maximum dietary inclusion rates of some fractionated corn co-products based on results from only a few animal feeding trials designed to determine animal growth/milk production responses. We have utilized this limited information to some extent when determining dietary inclusion rates for these co-products when formulating example diets.

Table 5. Summary of published studies involving feeding new fractionated corn co-products to livestock and poultry.

Species	HP-DDG	De-oiled DDG	Corn Germ	Corn Bran	Other
Beef feedlot cattle				Bremer et al. (2006) Berger and Singh (2009)	Partial DDGS fractionation (Depenbusch et al., 2008)
Lactating dairy cows	Kelzer et al. (2007) Mjoun et al. (2009b)	Mjoun et al. (2009a, b)	Kelzer et al. (2007) Abdelqader et al., (2006)	Kelzer et al. (2007) Janicek et al. (2007)	
Growing-finishing swine	Widmer et al. (2007) Widmer et al. (2008) Gutierres et al. (2009) Anderson et al. (2009)	Anderson et al. (2009)	Widmer et al. (2007) Widmer et al. (2008) Anderson et al. (2009)	Anderson et al. (2009)	Yeast product-Stein et al. (2005) Dried condensed soluble and dehydrated, de-germed corn co-products -Anderson et al. (2009)
Broilers	Batal (2007) Kim et al. (2008)		Batal (2007) Kim et al. (2008)	Batal (2007)	
Layers	Batal (2007) Kim et al. (2008)		Batal (2007) Kim et al. (2008)	Batal (2007)	
Turkeys	Batal (2007) Kim et al. (2008)		Batal (2007) Kim et al. (2008)	Batal (2007)	High protein hydrolyzed corn co-product (Abe et al., 2004)

Table 6. Maximum dietary inclusion rates of selected corn co-products for various species based on animal performance trials.

	Dairy	Beef	Swine	Poultry
HP-DDG	NA	NA	20%-30%	NA
De-oiled DDG	NA	NA	NA	NA
Corn bran	25%	45%	NA	NA
Corn germ	14%	NA	10%	NA

NA = not available

Changes in animal performance when feeding fractionated co-products

Dairy

Corn germ and corn bran are the only fractionated co-products that have been evaluated in performance trials to date. Adding 14% corn germ to the concentrate portion of a 55:45 forage to concentrate diet for lactating dairy cows will increase milk and milk fat yield, but at 21%, will decrease the concentration of milk fat (Abdelqader et al., 2006). Janicek et al. (2007) showed that when corn bran increased from 10 to 25% of the diet, there were no effects on dry matter intake and milk fat yield, but increased milk yield, milk protein yield, and feed conversion. The decrease in milk fat concentration with increasing levels of corn bran, coupled with the increase in total milk yield resulted in no differences between dietary treatments in 3.5% fat-corrected milk. Based on the results of these two studies, we conservatively assume in our calculation of displacement ratios for all co-products (including corn germ and corn bran) that milk yield and feed efficiency are unaffected although preliminary results from these two studies suggest improved performance.

Beef

Currently, only corn bran has been evaluated in a beef feedlot performance and carcass trial. Bremer et al. (2006) evaluated Dakota Bran Cake (DBRAN) on feedlot performance and carcass characteristics for finishing cattle and observed that feeding DBRAN up to 45% of the diet improves growth performance with no effects on carcass characteristics. Although, this study showed an improvement in cattle growth performance, it is the only study conducted and we have chosen to conservatively assume no change in growth performance when calculating displacement ratios for fractionated corn co-products fed to beef feedlot cattle.

Swine

One study (Widmer et al., 2008) evaluated the effects of feeding DDGS (10 or 20% of the diet), HP DDG (replaced 50 or 100% of soybean meal), and corn germ (5 or 10% of the diet) to growing-finishing pigs on growth performance, carcass quality, and palatability of pork. Results from this study showed that feeding diets containing 20% DDGS or high dietary inclusion rates of HP DDG had no negative effect on growth performance, carcass composition, muscle quality, and eating characteristics of bacon and pork chops, but may decrease pork fat quality. Similarly, feeding diets containing up to 10% corn germ had no negative effects on growth performance, carcass composition, carcass quality or eating characteristics of bacon and pork loins, but increased final body weight and improved bacon fat quality (reduced iodine value). Similar to preliminary results of feeding some of the fractionated corn co-products to dairy and beef cattle, there appear to be no negative effects, and potentially positive effects, on feeding diets containing high protein DDGS and corn germ to grower-finisher pigs, and the reduced oil in these co-products may improve pork quality.

Poultry

No performance trials have been conducted to evaluate the effects of feeding corn bran, corn germ, high-protein DDGS, and de-oiled DDGS on growth performance of broilers and turkeys, and egg production of layers. Without this information, we assume no change in bird performance when calculating displacement ratios for these ingredients.

Substitution rates of corn co-products for various competing ingredients

Knowing the complete nutrient profiles and digestibility estimates of energy, protein (amino acids) and phosphorus are essential when formulating animal diets with any ingredient. Because little research has been conducted to evaluate the nutrient composition and digestibility of fractionated corn co-products for various species, reasonable assumptions must be used to approximate displacement ratios in various animal diets. Furthermore, based on limited nutrient composition data available, nutrient content of these co-products can be highly variable and affect dietary usage rates and displacement ratios. As a result, conservative estimates of these factors were used in formulating diets and calculating displacement ratios.

References for scientific publications with results from feeding new, fractionated corn co-products to various livestock and poultry species are summarized in **Table 4**. The majority of these studies have evaluated nutrient content and digestibility, but not maximum dietary inclusion rates or determined their effects on animal performance. Estimates of dry matter, crude protein, crude fat, crude fiber, and ash concentrations for most of the known fractionated co-products are shown in **Table 7.**

Table 7. Nutrient composition of new, fractionated corn distiller's co-products (dry matter basis; Shurson and Alghamdi, 2008).

Company co-product	**Dry matter, %**	**Crude protein, %**	**Crude fat, %**	**Crude fiber, %**	**Ash, %**
Typical corn DDGS	89.3	30.9	10.7	7.2	6.0
Poet Dakota Gold HP	91.6	44.8	3.9	7.3	2.1
Poet Dakota Bran	ND[a]	14.6	9.8	3.8	4.6
Poet Dehydrated Corn Germ	93.2	16.9	18.9	5.5	5.8
Maize Processing Innovators (MPI) Quick Germ/Quick Fiber DDGS	ND	49.3	3.9	6.8	3.2
MPI E-Mill DDGS	ND	58.5	4.5	2.0	3.2
CPT Hi-Protein DDGS	ND	35.0-37.0	4.0-6.0	4.0-6.0	ND
Renessen Enhanced DDGS	ND	40.0-50.0	2.5-4.0	7.0-11.0	ND
Solaris NeutraGerm	97.0	17.5	45.0	6.0	1.9
Solaris Probran	90.0	9.5	2.0	16.6	1.0
Solaris Glutenol	90.0	45.0	3.3	3.8	4.0
Solaris Energia	90.0	30.0	2.5	8.2	2.5
FWS Tech. Enhanced DDGS	ND	35.0-37.0	6.5	ND	3.8
De-Oiled DDGS	89.9	31.3	2.3	ND	6.2
J. Jireh Products Dried Cond. Solubles	93.4	21.6	4.7	3.1	8.3

[a] ND = not determined

Nutrient digestibility estimates for some fractionated co-products have been determined and summarized for each species.

Dairy

Kelzer et al. (2007) conducted a study to determine protein fractions and evaluate differences in rumen undegradable protein (RUP), RUP digestibility (dRUP), and amino acid concentrations in corn germ, corn bran, high protein DDGS, two sources of DDG, wet corn gluten feed, and wet distillers grains (**Table 8**). Concentrations of RUP, dRUP, lysine, and methionine were different among corn milling by-product sources.

Beef

Bremer et al. (2006) evaluated Dakota Bran Cake (DBRAN) on feedlot performance and carcass characteristics for finishing cattle, and determined that it has approximately 100 to 108% the energy value of corn when fed at levels up to 45% of the diet.

Swine

Widmer et al. (2007) conducted three experiments to determine energy, phosphorus, and amino acid digestibility in high protein dried distillers grains (HP DDG) and corn germ, compared to corn. The digestible and metabolizable energy content of corn (4,056 and 3,972 kcal/kg of dry matter, respectively) was similar to that in corn germ (3,979 and 3,866 kcal/kg, respectively), but were surprisingly lower than HP DDG (4,763 and 4,476 kcal/kg, respectively). True total tract digestibility of phosphorus was higher in HP DDG (69%) compared to corn germ (34%), similar to values obtained by Kim et al. (2008) in poultry. Standardized ileal digestibility for crude protein and all amino acids except arginine, lysine, glycine, and proline were higher in HP DDG than in corn germ. Therefore, HP DDG has higher levels of digestible energy, phosphorus and most amino acids than corn germ for swine.

Anderson et al. (2009) evaluated 20 corn co-products from various ethanol plants in order to determine metabolizable energy content in diets for finishing pigs. Co-products included: DDGS (7), HP-DDG (3), bran (2), germ (2), gluten meal and feed, dehulled degermed corn, dried solubles, starch, and corn oil. Nutrient profiles and metabolizable energy content were highly variable among and within co-products.

Poultry

Batal (2007) determined the nutrient digestibility of DDGS, high protein corn distillers dried grains with solubles (HP-DDGS), dehydrated corn germ and bran for poultry (**Table 8**). These results show that new fractionation technologies used in ethanol production result in by-products that have unique nutritional properties and knowledge of their nutritional value is essential in order to assess their economic and feeding value.

High protein DDGS (33% protein, 0.33% phosphorus on a 90% dry matter basis) and corn germ meal (14% crude protein and 1.22% phosphorus) were fed to chicks and precision-fed roosters to determine true metabolizable energy (TMEn), amino acid digestibility, and phosphorus bioavailability for poultry (Kim et al., 2008). The TMEn and amino acid digestibility in corn germ meal was significantly higher compared to high protein DDGS, while P bioavailability was similar between DDGS and high protein DDGS (60 vs. 58%, respectively), but lower for corn germ meal (25%). These results suggest that corn germ meal is a better source of energy with higher amino acids digestibility than high protein DDGS, but DDGS and high protein DDGS are better sources of bioavailable phosphorus than corn germ meal for poultry.

Table 8. Comparison of protein fraction concentrations as a % of crude protein among seven corn milling co-products (Kelzer et al., 2007).

Protein fraction, % CP	Corn germ	Corn bran	High protein DDGS	DDGS 1	DDGS 2	Wet corn gluten feed	Wet distillers grains
Crude protein, % DM	16.3	13.5	47.2	30.1	28.9	26.7	29.9
Non-protein nitrogen	30.0	33.5	7.4	17.0	17.9	36.6	18.6
Rapidly degradable true protein	15.0	4.0	0.6	7.0	2.1	15.9	2.4
Moderately degradable true protein	38.1	54.3	82.4	67.0	41.0	33.2	53.1
Slowly degradable true protein	13.5	6.0	8.8	4.8	11.1	10.1	11.0
Undegraded true protein	3.4	2.2	0.8	4.2	27.9	4.1	14.9
Rumen undegraded protein	16.5	20.7	55.2	33.2	56.3	11.5	44.7
RUP digestibility	66.8	65.8	97.7	92.0	91.9	51.0	93.1
Lysine	2.9	3.2	2.0	1.9	1.9	3.5	1.9
Methionine	1.9	1.4	3.2	2.0	2.4	1.6	2.3

Source: Kelzer et al., 2007.

Table 9. Nutrient content and digestibility of DDGS, high protein DDGS, dehydrated corn germ, and corn bran for poultry (Batal, 2007).

Nutrient	DDGS	HP-DDGS	Dehydrated corn germ	Bran cake
Crude protein, %	27.0	44.0	15.5	11.6
Crude fiber, %	7.0	7.0	4.5	4.5
Crude fat, %	10.0	3.0	17.0	7.8
TME_n, kcal/kg	2,829	2,700	2,965	2,912
Lysine, %	0.79	1.03	0.83	0.43
Lysine availability, %	81	72	80	68
Lysine as a % of CP	2.9	2.3	5.4	3.7
Phosphorus, %	0.77	0.35	1.18	No data
P bioavailability, %	60	47	31	No data

Assumptions and Displacement Ratios - Dairy cattle

Two sets of diets were formulated for a 1400 lb mid-lactation dairy cow producing 80 lbs milk/day and consuming 50 lbs DM intake/day. The first set of diets used a typical Midwestern control diet consisting of alfalfa hay (17%), corn silage (52%)forage mix with variable amounts of corn grain, soybean meal (47%), dicalcium phosphate, calcium carbonate, and other minerals and vitamins for comparison (**Table 10**). The differences in the amount of alfalfa hay, corn silage, corn, soybean meal, and other ingredients were calculated with the addition of each of these individual co-products to the diet. By using this diet formulation approach, the amount of alfalfa hay and corn increased, while the amount of corn silage and soybean meal decreased in order to minimize diet cost and meet target nutrient levels, especially starch content. Under this scenario, corn grain displacement is negatively affected while soybean meal use is positively affected relative to their respective displacement ratios. However, another layer of assumptions and difficulty is added because of the potential increase in alfalfa acres and decrease in corn acres that would occur when accounting for the changes in alfalfa and corn silage use as a result of adding these co-products. In addition, minor and variable changes in the amount of dicalcium phosphate and calcium carbonate use are noted. I assume that feeding these diets would provide satisfactory milk production and milk composition compared to the control diet used for comparison.

Table 10. Partial replacement amounts of common feed ingredients and diet displacement ratios with inclusion of corn bran, de-oiled DDG, high-protein DDG, corn germ, and conventional DDG in lactating dairy cow diets when allowing adjustments in the amounts of forage (dry matter basis).

	Corn bran 7.4% DM intake	**De-oiled DDG 5.4% DM intake**	**HP DDG 7.24% DM intake**	**Corn Germ 4.6% DM intake**	**DDG 10% DM intake**
Alfalfa hay	+1.50	+7.66	+6.86	+5.06	+6.66
Corn silage	-9.00	-16.4	-11.00	-8.40	-16.66
Corn	+1.06	+7.26	+5.06	+1.86	+6.26
Soybean meal	-1.14	-4.22	-2.18	-2.62	-6.02
Soypass	0.00	0.00	0.00	0.00	0.00
Dical	-0.11	+0.11	+0.11	-0.19	-0.13
Calcium carbonate	+0.06	-0.26	-0.80	-0.06	-0.08
Displacement ratio	1.023	1.022	1.001	0.978	0.999

As shown in **Table 10**, overall diet displacement ratios were slightly above 1.0 for corn bran, de-oiled DDG and HP-DDG, whereas, conventional DDG was about 1.0 and corn germ was slightly less than 1.0. Because of the low starch content, but relatively high protein content in these co-products, adding them to the diet at approximately 5 to 10% resulted in a negative corn displacement ratio (corn was added to meet the dietary starch requirement,) but a significant and positive effect on soybean meal displacement (**Table 11**). Depending on the phosphorus content of these co-products, adding corn bran, corn germ, and conventional DDG had a positive, but small effect on inorganic phosphate displacement ratios. Adding de-oiled DDG and HP DDG had a negative effect on inorganic phosphate displacement because of their lower phosphorus content (**Table 11**).

Table 11. Corn, soybean meal, and inorganic phosphate displacement ratios for corn bran, de-oiled DDG, high-protein DDG, corn germ, and conventional DDG in lactating dairy cow diets when allowing dietary adjustments in the amounts of forage.

	Corn bran	**De-oiled DDG**	**HP DDG**	**Corn germ**	**Conventional DDG**
Corn displacement	-0.143	-1.344	-0.699	-0.404	-0.626
Soybean meal displacement	0.154	0.781	0.301	0.570	0.602
Inorganic phosphate displacement	0.015	-0.020	-0.015	0.041	0.013

In the second set of diets, we tried to maintain similar forage levels to minimize the increase in corn use while meeting the same nutrient requirements used in the first set of diets. When we did this, it dramatically reduced the dietary inclusion rates of all of the co-products evaluated, changed the diet composite displacement ratios slightly, but improved the corn and soybean meal displacement ratios compared to the first diet formation scenario (**Table 12**). Using this approach allows for direct calculation of corn and soybean meal displacement ratios (**Table 13**) without the assumptions and additional calculations needed to account for significant changes in alfalfa and corn silage use shown in **Table 10**.

Table 12. Partial replacement amounts of common feed ingredients and diet displacement ratios with inclusion of corn bran, de-oiled DDG, high-protein DDG, corn germ, and conventional DDG in lactating dairy cow diets when maintaining similar dietary levels of forage (dry matter basis).

	Corn bran 1.24%	**De-oiled DDG 1.52%**	**HP DDG 2.60%**	**Corn Germ 1.82%**	**DDG 2.20%**
Alfalfa hay	-0.400	-0.420	-0.380	-0.410	-0.190
Corn silage	+0.800	+0.760	+0.840	+0.770	+0.830
Corn	-0.100	+0.290	+0.310	-0.310	+0.110
Soybean meal	-1.540	-2.150	-3.530	-1.750	-2.540
Soypass	+0.040	+0.040	+0.040	+0.040	+0.040
Salt	+0.010	+0.010	+0.010	+0.010	+0.050
Min/vit	+0.010	+0.010	+0.010	+0.010	+0.010
Dical	-0.020	-0.040	+0.040	-0.120	+0.070
Calcium carbonate	-0.040	-0.020	+0.060	-0.060	-0.600
Displacement ratio	1.000	1.000	1.000	1.000	1.000

Using this diet formulation approach, overall diet displacement ratios were 1.0 for all co-products. Because of their low starch content, they were use at very low inclusion rates 1.2 to 2.6%, but it allows us to calculate a direct corn and soybean meal displacement without the added complexity of considering significant changes in forage composition in the diets. By using this approach, corn and soybean meal displacement ratios improved significantly compared to the first formulation approach used. Adding these co-products to the diets resulted in a positive, but relatively small corn displacement for corn bran (0.081) and corn germ (0.170), but corn displacement was negatively affected when de-oiled DDG, HP DDG and conventional DDG were added to the diet (**Table 13**). However, soybean meal displacement was very high (0.940 to 1.388) for all co-product diets, indicating that these co-products have substantial value as protein sources in dairy cow diets (**Table 13**). Adding corn bran, de-oiled DDG, and corn germ,had a positive effect on inorganic phosphate displacement ratios, but adding high-protein DDG and conventional DDG has a negative effect on inorganic phosphate displacement (**Table 13**). I chose to use these corn and soybean meal displacement ratios for calculating the composite index because they are on a corn and soybean meal equivalent basis, even though dietary inclusion rates are low.

Table 13. Corn, soybean meal, and inorganic phosphate displacement ratios for corn bran, de-oiled DDG, high-protein DDG, corn germ, and conventional DDG in lactating dairy cow diets when maintaining similar dietary levels of forage.

	Corn bran	De-oiled DDG	HP DDG	Corn germ	Conventional DDG
Corn displacement	0.081	-0.191	-0.119	0.170	-0.050
Soybean meal displacement	1.210	1.388	1.342	0.940	1.136
Inorganic phos. displacement	0.016	0.026	-0.015	0.066	-0.032

Assumptions and Displacement Ratios - Beef feedlot cattle

Two types of grain mixes are typically used for beef feed lot cattle. Beef producers n the Northern Plains states typically feed a high moisture corn and dry rolled corn mix, whereas producers in the Great Plains states feed a steam flaked corn diet. These differences will slightly affect displacement ratios. For purposes of keeping these calculations as simple as possible, I chose to use diets comprised of high moisture corn, dry rolled corn, and corn silage in these calculations. Calculations on displacement ratios for steam flaked corn diets can be provided if they are of interest for comparison purposes.

Unlike the relatively low dietary inclusion rates for these co-products in dairy diets, inclusion rates in beef feedlot cattle diets are relatively high, ranging from 16 to 53% depending on the co-product being considered (**Table 14**). As shown in **Table 14**, overall diet displacement ratios were highest for wet DDG (1.006), followed by corn germ (1.001), HP DDG (0.973), corn bran (0.971), and de-oiled DDG (0.808).

Table 14. Partial replacement amounts of common feed ingredients and diet displacement ratios with inclusion of corn bran, de-oiled DDG, high-protein DDG, corn germ, and conventional DDG in beef feedlot cattle diets (dry matter basis).

	Corn bran 53.05%	De-oiled DDG 37.1%	HP DDG 25.83%	Corn Germ 16.3%	Wet DGS 40%
HMC	-14.25	-1.21	-14.86	+0.23	-28.48
Corn silage	-16.66	-9.12	+10.15	+4.30	+10.34
DR Corn	-19.34	-19.34	-19.34	-19.34	-19.34
QLF	0.00	0.00	0.00	0.00	0.00
Soybean meal	-2.17	-2.17	-2.17	-2.17	-2.17
Urea	-0.44	-1.11	-1.11	0.00	-1.11
Dyna-K	0.00	0.00	0.00	0.00	0.00
Calcium carbonate	+1.37	+2.96	+2.21	+0.66	+0.54
Displacement ratio	0.971	0.808	0.973	1.001	1.006

These co-products have a major, positive effect on corn displacement ratios in beef cattle diets, with contributions to soybean meal and urea displacement ratios as well. The high protein DDG, conventional wet DDG, and corn germ have corn displacement ratios great than 1.0 due to their high energy value for beef feedlot cattle (**Table 15**). De-oiled DDG had the highest soybean meal and urea displacement value of all of the co-products considered, with significant, but lower contributions from the other co-products (**Table 15**). It appears that these co-products have the highest value in beef feedlot cattle diets compared to other species.

Table 15. Corn, soybean meal, and inorganic phosphate displacement ratios for corn bran, de-oiled DDG, high-protein DDG, corn germ, and conventional DGS in beef feedlot cattle diets.

	Corn bran	De-oiled DDG	HP DDG	Corn germ	Conventional DDG
Corn displacement	0.633	0.554	1.324	1.172	1.196
Soybean meal displacement	0.041	0.584	0.084	0.133	0.054
Urea displacement	0.008	0.030	0.043	0.000	0.028

Assumptions and Displacement Ratios – Swine

Typical corn-soybean meal based diets were formulated to meet the nutrient requirements of growing pigs. Diets contained high amounts of synthetic amino acids to minimize soybean meal use and excess crude protein (nitrogen) in the diets, and were formulated on a digestible amino acid and available phosphorus basis using conservative estimates of amino acid digestibility and phosphorus availability in the corn co-products. Metabolizable energy estimates for swine determined by Anderson et al. (2009) were used for all co-products evaluated. Energy, digestible amino acids, and available phosphorus content of the diets were maintained at constant levels, and animal fat was added to some diets containing co-products with low levels of metabolizable energy (corn bran and de-oiled DDG). As a result, overall diet displacement ratios were approximately 1.0. As shown in **Table 16**, de-oiled DDG, high protein DDG and conventional DDGS were added at 30% of the diet, while corn bran and corn germ were added at 10% inclusion rates to reflect potential actual feeding levels in swine diets.

Table 16. Partial replacement amounts of common feed ingredients and diet displacement ratios with inclusion of corn bran, de-oiled DDG, high-protein DDG, corn germ, and conventional DDGS in grower-finisher swine diets.

	Corn bran 10%	De-oiled DDG 30%	HP DDG 30%	Corn Germ 10%	Conventional DDG 30%
Corn	-10.83	-27.35	-27.27	-8.31	-25.41
Soybean meal, 47.5	+0.25	-2.60	-2.35	-1.65	-4.20
Animal fat	+0.68	+0.35	0.00	0.00	0.00
Monocal phos.	0.00	-0.30	-0.30	0.00	-0.30
Limestone	0.00	+0.10	+0.15	0.00	+0.10
Synthetic AA and phytase	-0.05	-0.20	-0.24	-0.043	-0.19
Displacement ratio	0.995	1.000	1.000	1.000	1.000

These co-products have a greater displacement of corn than soybean meal (**Table 17**), with corn displacement being highest for corn bran (1.083) and lowest for corn germ (0.831). Because of the high usage of synthetic amino acids and phytase in the diets, soybean meal and inorganic phosphate displacement were positive (except or diets containing corn bran), but lower than if these ingredients were not used.

Table 17. Corn, soybean meal, and inorganic phosphate displacement ratios for corn bran, de-oiled DDGS, high-protein DDGS, corn germ, and conventional DDGS in grower-finisher swine diets.

	Corn bran	De-oiled DDGS	HP DDGS	Corn germ	Conventional DDG
Corn displacement	1.083	0.912	0.909	0.831	0.847
Soybean meal displacement	-0.025	0.087	0.078	0.165	0.140
Inorganic phos. displacement	0.000	0.010	0.010	0.000	0.010
Synthetic amino acid and phytase displacement	0.005	0.007	0.008	0.004	0.006

Assumptions and Displacement Ratios – Poultry

Grower turkey diets were formulated using the best available data on nutrient composition of the corn co-products. The feed ingredient displacements shown in **Table 18** are based on the highest likely dietary inclusion for each co-product (15 to 20% of the diet). Corn bran was not considered because of its high fiber and low energy value for poultry. Broiler and layer diets would likely contain lower dietary inclusion rates of these co-products until more feeding trials have been conducted demonstrating their acceptability as alternative feed ingredients. Constant energy, amino acids, and phosphorus were maintained in these diets resulting in an overall composite diet displacement value of approximately 1.0. Due to the estimated low energy content of these co-products, animal fat was added to maintain acceptable dietary energy levels. Corn germ has the highest value in turkey diets because it has the highest corn displacement value (1.071, **Table 19**), reduces the amount of synthetic amino acid supplementation, and reduces the amount of inorganic phosphorus supplementation needed. De-oiled DDG, high protein DDG, and conventional DDGS additions to the diet result in significant soybean meal displacement (0.589, 0.673, and 0.405, respectively), compared to corn germ. High protein DDG had a negative inorganic phosphate displacement, whereas de-oiled DDG, corn germ and conventional DDG had a small but positive effect (**Table 18**).

Table 18. Partial replacement amounts of common feed ingredients and diet displacement ratios with inclusion of corn bran, de-oiled DDGS, high-protein DDGS, corn germ, and conventional DDGS in grower turkey diets.

	De-oiled DDG 15%	**HP DDG 15%**	**Corn Germ 20%**	**DDG 20%**
Corn	-8.84	-5.27	-21.42	-12.40
Soybean meal 47.5	-7.62	-10.09	-0.02	-8.09
Animal fat	+1.44	+0.18	+1.63	+0.48
Monocal phos.	-0.07	+0.11	-0.07	-0.07
Limestone	+0.06	+0.02	+0.03	+0.06
Salt	-0.12	-0.04	+0.01	-0.09
Synthetic amino acids	+0.12	+0.07	-0.19	+0.10
Displacement ratio	1.002	1.001	1.002	1.001

Table 19. Corn, soybean meal, and inorganic phosphate displacement ratios for corn bran, de-oiled DDGS, high-protein DDGS, corn germ, and conventional DDGS in turkey grower diets.

	De-oiled DDG	**HP DDG**	**Corn germ**	**Conventional DDG**
Corn displacement	0.589	0.351	1.071	0.620
Soybean meal displacement	0.508	0.673	0.001	0.405
Inorganic phos. displacement	0.005	-0.007	0.005	0.005
Synthetic amino acids displacement	-0.008	-.005	0.010	-0.005

Overall estimated displacement ratios for fractionated corn co-products

Using my assumptions for projected market share of the four fractionated co-products evaluated (Table 4), estimated dietary inclusion rates, ingredient substitution rates for typical animal diets, and no change in animal performance when feeding the co-products, corn bran has the lowest overall displacement ratio (weighted across projected species market share) of 0.936, and high protein DDG has the highest ratio (1.165), with de-oiled DDG (1.075) and corn germ (1.036) being intermediate **(Table 20, 21, 22, and 23)**. If some of the feed efficiency and performance advantages from feeding these co-products were accounted in these calculations, these ratios would be higher. However, due to the limited amount of comparative animal performance data available, performance responses were assumed to be unchanged when feeding these co-products. Projected market share for each co-product is speculative, but is based on my nutritional assessment of the nutrient characteristics of each co-product and how well they may be utilized in diets for various species. Certainly, cost of these co-products relative to corn, soybean meal and other ingredients will be a deciding factor on their ultimate market value and extent of use. Regardless, significant amounts of corn and soybean meal, along with lesser amounts of other important ingredients (e.g. synthetic amino acids, urea, and inorganic phosphate) can be replaced by adding these co-products to livestock and poultry feeds.

When considering corn and soybean meal displacement ratios (weighted by estimated species market share), 1 lb of corn bran will replace 0.42 lbs of corn and 0.51 lbs of soybean meal, causing it to have the lowest overall nutritional value among these co-products (**Table 20**). One lb. of de-oiled DDG would replace 0.52 lbs of corn and 0.58 lbs of soybean meal across animal species, giving it a 1:1.1 overall corn-soybean meal displacement ratio (**Table 21**). High protein DDG is the co-product with the highest nutritional value and displacement ratio among the four being compared, with 1 lb of HP DDG replacing 0.64 lbs of corn and 0.55 lbs of soybean meal (1:1.19, **Table 22**). Corn germ was the only co-product that replaced substantially more corn (0.94) compared with soybean meal (0.13) across all animal diets, but still resulted in an overall corn-soybean meal displacement ratio of greater than 1:1 (1.07, **Table 23**). It is important to note that adding the corn co-products to practical animal diets results in soybean meal displacement ratios that are substantially higher than used in any of the models being used by the EPA to estimate indirect land use change from corn ethanol production. The relatively high amount of soybean meal displacement when feeding DDG and some undetermined future amount of these fractionated co-products has a much more positive impact on land use change than is currently being accounted for in the FASOM and CARD/FAPRI models.

Table 20. Summary of corn bran displacement ratio by species and overall co-product displacement ratio.

Parameter	Dairy	Beef	Swine	Poultry	Overall Ratio (lb/lb co-product)
Market share, %	40	58	2	0	100
Corn	0.081	0.633	1.083	-	0.421
Soybean meal	1.210	0.041	-0.025	-	0.507
Urea	-	0.008	-	-	0.005
Synthetic amino acids	-	-	0.005	-	0.000
Fat	-	-	-0.068	-	-0.001
Inorganic phosphate	0.016	-	-	-	0.006
Limestone	0.032	-0.026	-	-	-0.002
Salt	-	-	-	-	-
Total	**1.339**	**0.656**	**0.995**	**0**	**0.936**

Table 21. Summary of de-oiled DDG displacement ratio by species and overall co-product displacement ratio.

Parameter	Dairy	Beef	Swine	Poultry	Overall Ratio (lb/lb co-product)
Market share, %	20	30	30	20	100
Corn	-0.191	0.554	0.912	0.589	0.519
Soybean meal	1.388	0.584	0.087	0.508	0.581
Urea	-	0.030	-	-	0.009
Synthetic amino acids	-	-	0.007	-0.008	0.001
Fat	-	-	-0.012	-0.096	-0.023
Inorganic phosphate	0.026	-	0.010	0.005	0.009
Limestone	0.013	-0.080	-0.003	-0.004	-0.023
Salt	-	-	-	0.008	0.002
Total	**1.236**	**1.088**	**1.001**	**1.002**	**1.075**

Table 22. Summary of high protein DDG displacement ratio by species and overall co-product displacement ratio.

Parameter	Dairy	Beef	Swine	Poultry	Overall Ratio (lb/lb co-product)
Market share, %	30	30	25	15	100
Corn	-0.119	1.324	0.909	0.351	0.641
Soybean meal	1.342	0.084	0.078	0.673	0.548
Urea	-	0.043	-	-	0.013
Synthetic amino acids	-	-	0.008	-0.005	0.001
Fat	-	-	-	-0.012	-0.002
Inorganic phosphate	-0.015	-	0.010	-0.007	-0.003
Limestone	-0.023	-0.086	-0.005	-0.001	-0.034
Salt	-	-	-	0.003	0.000
Total	**1.185**	**1.365**	**1.000**	**1.002**	**1.165**

Table 23. Summary of corn germ DDG displacement ratio by species and overall co-product displacement ratio.

Parameter	Dairy	Beef	Swine	Poultry	Overall Ratio (lb/lb co-product)
Market share, %	10	5	20	65	100
Corn	0.170	1.172	0.831	1.071	0.938
Soybean meal	0.940	0.133	0.165	0.001	0.134
Urea	-	-	-	-	0.000
Synthetic amino acids	-	-	0.004	0.010	0.007
Fat	-	-	-	-0.082	-0.053
Inorganic phosphate	0.066	-	-	0.005	0.010
Limestone	0.033	-0.040	-	-0.002	0.000
Salt	-	-	-	-	-
Total	**1.209**	**1.265**	**1.000**	**1.003**	**1.036**

Conclusions

The corn and soybean meal displacement ratios used in the FASOM and CARD/FAPRI models underestimate the actual positive impact of feeding corn co-products produced by the ethanol industry, and as a result, these models have inappropriately and excessively penalized ethanol production for its impacts on indirect land use change. This is particularly evident in the lack of credit given for soybean meal displacement when animal diets contain DDG, and is also evident when considering the soybean meal displacement ratios of fractionated corn co-products **(Table 24).**

Table 24. Comparison of DDG mass displacement ratios for conventional DDG from recent reports.

	DGS Mass Replacement Ratio (1 lb. DGS: conventional feed)			
	Corn	**Soybean meal**	**Other**	**Total**
Shurson (2009)	0.895	0.334	0.02	**1.249**
Argonne (2008)	0.955	0.291	0.025	**1.271**
O'Connor [IEA] (2009)	0.680	0.600	0.0	**1.280**
CARB, GTAP	1.0	0.0	0.0	**1.0**
FASOM	0.915	0.085	0.0	**1.0**
FAPRI	0.950	0.050	0.0	**1.0**

I believe that the EPA has greatly overestimated the future market share of corn co-products from front-end fractionation. I propose that the percentage of front-end fractionation technology should be closer to 5%, and consideration should be given to lowering the estimate for back-end oil extraction technology to 15% of total dry mill ethanol production by the year 2022. This is in contrast to the 20% and 22% projection for front-end fractionation and back-end oil extraction co-products, respectively, that are currently being used by the EPA. Reasons for considering lower levels of adoption of fractionation technology by the ethanol industry include: high capital investment, narrowing profit margins, difficulty keeping the technology functional, undeveloped and uncertain market for the co-products, and higher feeding value (and potentially economic value) for conventional DGS compared to fractionated corn co-products.

When co-products from fractionation and oil separation technologies are factored in at the rates I propose in this paper (15% oil separation, 5% front-end fractionation, and 80% conventional), the overall aggregated dry mill co-product mass displacement ratio drops marginally from 1.249 lbs. to 1.215 lbs. (**Table 25**). However, slightly more soybean meal is displaced when all co-products are aggregated versus strictly conventional DGS (**Table 26**). Table 26 shows that the overall displacement ratios are quite similar for strictly conventional DGS and the 2022 mix of conventional and fractionated co-products assumed in this paper. However, it should be noted that the displacement ratio that is inclusive of fractionated co-products can change dramatically based on the assumptions used regarding market share by species and market penetration of fractionation technologies. Those assumptions are open to debate and this report simply offers one person's view of the future production and use of co-products from fractionation technologies.

Table 25. Aggregated mass displacement ratios including co-products from front-end fractionation and oil separation processes

	HP DDG[a]	De-oiled DDG[a]	Bran[a]	Germ[a]	Conventional DGS
% Market share	2.94	15.00	0.88	1.17	80.00
Overall species combined displacement ratio	1.165	1.075	0.936	1.036	1.249[b]
Shurson aggregated displacement ratio					**1.215**

[a]Overall species combined displacement ratios from Tables 20-23 of this report.
[b]Overall species combined displacement ratio for conventional DGS from Shurson (2009) report.

Table 26. Base feed components displaced, aggregated co-product mix (including front-end fractionation and oil separation processes) vs. 100% conventional DGS

Dry Mill Co-Products Mass Replacement Ratio (1 lb. co-product: conventional feed)				
	Corn	**Soybean meal**	**Other**	**Total**
Shurson (incl. fractionation & oil separation)	0.828	0.376	0.011	**1.215**
Shurson (March, 2009) [100% conventional DGS]	0.895	0.334	0.02	**1.249**

Animal manure nutrient value is another significant factor that has not been considered in any of the models used to estimate indirect land use changes. Proper land application of animal manure significantly reduces the need for expensive synthetic fertilizer (and the energy used to produce it) and significantly reduces crop input costs. In some animal species, feeding corn co-products can increase the nitrogen and phosphorus content of manure compared to feeding conventional diets. All livestock and poultry producers are required to determine nutrient content of manure and properly apply it to crop land to achieve its maximum value while minimizing any negative environmental impacts by using comprehensive nutrient management plans. The impact of animal manure must be considered in determining the overall impact of the ethanol industry on chemical inputs and indirect land use changes.

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APPENDIX A

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 Fuel Standard for Ethanol

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March 25, 2009

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Introduction

The purpose of this report is to provide an independent, scientific evaluation of the information contained in two reports being used as references regarding the land use credit associated with the primary co-product, distiller's grains with solubles (DGS), generated from corn ethanol production. The information reviewed in this report was obtained from two sources: "Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis" by Arora, Wu and Wang (2008) and Appendix C11 "Co-product Credit Analysis when Using Distiller's Grains Derived from Corn Ethanol Production" by the California Air Resources Board. It is critical that accurate, science-based information be used for government policy decisions. Therefore, the following report is a critique of the scientific validity of the information contained in these two references in order to provide the "current state of knowledge" relative to the use of ethanol co-products in livestock and poultry feeds. The intended use of this report is to provide a third-party evaluation of these issues for the Renewable Fuels Association as it prepares comments that will be submitted to the California Air Resources Board on the Low Carbon Fuel Standard.

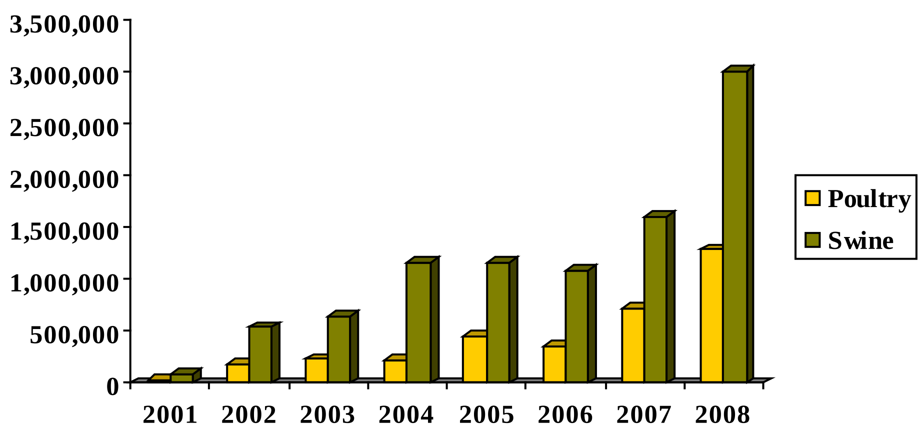
Review of Argonne National Laboratory Analysis (Arora et al., 2008)

The authors of this report correctly acknowledge that the addition of distillers grains with solubles to dairy, beef, and swine feeds has different effects on the amount of corn, soybean meal, and urea (which applies to dairy and beef diets only) that it partially replaces. Although dairy and beef cattle have historically been, and continue to be, the predominant consumers (80%) of DGS in animal agriculture, the amount being used in swine and poultry diets has been increasing over the past several years (Figure 1). In 2001, total annual estimated consumption of DGS was 89,000 MT for swine and 35,000 MT for poultry whereas in 2008, swine and poultry DGS consumption was about 3.0 and 1.3 million MT, respectively. This is a tremendous increase in DGS use over only an 8-year period and represents only 35 and 22% of the potential use in swine and poultry feed in the U.S., respectively (Cooper, 2006).

The percentage estimates of DGS consumed by various livestock and poultry species in 2008 are shown in Table 1. Dairy cattle consumed the greatest amount of DGS (9.0 million MT), followed by beef cattle (8.2 million MT), swine (3.0 million MT), and poultry (1.3 million MT), with the remaining 4.5 million MT being exported. As the amount of DGS production has increased, the estimated quantities of DGS consumed by all livestock and poultry sectors have also increased, and the estimated percentages of distribution of total DGS consumption have changed to include a higher percentage of total production in swine and poultry diets. Three primary factors that will affect further future market penetration in the various food animal sectors, and the percentage use of total DGS production are:

1. The price relationship between DGS and the ingredients it competes with in livestock and poultry diets (e.g. corn and soybean meal [all species], urea [cattle], and inorganic phosphate, fat, and synthetic amino acids [swine and poultry].
2. Availability of supply of the co-product as a feed ingredient.
3. Research focused on developing solutions for overcoming the barriers to increase DGS use in the livestock and poultry industries.

Figure 1. Estimated use of DGS in U.S. poultry and swine diets from 2001- 2008 (Metric Tonnes).



Source: S. Markham, CHS, Inc. (personal communication).

Therefore, when calculating land use credits due to DGS production and consumption, the usage in the swine and poultry sectors needs to be accurately estimated. Although the Arora et al (2008) report was the most comprehensive and objective analysis of the impact of DGS displacement ratios, the results are somewhat biased because it did not provide a thorough and accurate evaluation of the impact of DGS consumption in the swine and poultry industries.

Table 1. Estimated North American DGS usage rate by species (2008).

Species	% of total non-export[1]	Metric Tonnes
Dairy Cattle	42	9,025,800
Beef Cattle	38	8,166,200
Swine	14	3,008,600
Poultry	6	1,289,400
Exports	-	4,510,000[2]
Total	100	26,000,000[3]

[1] Source: S. Markham, CHS, Inc. (personal communication).

[2] Source: D. Keefe, U.S. Grains Council

[3] Source: Renewable Fuels Association www.ethanolrfa.org

In addition, the calculations for displacement ratios for DGS in the Arora et al. (2008) report only accounted for the amount of corn, soybean meal and urea replaced. While this is valid for calculating displacement ratios for cattle feeds, it does not fully account for partial replacement of other common ingredients used in swine and poultry diets such as inorganic phosphate, fat, synthetic amino acids, and salt.

2.1.1.2 DGS Inclusion in Feed and Animal Performance

Beef cattle

Arora et al. (2008) chose an excellent source of data and information for beef cattle using the review and meta-analysis by Klopfenstein et al. (2008) involving nine experiments to measure growth performance at DGS dietary inclusion levels up to 40%. Using these data for calculating feed ingredient displacement ratios for DGS in beef feedlot cattle diets is very appropriate.

Dairy cattle

Data from a recent study by Anderson et al. (2006) were used in the calculation of displacement ratios for DGS in lactating dairy cattle diets. The dietary inclusion rates of DGS in the Anderson et al. (2006) study represent the current range in feeding levels in the dairy industry, and the milk production and composition responses are consistent with other published studies. Although a more thorough review and summary of results from multiple studies should have been done, the data and assumptions used in their calculations are scientifically valid and representative of diet composition changes, as well as milk production levels and composition when feeding DGS diets to lactating dairy cows.

Swine

The analysis of DGS use in swine feeds was inadequately described by Arora et al. (2008) and was based on results from only a few select studies. It is more appropriate to use information from all of the published scientific studies to accurately characterize growth responses of growing swine fed diets containing DGS at levels of 10 to 30% of the diet. Stein and Shurson (2008) recently conducted a comprehensive literature review of results from all published studies and summarized growth performance responses for weanling pigs (Table 2) and grower-finisher pigs (Table 3). The majority of the studies conducted have shown no change in weanling pig and growing-finishing pig performance when DGS is included in the diet at levels up to 30% compared to feeding typical corn-soybean meal based diets. Although feed conversion (G:F) was improved in 50% of the weanling pig studies and 16% of the growing-finishing pig studies, indicating improved utilization of DGS diets compared to conventional corn-soybean meal diets, I chose to be conservative by assuming that feeding DGS diets results in no change in growth rate or efficiency of feed utilization. Therefore, when calculating displacement ratios for DGS, I did not give any credit for improvements in performance but rather focused on the amounts of common feed ingredients that DGS partially replaces (Table 4).

Currently, the industry average dietary inclusion rate of DGS in growing swine diets is 20%, which is double the assumption used in the Argonne report, and it has been as high as 40% for growing-finishing pigs when it has been priced substantially lower than the feeding value of corn, soybean meal, and inorganic phosphate. At a 20% dietary DGS inclusion rate, 400 lbs of DGS plus 6.4 lbs of calcium carbonate, and 2.8 lbs of synthetic amino acids replace 279.6 lbs of corn, 118 lbs of soybean meal, and 11.6 lbs of dicalcium phosphate per ton (2000 lbs) of complete feed (Table 4), resulting in a displacement ratio of 0.699 for corn, 0.295 for soybean meal, and 0.029 for dicalcium phosphate (Table 5). At the 30% dietary DGS inclusion rate the displacement ratios are 0.688 for corn, 0.307 for soybean meal, and 0.027 for dicalcium phosphate (Table 5).

Table 2. Effects of including corn distillers dried grains with solubles (DGS) in diets fed to weanling pigs[1]

Item	N	Response to dietary corn DGS		
		Increased	Reduced	Not changed
ADG	10	0	0	10
ADFI	10	0	2	8
G:F	10	5	0	5

[1]Data calculated from experiments by Whitney and Shurson (2004), Gaines et al. (2006), Linneen et al. (2006), Spencer et al. (2007), Barbosa et al. (2008), and Burkey et al. (2008).

Table 3. Effects of including corn distillers dried grains with solubles (DGS) in diets fed to growing-finishing pigs[1, 2]

Item	N	Response to dietary corn DGS		
		Increased	Reduced	Not changed
ADG	25	1	6	18
ADFI	23	2	6	15
G:F	25	4	5	16

[1] Data based on experiments published after 2000 and where a maximum of 30% DDGS was included in the diets.

[2]Data calculated from experiments by Gralapp et al. (2002), Fu et al. (2004), Cook et al. (2005), DeDecker et al. (2005), Whitney et al. (2006), McEwen (2006, 2008), Gaines et al. (2007ab); Gowans et al.(2007), Hinson et al. (2007), Jenkin et al. (2007), White et al. (2007), Widyaratne and Zijlstra (2007), Xu et al. (2007ab, 2008ab), Augspurger et al. (2008), Drescher et al. (2008), Duttlinger et al. (2008), Hill et al. (2008), Linneen et al. (2008), Stender and Honeyman (2008), Weimer et al. (2008), and Widmer et al. (2008).

Table 4. Partial replacement amounts of common feed ingredients with 20 or 30% DGS in typical swine grower diets.

Ingredient, %	0% DGS	20% DGS	Difference	30% DGS	Difference
Corn	81.30	67.32	-13.98	60.65	-20.65
Soybean meal, 46% CP	16.50	10.60	-5.90	7.30	-9.20
DGS	0.00	20.00	+20.00	30.00	+30.00
Dicalcium phosphate	0.82	0.24	-0.58	0.00	-0.82
Calcium carbonate	0.68	1.00	+0.32	1.13	+0.45
Salt	0.30	0.30	0.00	0.30	0.00
Synthetic amino acids	0.15	0.29	+0.14	0.37	+0.22
Vitamins and trace minerals	0.25	0.25	0.00	0.25	0.00
Total	100.00	100.00		100.00	

Table 5. Summary of co-product displacement ratios for swine when DGS is added at 20 and 30% dietary inclusion rates.

Dietary DGS Inclusion Rate	Corn	Soybean meal	Dicalcium phosphate
20%	0.699	0.295	0.029
30%	0.688	0.307	0.027

Poultry

Use of DGS in broiler, layer, and turkey diets was omitted from the analysis in the Argonne report (Arora et al., 2008). The authors cited that "poultry consumption was excluded because feed composition and performance data available for poultry were insufficient". While the

NASS-USDA (2007) survey did not include poultry data, other sources could have been used as a reference. Therefore, I elected to provide the following summary of DGS usage in broiler, layer, and turkey diets and calculate displacement ratios for common ingredients partially replaced in these diets, and include this information in the final composite displacement ratios for all food animal species.

Current dietary inclusion rates of DGS in broiler diets range from 3 to 15%, with an average of 5% (Dr. Amy Batal, 2009, personal communication). Commercial layer diets contain between 3 to 12% DGS, with an average dietary inclusion rate of 7% (Dr. Amy Batal, personal communication). For turkeys, typical dietary DGS use levels are 10%, but in 2008, levels of 20 to 30% DGS were used when feed prices were extremely high (Dr. Sally Noll, personal communication). Tables 6, 7, and 8 summarize the partial replacement rates of corn, soybean meal, and inorganic phosphate with DGS in broiler, layer, and turkey diets, respectively. The ranges in dietary DGS inclusion rates for broiler, layer, and turkeys used in this analysis result in no change in growth performance compared to feeding conventional corn-soybean meal based diets.

Table 6. Partial replacement amounts of common feed ingredients with 5 or 10% DGS in typical broiler grower diets.

Ingredient, %	**0% DGS**	**5% DGS**	**Difference**	**10% DGS**	**Difference**
Corn	64.87	61.81	-3.06	58.75	-6.12
Soybean meal, 49% CP	27.19	24.99	-2.20	22.79	-4.40
DGS	0.00	5.00	+5.00	10.00	+10.00
Poultry by-product	3.00	3.00	0.00	3.00	0.00
Defluorinated phos.	1.05	0.95	-0.10	0.85	-0.20
Calcium carbonate	0.59	0.68	+0.09	0.77	+0.18
Salt	0.39	0.38	-0.01	0.37	-0.02
Synthetic amino acids	0.32	0.36	+0.04	0.42	+0.10
Fat A-V Blend	2.26	2.49	+0.23	2.72	+0.46
Vitamins, trace minerals, and additives	0.33	0.34	+0.01	0.33	0.00
Total	100.00	100.00	100.00	100.00	100.00

At a 5% dietary DGS inclusion rate, 100 lbs of DGS plus 1.8 lbs of calcium carbonate, 0.80 lbs of synthetic amino acids, and 4.6 lbs of animal-vegetable blend fat replaces 61.2 lbs of corn, 44 lbs of soybean meal, and 2 lbs of defluorinated phosphate in one ton (2000 lbs) of complete feed, resulting in a displacement ratio of 0.612 for corn, 0.440 for soybean meal, and 0.020 for defluorinated phosphate. At the 10% dietary DGS inclusion rate the displacement ratios for corn, soybean meal, and defluorinated phosphate are the same as those at the 5% dietary inclusion level.

Table 7. Partial replacement amounts of common feed ingredients with 5 or 10% DGS in typical layer diets (peak egg production).

Ingredient, %	**0% DGS**	**5% DGS**	**Difference**	**10% DGS**	**Difference**
Corn	58.64	55.60	-3.04	52.56	-6.08
Soybean meal, 49% CP	26.53	24.34	-2.19	22.14	-4.39
DGS	0.00	5.00	+5.00	10.00	+10.00
Defluorinated phos.	2.26	2.16	-0.10	2.06	-0.20
Calcium carbonate	8.92	9.01	+0.09	9.10	+0.18
Salt	0.19	0.18	-0.01	0.17	-0.02
Synthetic amino acids	0.22	0.26	+0.04	0.30	+0.08
Fat A-V Blend	2.90	3.12	+0.22	3.34	+0.44
Vitamins, trace minerals, and additives	0.34	0.33	-0.01	0.33	-0.01
Total	100.00	100.00		100.00	

Similar to broiler diets, at a 5% dietary DDGS inclusion rate in layer diets, 100 lbs of DDGS plus 1.8 lbs of calcium carbonate, 0.80 lbs of synthetic amino acids, and 4.4 lbs of animal-vegetable blend fat replaces 60.8 lbs of corn, 43.8 lbs of soybean meal, and 2 lbs of defluorinated phosphate per ton (2000 lbs) of complete feed, resulting in a displacement ratio of 0.608 for corn, 0.438 for soybean meal, and 0.020 for defluorinated phosphate. At the 10% dietary DDGS inclusion rate, the displacement ratios for corn, soybean meal, and defluorinated phosphate are the same as those for the 5% dietary inclusion level.

Table 8. Partial replacement amounts of common feed ingredients with 10 or 20% DDGS in typical turkey grower diets (11-14 week old tom, or 8-11 week old hen).

Ingredient, %	**0% DGS**	**10% DGS**	**Difference**	**20% DGS**	**Difference**
Corn	59.57	54.10	-5.47	48.62	-10.95
Soybean meal, 46% CP	28.68	24.08	-4.60	19.47	-9.21
DGS	0.00	10.00	+10.00	20.00	+20.00
Dicalcium phosphate	0.95	0.69	-0.26	0.43	-0.41
Calcium carbonate	0.72	0.91	+0.19	1.09	+0.37
Salt	0.23	0.19	-0.04	0.15	-0.08
Synthetic amino acids	0.31	0.37	+0.06	0.39	+0.08
Animal fat	5.03	5.22	+0.19	5.41	+0.38
Vitamins, trace minerals, and additives	4.51	4.44		4.44	
Total	100.00	100.00		100.00	

In turkey diets, a 10% dietary DGS inclusion rate results in adding 200 lbs of DGS plus 3.8 lbs of calcium carbonate, 1.20 lbs of synthetic amino acids, and 3.8 lbs of animal fat to replace 109.4 lbs of corn, 92 lbs of soybean meal, 5.2 lbs of defluorinated phosphate, and 0.80 lbs of salt per ton (2000 lbs) of complete feed, resulting in a displacement ratio of 0.547 for corn, 0.460 for soybean meal, 0.026 for dicalcium phosphate, and 0.004 for salt. At the 20% dietary DGS inclusion rate, the displacement ratios for all of these ingredients are the same as the 10% DGS dietary level.

Table 9 shows a summary of DGS displacement ratios for broilers, layers, and turkeys. Since these values are similar, I chose to average them to obtain a composite ratio for corn, soybean meal, and phosphate for the overall displacement ratio calculations for poultry shown in Table 10. These values are the same at DGS inclusion rates up to 20% which exceeds current average dietary inclusion rates of 5% for broilers, 7% for layers, and 10% for turkeys.

Table 9. Summary of DGS displacement ratios for poultry.

Species	**Corn**	**Soybean meal**	**Phosphate**
Broilers	0.612	0.440	0.020
Layers	0.608	0.438	0.020
Turkeys	0.547	0.460	0.026
Average	**0.589**	**0.446**	**0.022**

2.1.2 Step 2: Characterize U.S. Distillers Grains Consumption by Animal Type

The Argonne report referred to the NASS-USDA survey published in 2007 as a source of DGS consumption data by species. However, this survey was conducted before the record high corn and soybean meal prices occurred in 2008, and therefore, the dietary inclusion rates for various species reported in this survey are conservative, especially for swine based on current diet usage rates in 2008-2009. Usage estimates of DGS in poultry diets was not included in this survey.

2.1.3 Step 3: Characterize Life Cycle of Animals

The information provided in the Argonne report for beef and dairy cattle is valid and adequately accounts for improved growth performance of feedlot beef cattle and improvements in milk production in lactating dairy cattle. Because growth performance of swine, broilers, layers, and turkeys are unchanged with typical dietary inclusion rates of DGS as previously described, no adjustments in displacement ratios for DGS are needed like those for cattle. This was accurately represented for swine in the Argonne report, although the authors used a 10% dietary DGS inclusion rate where I have used displacement ratios assuming a 20% DGS dietary inclusion rate for swine. The Argonne report did not include calculations for displacement ratios for poultry, however, they will be used in the final displacement ratio calculations presented here.

2.1.4 Step 4: Results - Displacement Ratio of Distillers Grains

The final composite DGS ratio results are presented in Table 10. By adding the proportional amounts of each ingredient that is decreased or increased as a result of using DGS in the diets, while accounting for market share for each species, 1 kg or 1 lb of DGS can displace 1.244 kg or lbs of other dietary ingredients to achieve the same level of performance (or improved performance as with cattle). This displacement ratio is slightly lower, but similar to the value of 1.271 kg obtained in the Arora et al. (2008) report which had limited information on swine dietary DGS usage and expected growth performance results, and DGS usage in poultry diets was not included.

In my analysis, the overall displacement ratio for corn and soybean meal was 1.229 compared to the Argonne calculation of 1.28. The reason for this slightly lower value was that the corn displacement value (0.895) was slightly lower in my analysis compared to the value (0.955) calculated in the Arora et al. (2008) report. However, the soybean meal displacement ratio was higher (0.334 vs. 0.291) value in Argonne report. This indicates that 27% of the corn and soybean meal displacement value is soybean meal compared to 24% in the Argonne report. Most of this change can be explained by the greater proportion of soybean meal displaced (and less corn) in swine and poultry diets, with the remaining contribution coming mostly from savings in phosphate supplementation.

Table 10. Summary of DGS displacement ratio by species and overall DGS displacement ratio[1].

Parameter	Dairy	Beef	Swine (20%)	Poultry	Overall Ratio (kg/kg DGS)
Market share, %	42	38	14	6	100
Corn	0.731	1.196	0.699	0.589	0.895
Soybean meal	0.633	-	0.295	0.446	0.334
Urea	-	0.056	-	-	0.021
Synthetic amino acids	-	-	+0.140	+0.073	(0.024)
Fat	-	-	-	+0.363	(0.022)
Inorganic phosphate	-	-	0.580	0.220	0.094
Calcium carbonate	-	-	+0.320	+0.183	(0.056)
Salt	-	-	-	0.027	0.002
Total	**1.364**	**1.252**	**1.114**	**0.663**	**1.244**

[1]Values designated with + indicate additions to maintain equivalent dietary nutrient levels when DGS is added to diets for swine and poultry and values in ( ) indicate subtractions from the overall composite ratio.

Review and Critique of Appendix C11 Co-product Credit Analysis when Using Distiller's Grains Derived from Corn Ethanol Production (CARB)

The authors of this Appendix acknowledge that when DGS displaces traditional feed ingredients such as corn and soybean meal, it reduces green house gas emissions and becomes a life-cycle carbon intensity credit for corn ethanol. However, they criticize the Argonne National Laboratory report (Arora et al., 2008) as having insufficient justification for adopting the DGS displacement value in this report. I strongly disagree. In the preceding analysis of this report, I have noted the areas of insufficient information and have made calculations to be more reflective of actual DGS use among the major livestock and poultry species that consume it. Although this Appendix of the CARB report attempts to describe some of the challenges of using DGS in livestock and poultry feeds, it does not accurately represent factual information for making informed decisions on the impact of feeding DGS on land use credits. The following is a summary of critical evaluation of the incorrect information and improper context of statements in this Appendix.

In this Appendix, the California Air Resources Board (CARB) indicated that their staff conducted an extensive literature review to determine the likelihood that significant quantities of traditional feed ingredients will be replaced by DGS. The accuracy of this statement is highly questionable because they vaguely reference a limited number of sources of information, and no list of publications or other sources of information are provided at the end of the Appendix. Furthermore, the most striking point of the information in this Appendix is that they question whether the barriers to DGS use will be overcome to allow it to be used in livestock and poultry feeds in a significant way. **The fact is, ALL of the growing supply of DGS has been, and continues to be used in livestock and poultry feeds both domestically and in the export market**. Although the barriers they have identified are realistic, their impact is more on further market penetration and use in the various livestock and poultry sectors than on the ethanol industry's ability to market the quantities of DGS currently being produced. Variability in nutrient content along with handling, storage and transportation are challenges that have, to some degree, limited market penetration of DGS use for some species. However, under competitive market price conditions, DGS will continue to be fully utilized in livestock and poultry feeds.

There are several additional technical errors in the CARB Appendix C11.

1. In Table C-11-1, they do not reference the source of the information in the table, generalize ranges in digestibility and availability across species, and do not define "availability". Data in this table are being used to argue that variability in nutrient content will determine the **feasibility** of displacing traditional feeds with DGS. It is not a

question of feasibility, but rather a question of managing variability and appropriately valuing and determining nutrient loading values of the source of DGS being fed.

2. Livestock **ARE** able to digest a much higher percentage of the protein (amino acid fraction) than the 16.8 to 28.8% that was indicated. Wet and dry DGS contains about 55% ruminally undegradable protein, and the crude protein digestibility of DGS for swine ranges from 58 to 71%. If protein digestibility were as low as indicated in this Appendix, there would be much lower levels of soybean meal or urea replaced in animal feeds by DGS than is currently done.

3. Yes, DGS is low in lysine content relative to the nutrient requirements of pigs and poultry. That is why **diets for swine and poultry** are supplemented with synthetic lysine and other amino acids to make up for low levels of lysine and a few other amino acids. Supplemental synthetic amino acids are generally not used in cattle diets.

4. High sulfur content of DGS can be a concern in cattle diets in geographic areas where sulfur content of water, forages and other feed ingredients are also high, and a high dietary inclusion rate (40%) of DGS with high sulfur content is fed. However, this has not limited DGS use in cattle feeds (38% of total DGS production is fed to beef feedlot cattle). Historically, there have been a few cases of polioencephalamalacia that have occurred in beef feedlots when high amounts of DGS containing high levels of sulfur have been fed along with high sulfur content of other feed ingredients.

5. The phosphorus content and digestibility in DGS is high (65 to 90%) for all species. This provides a significant nutritional advantage for DGS in swine and poultry diets because it allows for a significant reduction in the need for supplemental inorganic phosphate to meet the animals phosphorus requirement while substantially reducing diet cost. Furthermore, using DGS to displace corn and soybean meal, which have much lower phosphorus content and digestibility, can substantially reduce the amount of phosphorus excreted in manure.

6. Hogs do not get urinary calculi, but it can occur in ruminants. It is essential to add supplemental calcium to diets containing DGS because it is very low in calcium compared to phosphorus, and the proper calcium:phosphorus ratio must be maintained to insure optimal health and growth performance of all food animal species.

7. Lactating dairy cow diets high in fat do not cause milk to contain an unacceptably high fat content. Feeding high fat diets to lactating dairy cows actually can depress milk fat content. That is why dairy cattle feeds should not contain more than about 20% DGS to avoid potential milk fat depression.

8. While it is true that fine particle size of complete feeds can increase the incidence of gastric ulcers in swine, particle size of DGS often exceeds 700-800 microns and only represents a maximum of 20 to 30% of the diet. Particle size of corn and soybean meal has a greater effect on overall diet particle size than most sources of DGS.

9. DDGS is a preferred energy and protein source for cattle because the fermentable carbohydrate (fiber) in DDGS reduces the risk of rumen acidosis compared to feeding corn which has a very rapidly fermentable carbohydrate (starch) that can increase the risk of acidosis.

10. Handling of some sources of dried DGS and transportation costs of wet DGS are challenges but they have not prevented widespread use of DGS in livestock and poultry feeds domestically or in the export market.

11. Livestock producers depend on their nutritionists to help them use diets containing DGS to obtain the best performance at the lowest cost. The majority of animal nutritionists in the feed industry have extensive knowledge of the benefits and limitations of feeding DGS to various livestock and poultry species. Lack of knowledge may have limited DGS use several years ago, but not today.

12. Exports of DGS increased 91% in 2008 from 2.36 million MT to 4.51 MT. There is no doubt that the efforts of U.S. Grains Council have been extremely effective in increasing the export market for DGS.

13. The conclusions in this Appendix are not realistic or valid. The staff who compiled and wrote this Appendix have demonstrated great incompetence in their understanding of the use of DGS in animal feeds.

In summary, the Arora et al. (2008) report slightly overestimated the DGS displacement ratio by not accurately accounting for the contributions consumed by swine and poultry. Based on current estimates for market share for each species and a revised composite DGS displacement ratio, 1 kg or 1 lb of DGS can displace 1.244 kg or lbs of other dietary ingredients to achieve the same level of performance (or improved as with cattle), which is slightly lower, but similar to the value of 1.271 kg obtained in the Arora et al. (2008) report. The information contained in the CARB Appendix does not appear to acknowledge that **all** of the 26 million tonnes of DGS produced in 2008 **was** consumed by livestock and poultry, and inaccurately describes the nature of the challenges for increased use of DGS in livestock and poultry feeding in the future. The information contained in the CARB Appendix C11 is misleading and has no value in establishing land use credits for current DGS production and use.

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