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Economic Value of Ethanol Byproducts in Swine Diets: Evaluating Profitability of Corn Fractionation Techniques

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Introduction

According to the National Corn Grower's Association (NCGA, 2007), the U.S. ethanol industry will be generating approximately 16 million tons of distiller's grains in 2012, or more than twice the amount produced in 2004. In addition to DDGS, new dry-milling processes have resulted in new feedstuffs such as germ and bran as a protein and energy supplement. Technology for corn-to-ethanol conversion continues to improve. The dramatic increase in fuel ethanol production, with a concurrent increase in feed products from the same plants, warrants a thorough nutritional assessment of these new byproducts in order to determine their economically optimal utilization in the livestock feeding sectors. In addition, there is an urgent need to determine the profitability of new techniques employed in ethanol production and understand how these new techniques affect the nutritional value of the resulting byproducts.

Among many technological improvements that have been made to the conventional ethanol processing methods to improve yield and reduce operating costs, corn fractionation, which has been used for some time in wet milling, is arguably the most cost-effective technology. Although there are many variants, the basic process of corn fractionation involves fractionating or separating the corn kernel into three fractions: fiber, germ and endosperm. The technique helps increase starch availability for ethanol production, as well as increase protein concentration of the resulting byproducts. It is also claimed to increase profitability of ethanol plants through higher ethanol yields and reductions in plant emissions and energy costs. A number of companies, including Renessen LLC (Jakel, 2006), Poet LLC and FWS Technologies, have developed and improved the fractionation technique to increase ethanol yields and produce high value byproducts. As of October 2007, Poet Ethanol, the largest dry-mill ethanol producer in the United States, has three ethanol plants using the new and improved bio-refining technology for advanced corn fractionation, marketed as the "BFrac" technique. The technology produces Dakota Gold HP, Dakota Bran and Dakota Gold Corn Germ Dehydrated (see Figure 1).

DDGS, with its high fiber content, is fed primarily to ruminants. However, with new fractionation techniques that reduce fiber content, DDGS could be used effectively for non-ruminants such as swine and poultry. Feed costs typically represent more than 60% of total costs of production for livestock producers. Protein and energy are the nutrients with the largest impact on feed cost. Even with the introduction of new value-added products from improved technologies, little research has been done to compare the economic value of different types of DDGS and new feed byproducts in the market.

Given the importance of feed costs and the effect of fractionation techniques on the nutritional value of the feed byproducts, the first objective of this study is to estimate and compare the economic value of feed byproducts as ingredients for swine diets from traditional ethanol plants and from plants that employ fractionation techniques. Processing techniques have a major impact on the nutritional profile of the resulting byproducts. Therefore, the second objective of this study is to determine if the changes in investment and operating costs associated with the new corn fractionation technology can be justified economically given the projected changes in the value of byproducts. For this purpose, shadow prices and yield data are used to calculate the revenue from conventional and fractionation techniques of ethanol production in order to determine the possibility of offsetting processing costs of the new technology.

Background

Economic viability of the entire grain-based fuel ethanol industry is heavily dependent on the market value of the distiller's grains byproduct that is sold as feed to the livestock industry. Economic Research Service of the United States Department of Agriculture (USDA-ERS) estimates that 75

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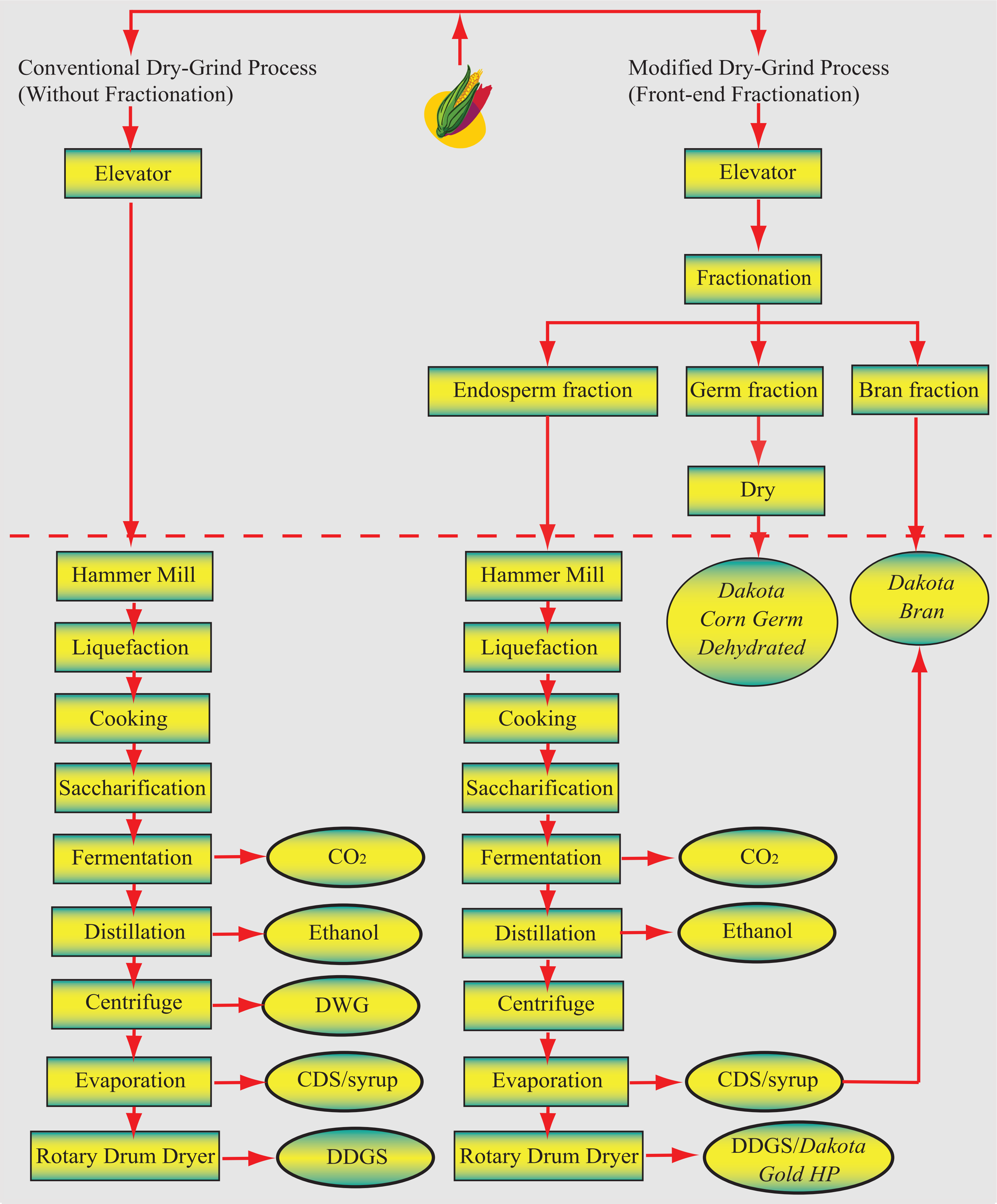

Figure 1. Ethanol Production, With and Without Fractionation Technology

percent of distiller's grains produced are fed to livestock in the U.S., 10 percent is exported and 15 percent goes to other non-feed domestic uses. Of the 75 percent within the livestock portion, 80 percent is assumed to go to beef cattle, 10 percent to dairy cattle, and 5 percent each to hogs and poultry (USDA-ERS, 2007). Animal nutrition studies estimate that distiller's grains on a dry matter basis are assumed to replace corn in rations of 1 pound distiller's grains for 0.85 pound corn for hog rations (Shurson *et al*., 2003; Vander Pol *et al*., 2006).

The germ fraction of the corn kernel, produced from fractionation, can be used as a protein and energy supplement to replace concentrates (corn and SBM) in feedlot and dairy diets (Kleinhans, Pritchard, and Holt, 2005). The bran fraction of the corn kernel is added to the corn condensed distiller's solubles (CDS) or syrup to produce a high fiber byproduct. This study calculated the economic value of fractionated DDGS and the germ fraction for use in swine diets.

Data and Methodology

In a typical feed ration model, a ration is formulated to minimize cost while providing sufficient nutrients to meet the needs of the animal type being fed. In order to value the byproducts (DDGS and Germ) as a feed ingredient, it is necessary to determine the nutrient requirements for various production phases of swine. These requirements will include the minimum and maximum levels of protein, amino acids, and other nutrients necessary for healthy hog growth at different stages of development. Second, the nutritional profile of the feed byproducts to be used by producers and other main feed ingredients are required. The levels available to hogs will provide the economic valuation necessary to determine inclusion levels in a nutritious diet. Thirdly, the various prices for all the feed ingredients need to be found to provide the proper valuation and minimal cost for a diet containing DDGS and Germ. Finally, these factors need to be brought together to determine the ability DDGS or Germ has to complement corn and soybean meal in a viable swine diet.

An evaluation of DDGS inclusion levels in swine diets requires a study of hog response at various growth stages. Optimal swine diet is based on digestible lysine levels with the other prominent amino acids as a percentage of digestible lysine. The prices for major feed ingredients were taken from Feed Ingredient Weekly, October 2007 (Informa Economics, 2007), while synthetic amino acid prices were obtained from Akey's Feed Company (Richert, 2007).

Nutrient data on conventional DDGS (without fractionation technique) was obtained from Big River Resources Ethanol plant at West Burlington, Iowa (Richert, 2007). The Iowa plant uses state-of-the-art technology to produce high quality DDGS using conventional dry milling technique. Data on the nutrient profile of fractionated byproducts for swine diets i.e. fractionated DDGS and Germ (from BFrac technology) was obtained from the Poet LLC website (2006) (Table 1). Data show that fractionated DDGS is higher in digestible lysine than either Iowa DDGS or Germ. Low digestibility of lysine in DDGS is a result of heat damage due to excessive heating during the drying process (Stein, 2006). The Germ fraction has lower digestible lysine content than the fractionated DDGS because Germ is produced by further drying the germ fraction of the corn kernel.

Diets of grow-finish pigs weighing 45-95 lbs (Grower1), 95-155 lbs (Grower2), 155-205 lbs (Finisher1), 205-260 lbs (Finisher2) and 300-500 lbs (Gestating Sow) were formulated to contain the same level of apparent digestible lysine within each of the dietary phases. These experimental diets were formulated assuming perfect knowledge of unit prices of feedstuffs, nutrient requirements, and nutrient composition of feedstuffs. Two diets are formed at the Finisher2 production

Table 1. Nutrient Composition Comparison (as Fed Basis) between Byproducts

	Units	Iowa DDGS	Fractionated DDGS	Germ
Metabolizable Energy	kcal/lb	1775	1687	1828
Crude Protein	%	29.1	41.0	15.7
App. Dig. Lysine	%	0.51	0.70	0.47
App. Dig. Meth+Cys	%	0.85	1.72	0.46
App. Dig. Threonine	%	0.73	1.16	0.30
App. Dig. Tryptophan	%	0.15	0.27	0.13
App. Dig. Isoleucine	%	0.75	1.16	0.23
App. Dig. Valine	%	0.98	1.57	0.43
Calcium	%	0.03	0.01	0.02
Phosphorous	%	0.81	0.35	1.28
Digestible Phosphorous	%	0.49	0.28	0.77
Crude Fiber	%	6.20	6.67	5.10

phase -- one with Paylean-9®, and one without Paylean-9®. Paylean® (ractopamine hydrochloride by Elanco) is a feed additive that can increase the rate and efficiency of muscle tissue growth in pigs that helps produce lean and quality pork (Schinckel, Richert, and Kendall, 2001). Paylean-9® refers to Paylean® at 9 grams per ton mixed into the feeds for the finishing production phase only. According to Elanco, Paylean® can be fed at levels of 4.5 to 9 grams per ton for the last 45-90 lbs live weight prior to market. The 9 grams per ton level results in substantial reduction in carcass fat gain especially at the time of the maximal Paylean® response.

Linear Programming Model for Diet Cost

A feed ration model, in the form of a constrained cost minimization linear program (LP), was used to impute the value of the Iowa DDGS, fractionated DDGS and Germ. The model minimizes feed cost subject to upper and lower bounds on nutrients specific to the growth stage of the pig. The model chooses a cost minimizing mix of the feedstuffs that sum to a full diet complement equal to one so that the reported inclusion rates for each item are in percentage terms. The value of the byproduct was observed as the shadow price on the byproduct inclusion constraint. The maximum and minimum nutrient inclusion rates in the diet was obtained from Tri-State Swine Nutrition Guide, Bulletin 869-98 (1998) and the National Research Council (NRC) guidelines for swine (NRC, 1998). The shadow value, at the maximum inclusion levels, serves as a proxy for the market value of the DDGS and Germ as a feed ingredient incorporated at the specified levels conditional upon the prices of other feed ingredients and the specified nutrient limits.

Excel Spreadsheet Model for Ethanol Plant

The second objective of this paper was to determine the plant revenue from the byproducts from the two technologies under study, with and without fractionation. For this purpose, a model of a 50 million gallon per year (MGY) ethanol plant was constructed in Excel. Data on capital cost, operating cost, amount of corn required and yield information for the model plant employing fractionation technology was obtained from FWS Technologies (2006), a division of the FWS Group of Companies based in Winnepeg, Canada. The spreadsheet uses this information along with prices of corn (input) and outputs (ethanol and byproducts) to calculate revenue and cost of ethanol production.

The minimum across the different rations of the shadow values from the LP model for Iowa DDGS, fractionated DDGS and Germ, at their maximum inclusion level were used as proxies for the market values of the byproducts. Shadow prices represent the maximum a firm would be willing to pay. What they actually pay is different for a wide range of reasons on both the supply and demand sides. To account for that difference, the market price for DDGS divided by the shadow value of the Iowa DDGS to serve as the ratio of DDGS market and shadow values for fractionated DDGS and Germ is used. This is an approximation, but it is the best value that can be obtained within the scope of the analysis and given the paucity of market data on the other products. Earnings, before interest, taxes, depreciation and amortization (EBITDA), was used to evaluate a plant's profitability and operating performance.

Financial assumptions for the ethanol plant were made as 40% proportion of equity paid on the debt capital, 60% proportion of debt paid on the debt capital, a debt interest rate of 8% and the rate of return on equity capital as 12% (Tyner and Taheripour, 2007). Therefore, the weighted average return percent required by investors on new debt and equity capital is 9.6%. This value is used as the discount rate for the investment decisions on the new technology. Using the discount rate and the life of the plant as 20 years, the present value of the increased annual revenue is calculated. This value also represents the maximum ethanol producers could pay in increased capital cost for the fractionation plant.

Results and Discussion

The first objective of this study was to estimate and compare the economic value of the Iowa DDGS and the fractionated byproducts. Diet formulations will depend on the nutritional profile of the byproducts included in the diet and the nutrient requirements of the pig's phase of growth. The data show large differences in nutrient concentrations of the byproducts for the two processing methods (see Table 1). It is important to remember that in this paper, swine diets are balanced on digestible lysine levels with the other prominent amino acids as a percentage of digestible lysine (see Tables 2 and 3). Tables 4, 5 and 6 present the least cost diet and nutrient composition for each of the feeding phases with maximum inclusion levels of Iowa DDGS, fractionated DDGS and Germ respectively.

Comparing the diets for the various distiller's products to the corn-soybean meal based diets formulated by the same model as "control" diets (see Table 7), there are varying rates of replacement for corn and soybean meal in the diet. The Iowa DDGS product replaces both corn and soybean meal at a ratio of 75-77% corn and 23-25% SBM. However, the fractionated DDGS replaces a much greater amount of SBM on a ratio basis, 47-52% SBM and 48-56% Corn. The germ product is more similar to the conventional DDGS with a 81-85% Corn: 13-19% SBM dietary replacement ratio.

Results presented in Table 8 show that the diet containing fractionated DDGS has about half or less of the inclusion rates of the Iowa DDGS in all the grow-finish phases. Due to the rich amino acid profile of the fractionated DDGS, a lower inclusion rate is necessary to meet the amino acid constraints while maintaining proper metabolizable energy levels. At

Table 2. Nutrient Composition per lb of Feed Ingredient[a]

	Corn	SBM	Limestone	DiCalPhos	Vitpremix
Metabolizable Energy	1551	1533	0	0	0
Crude Protein	8.30%	47.50%	0.00%	0.00%	0.00%
App. Dig. Lysine	0.17%	2.57%	0.00%	0.00%	0.00%
App. Dig. Meth+Cys	0.30%	1.16%	0.00%	0.00%	0.00%
App. Dig. Threonine	0.20%	1.44%	0.00%	0.00%	0.00%
App. Dig. Tryptophan	0.04%	0.53%	0.00%	0.00%	0.00%
App. Dig. Isoleucine	0.31%	1.81%	0.00%	0.00%	0.00%
App. Dig. Valine	0.22%	1.84%	0.00%	0.00%	0.00%
Calcium	0.03%	0.34%	38.50%	21.50%	0.00%
Phosphorous	0.28%	0.69%	0.02%	18.50%	0.00%
Digestible Phosphorous	0.04%	0.16%	0.02%	18.50%	0.00%
Crude Fiber	2.30%	3.40%	0.00%	0.00%	0.00%
Vit. Premix	0.00%	0.00%	0.00%	0.00%	100.00%

[a] Ingredient composition for these feedstuffs are from the Swine NRC, 1998.

Table 2 (Cont.). Nutrient Composition per lb of Feed Ingredient[a]

	Lysine HCL	DL Meth	Grease	Lthreo	Ltryp
Metabolizable Energy	0	0	3615	0	0
Crude Protein	78.00%	98.00%	0.00%	98.00%	98.00%
App. Dig. Lysine	78.00%	0.00%	0.00%	0.00%	0.00%
App. Dig. Meth+Cys	0.00%	98.00%	0.00%	0.00%	0.00%
App. Dig. Threonine	0.00%	0.00%	0.00%	98.00%	0.00%
App. Dig. Tryptophan	0.00%	0.00%	0.00%	0.00%	98.00%
App. Dig. Isoleucine	0.00%	0.00%	0.00%	0.00%	0.00%
App. Dig. Valine	0.00%	0.00%	0.00%	0.00%	0.00%
Calcium	0.00%	0.00%	0.00%	0.00%	0.00%
Phosphorous	0.00%	0.00%	0.00%	0.00%	0.00%
Digestible Phosphorous	0.00%	0.00%	0.00%	0.00%	0.00%
Crude Fiber	0.00%	0.00%	0.00%	0.00%	0.00%
Vit. Premix	0.00%	0.00%	0.00%	0.00%	0.00%

[a] Ingredient composition for these feedstuffs are from the Swine NRC, 1998.

the maximum inclusion levels, the nutrient composition of the diet hits the maximum allowable for digestible sulphur amino acid (methionine + cystine). At low inclusion levels, it replaces less of corn and phosphorus in the diet. However, if the sulphur amino acids constraint is relaxed, higher maximum inclusion levels of the fractionated DDGS are possible. At higher inclusion levels, it not only replaces more corn but also more soybean meal (SBM) in the diet.

A higher inclusion level of Iowa DDGS is possible due to its low levels of digestible lysine, relative to the amino acid and lysine requirements of swine (37% lower than fractionated DDGS). The DDGS inclusion levels of Iowa DDGS matches the approximate maximum inclusions that would be recommended by swine nutritionists (30% early and 20% max. late finishing). Many nutritionists are recommending 0-10% DDGS in the finisher 2 diets due to the risk of producing pork with soft bellies because of the high levels of corn oil in the DDGS products. Germ, being low in protein but rich in energy source, allowed for high optimal inclusion levels in grower and gestating sow diets.

While the maximum inclusion level of Iowa DDGS in the Finisher2 diet without Paylean-9® is 19.23%, it can be increased to 26.62% with the addition of Paylean-9® which can aid in building up muscle tissue growth in finishing pigs.

Table 3. Maximum and Minimum Nutrient Inclusion Rates in Swine Diets (in lb per lb of diet)

	Grower 1 (45-95 lbs)		Grower 2 (95-155 lbs)		Finisher 1 (155-205 lbs)	
	Min	Max	Min	Max	Min	Max
Metabolizable Energy	1500	100000	1500	1000000	1500	100000
Crude Protein	0.18	100000	0.15	1000000	0.14	100000
App. Dig. Lysine	0.0095	0.00951	0.0085	0.00851	0.00725	0.00726
App. Dig. Meth+Cys	0.00551	0.0065	0.0051	0.0061	0.004423	0.0054
App. Dig. Threonine	0.0057	0.0067	0.00527	0.0062	0.004568	0.0055
App. Dig. Tryptophan	0.001615	0.00261	0.001445	0.0024	0.001233	0.0022
App. Dig. Isoleucine	0.005225	100000	0.004675	100000	0.003988	100000
App. Dig. Valine	0.006365	100000	0.005695	100000	0.004858	100000
Calcium	0.0072	0.0082	0.0072	0.0082	0.0058	0.0068
Phosphorous	0.000001	0.0072	0.0000001	0.0072	0.000001	0.0058
Digestible Phosphorous	0.003	100000	0.0024	100000	0.0021	100000
Crude Fiber	0.000001	0.035	0.0000001	0.035	0.000001	0.035
Vit. Premix	0.0015	0.0015	0.0015	0.0015	0.0013	0.0013
Paylean9	--	--	--	--	--	--

Table 3 (Cont.). Maximum and Minimum Nutrient Inclusion Rates in Swine Diets (in lb per lb of diet)

	Finisher 2 (205-260 lbs)		Finisher 2 with Paylean9		Gestating Sow (300-500 lbs)	
	Min	Max	Min	Max	Min	Max
Metabolizable Energy	1500	100000	1500	100000	1480	100000
Crude Protein	0.12	100000	0.16	100000	0.12	100000
App. Dig. Lysine	0.006	0.00601	0.0095	0.0095	0.004	0.00401
App. Dig. Meth+Cys	0.00372	0.0047	0.00589	0.0068	0.0028	0.0038
App. Dig. Threonine	0.00384	0.0048	0.00608	0.007	0.0032	0.0042
App. Dig. Tryptophan	0.00102	0.002	0.001615	0.0026	0.00072	0.0017
App. Dig. Isoleucine	0.0033	100000	0.005225	100000	0.0024	100000
App. Dig. Valine	0.00402	100000	0.006365	100000	0.00272	100000
Calcium	0.0050	0.0060	0.0058	0.0068	0.0075	0.01
Phosphorous	0.000001	0.0050	0.0000001	0.0058	0.000001	0.0075
Digestible Phosphorous	0.0019	100000	0.0021	100000	0.0042	0.005
Crude Fiber	0.000001	0.035	0.000001	0.035	0.000001	0.035
Vit. Premix	0.00125	0.00125	0.0013	0.0013	0.005	0.005
Paylean9	--	--	0.00025	0.0003	--	--

The digestible lysine level in Germ is around 9% lower than that of Iowa DDGS. Although a poor protein and digestible lysine source, Germ has a higher metabolizable energy (ME) value than either Iowa DDGS or fractionated DDGS. These factors explain the high maximum inclusion levels of Germ in grower and gestating sow diets. One issue not evaluated in this model was the effect of the additional corn oil in the DDGS and germ products would have on pork quality. These elevated levels of corn oil could limit the ethanol industry byproducts inclusion rates in swine finishing diets.

The shadow value of the DDGS provides an upper bound on its market value at various levels of inclusion. According to Shurson, the ME content, amino acid level and digestibility, and digestible phosphorus levels of feed ingredients are the primary factors that influence the suitability and value of DDGS in swine diets (Shurson, 2006). Nutrient data shows

Table 4. Swine Diet Composition with Maximum Inclusion Level of Iowa DDGS[b]

Feed Ingredient	Grower 1 (45-95 lbs)	Grower 2 (95-155 lbs)	Finisher 1 (155-205 lbs)	Finisher 2 (205-260 lbs)	Finisher 2 with Paylean9	Gestating Sow (300-500 lbs)
DDGS	26.95%	27.92%	28.65%	19.23%	26.62%	9.66%
Corn	51.38%	54.26%	58.59%	70.23%	52.22%	81.92%
SBM	19.04%	15.32%	10.76%	8.63%	19.08%	4.87%
Limestone	1.55%	1.76%	1.58%	1.19%	1.46%	1.49%
DiCalPhosphate	0.62%	0.30%	0.04%	0.39%	0.14%	1.78%
Vit. Premix	0.15%	0.15%	0.13%	0.13%	0.13%	0.15%
Lysine HCL	0.30%	0.28%	0.26%	0.21%	0.30%	0.11%
DL-Methionine	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Grease	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
L-threonine	0.00%	0.00%	0.00%	0.00%	0.03%	0.02%
L-tryptophan	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Paylean®	--	--	--	--	0.02%	--
Total	100%	100%	100%	100%	100%	100%
Nutrient Composition						
Metabolizable Energy	1567	1572	1582	1563	1575	1517
Crude Protein	21.39%	20.13%	18.51%	15.68%	21.41%	12.03%
App. Dig. Lysine	0.95%	0.85%	0.73%	0.60%	0.95%	0.40%
App. Dig. Meth+Cys	0.60%	0.57%	0.54%	0.47%	0.60%	0.38%
App. Dig. Threonine	0.57%	0.53%	0.48%	0.41%	0.61%	0.32%
App. Dig. Tryptophan	0.16%	0.14%	0.12%	0.10%	0.16%	0.07%
App. Dig. Isoleucine	0.71%	0.65%	0.59%	0.52%	0.71%	0.41%
App. Dig. Valine	0.73%	0.68%	0.61%	0.50%	0.73%	0.37%
Calcium	0.82%	0.82%	0.68%	0.60%	0.68%	1.00%
Phosphorous	0.61%	0.54%	0.48%	0.48%	0.52%	0.67%
Dig Phosphorous	0.30%	0.24%	0.19%	0.21%	0.21%	0.42%
Crude Fiber	3.50%	3.50%	3.49%	3.10%	3.50%	2.65%
Paylean9®	--	--	--	--	0.02%	--

[b] Based on prices ($.lb) from Feed Ingredient Weekly, October 2007: DDGS = $0.06, Corn = $0.06, SBM = $0.13, Limestone = $0.05, DiCalcium Phosphate = $0.28, Vit. Premix = $0.85, Lysine HCL = $0.99, DL-Methionine = $1.30, Grease = $0.24, L-threonine = $1.20, L-tryptophan = $22.50, and Paylean® = $26.00

that the crude fiber content of fractionated DDGS is slightly higher than either Iowa DDGS or Germ (see Table 1). Intuitively, the high crude fiber content in the diet with fractionated DDGS should cause its shadow value to be lower in comparison to the diet containing Iowa DDGS or Germ. But in the grower and finisher dietary phases, the nutrient limiting constraint for sulfur amino acids, Apparent Digestible Methionine + Cystine, is binding for diets with fractionated DDGS and non-binding for grower diets with Iowa DDGS. The counterintuitive results for this diet phase could be explained by this fact.

The results show that the total cost of diets containing Iowa DDGS is lower than the diets containing fractionated DDGS in all the diet phases. The lower diet cost is explained by the levels of digestible phosphorus in the diet, which is the third most expensive ingredient in swine diet after amino acids. Iowa DDGS has around 43% higher digestible phosphorus than fractionated DDGS (see Table 1). This means that the diet with Iowa DDGS will be lower due to a reduced need for inorganic phosphorus as supplement which is priced at 0.28 $/lb. The same argument applies to the reason why the diet containing Germ has lower cost than those containing Iowa DDGS or fractionated DDGS. Germ has around 57% higher digestible phosphorus levels than Iowa DDGS. Hence, the diet containing Germ has a lower cost than the diet with Iowa DDGS as well as diets with fractionated DDGS. With the addition of Paylean-9® to the Finisher2 diets, the diets become more expense even though

Table 5. Swine Diet Composition with Maximum Inclusion Level of Fractionated DDGS[b]

Feed Ingredient	Grower 1 (45-95 lbs)	Grower 2 (95-155 lbs)	Finisher 1 (155-205 lbs)	Finisher 2 (205-260 lbs)	Finisher 2 with Paylean9	Gestating Sow (300-500 lbs)
DDGS	14.08%	13.08%	9.79%	6.57%	16.92%	0.90%
Corn	64.27%	68.41%	75.05%	81.29%	63.35%	86.20%
SBM	18.77%	15.75%	12.91%	10.07%	17.38%	9.31%
Limestone	1.30%	1.48%	1.26%	0.98%	1.23%	1.34%
DiCalPhosphate	1.10%	0.81%	0.60%	0.76%	0.58%	1.98%
Vit. Premix	0.15%	0.15%	0.13%	0.13%	0.13%	0.15%
Lysine HCL	0.33%	0.30%	0.25%	0.20%	0.35%	0.01%
DL-Methionine	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Grease	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
L-threonine	0.01%	0.01%	0.01%	0.00%	0.03%	0.00%
L-tryptophan	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Paylean®	--	--	--	--	0.02%	--
Total	100%	100%	100%	100%	100%	100%
Nutrient Composition						
Metabolizable Energy	1522	1523	1527	1526	1534	1497
Crude Protein	20.29%	18.77%	16.58%	14.38%	20.76%	12.00%
App. Dig. Lysine	0.95%	0.85%	0.73%	0.60%	0.95%	0.40%
App. Dig. Meth+Cys	0.65%	0.61%	0.54%	0.47%	0.68%	0.38%
App. Dig. Threonine	0.57%	0.53%	0.46%	0.38%	0.61%	0.32%
App. Dig. Tryptophan	0.16%	0.14%	0.12%	0.10%	0.16%	0.08%
App. Dig. Isoleucine	0.70%	0.65%	0.58%	0.51%	0.71%	0.45%
App. Dig. Valine	0.71%	0.65%	0.56%	0.47%	0.73%	0.38%
Calcium	0.82%	0.82%	0.68%	0.60%	0.68%	1.00%
Phosphorous	0.56%	0.50%	0.44%	0.46%	0.46%	0.68%
Dig Phosphorous	0.30%	0.24%	0.19%	0.21%	0.21%	0.42%
Crude Fiber	3.06%	2.98%	2.82%	2.65%	3.18%	2.37%
Paylean9®	--	--	--	--	0.02%	--

[b] Based on prices ($.lb) from Feed Ingredient Weekly, October 2007: DDGS = $0.06, Corn = $0.06, SBM = $0.13, Limestone = $0.05, DiCalcium Phosphate = $0.28, Vit. Premix = $0.85, Lysine HCL = $0.99, DL-Methionine = $1.30, Grease = $0.24, L-threonine = $1.20, L-tryptophan = $22.50, and Paylean® = $26.00

the maximum inclusion levels are similar to or lower than the other phases.

For the 50 MGY ethanol plant model, the minimum shadow price of the byproducts across the different rations from the LP model, adjusted to reflect marketing costs, were 118 $/ton for Iowa DDGS, 107.78 $/ton for the fractionated DDGS and 101.30 $/ton for Germ. Results presented in Table 9 show that greater revenue is generated from high value byproducts from the ethanol plant employing the fractionation technique based on the ingredient shadow prices. The ethanol plant operating without fractionation technology produces fifty million gallons of ethanol and $28,367,857 in EBITDA. The ethanol plant operating with fractionation technology produces fifty five million gallons of ethanol (a 10% increase) and $32,818,123 in EBITDA, which is $12,489,364 greater revenue than the traditional plant.

Production costs for the plant include the cost of corn and operating cost. The ethanol plant employing the fractionation technique requires about 15% more corn than a conventional plant not employing the fractionation technique. Hence, the cost of corn is higher for the plant employing the fractionation technique by $9,389,098. Fractionation techniques employed by both Poet ethanol plants as well as FWS Companies boast of fewer processing steps which translate to lower operating costs. Hence, the operating cost of the ethanol plant employing the fractionation technique is lower than that without the fractionation technique by $1,350,000. Production costs for the plant employing

Table 6. Swine Diet Composition with Maximum Inclusion Level of Germ[b]

Feed Ingredient	Grower 1 (45-95 lbs)	Grower 2 (95-155 lbs)	Finisher 1 (155-205 lbs)	Finisher 2 (205-260 lbs)	Finisher 2 with Paylean9	Gestating Sow (300-500 lbs)
DDGS	35.86%	37.66%	25.03%	8.27%	21.01%	32.25%
Corn	40.43%	42.96%	59.57%	78.16%	53.71%	60.89%
SBM	21.37%	17.00%	13.40%	11.63%	23.24%	3.76%
Limestone	1.89%	1.93%	1.59%	1.10%	1.51%	2.08%
DiCalPhosphate	0.00%	0.00%	0.00%	0.51%	0.00%	0.76%
Vit. Premix	0.15%	0.15%	0.13%	0.13%	0.13%	0.15%
Lysine HCL	0.21%	0.21%	0.21%	0.16%	0.21%	0.06%
DL-Methionine	0.02%	0.01%	0.00%	0.00%	0.06%	0.00%
Grease	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
L-threonine	0.07%	0.08%	0.07%	0.04%	0.10%	0.05%
L-tryptophan	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Paylean®	--	--	--	--	0.02%	--
Total	100%	100%	100%	100%	100%	100%
Nutrient Composition						
Metabolizable Energy	1610	1615	1587	1542	1573	1592
Crude Protein	19.39%	17.81%	15.47%	13.47%	19.13%	12.00%
App. Dig. Lysine	0.95%	0.85%	0.72%	0.60%	0.95%	0.40%
App. Dig. Meth+Cys	0.55%	0.51%	0.45%	0.40%	0.59%	0.37%
App. Dig. Threonine	0.57%	0.53%	0.46%	0.38%	0.61%	0.32%
App. Dig. Tryptophan	0.17%	0.15%	0.13%	0.10%	0.17%	0.09%
App. Dig. Isoleucine	0.59%	0.53%	0.48%	0.47%	0.64%	0.33%
App. Dig. Valine	0.64%	0.57%	0.49%	0.42%	0.64%	0.34%
Calcium	0.82%	0.82%	0.68%	0.60%	0.68%	1.00%
Phosphorous	0.72%	0.72%	0.58%	0.50%	0.58%	0.75%
Dig Phosphorous	0.33%	0.33%	0.24%	0.21%	0.22%	0.42%
Crude Fiber	3.49%	3.49%	3.10%	2.61%	3.10%	3.17%
Paylean9®	--	--	--	--	0.02%	--

[b] Based on prices ($.lb) from Feed Ingredient Weekly, October 2007: DDGS = $0.06, Corn = $0.06, SBM = $0.13, Limestone = $0.05, DiCalcium Phosphate = $0.28, Vit. Premix = $0.85, Lysine HCL = $0.99, DL-Methionine = $1.30, Grease = $0.24, L-threonine = $1.20, L-tryptophan = $22.50, and Paylean® = $26.00

fractionation technology, mainly as a result of higher corn cost, is higher by $8,039,098 than the plant operating without the fractionation technique. The increased revenue from the greater ethanol yield and from the increase in value of the byproducts offsets the costs, resulting in increased net income from fractionation technique of $4,450,266. Assuming a plant life of 20 years and a discount rate of 9.6 percent, the present value of the increased net income that represents the maximum amount ethanol producers could pay in increased capital cost for the fractionation plant is $38,945,481.

Conclusions

Fractionation technology results in high protein but lower fat content in DDGS, which slightly affects the byproduct's energy value for swine diets. Despite a good amino acid profile of the fractionated DDGS, much of the increase in crude protein is at the expense of phosphorus which is reduced by around 43%. Since diets were formulated on a digestible lysine basis, the amino acid profile and low digestibility of lysine in Iowa DDGS allowed for higher inclusion levels in all phases of the diet while still maintaining a low total diet cost in comparison to diets containing lower levels of fractionated DDGS.

Table 7. Control Corn-Soybean Meal Swine Diet Composition[b]

Feed Ingredient	Grower 1 (45-95 lbs)	Grower 2 (95-155 lbs)	Finisher 1 (155-205 lbs)	Finisher 2 (205-260 lbs)	Finisher 2 with Paylean9	Gestating Sow (300-500 lbs)
DDGS	0.00	0.00	0.00	0.00	0.00	0.00
Corn	71.10%	75.31%	80.24%	84.77%	71.67%	86.36%
SBM	26.07%	21.95%	17.56%	13.19%	26.00%	10.17%
Limestone	1.16%	1.36%	1.16%	0.91%	1.06%	1.33%
DiCalPhosphate	1.23%	0.93%	0.69%	0.83%	0.75%	1.98%
Vit. Premix	0.15%	0.15%	0.13%	0.13%	0.13%	0.15%
Lysine HCL	0.20%	0.02%	0.18%	0.15%	0.20%	0.00%
DL-Methionine	0.04%	0.03%	0.00%	0.00%	0.08%	0.00%
Grease	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
L-threonine	0.05%	0.06%	0.04%	0.02%	0.09%	0.02%
L-tryptophan	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Paylean®	--	--	--	--	0.02%	--
Total	100%	100%	100%	100%	100%	100%
Diet Costs, $/ton	170.22	163.11	153.80	147.23	183.99	144.96

[b] Based on prices ($.lb) from Feed Ingredient Weekly, October 2007: DDGS = $0.06, Corn = $0.06, SBM = $0.13, Limestone = $0.05, DiCalcium Phosphate = $0.28, Vit. Premix = $0.85, Lysine HCL = $0.99, DL-Methionine = $1.30, Grease = $0.24, L-threonine = $1.20, L-tryptophan = $22.50, and Paylean® = $26.00

Table 8. Total Diet Cost and Shadow Value of Byproducts (in $/ton) at Maximum Inclusion Level[b]

	Iowa DDGS			Fractionated DDGS			Germ		
Pig Growth Stage	Max. %	Shadow Value	Total Diet Cost	Max. %	Shadow Value	Total Diet Cost	Max. %	Shadow Value	Total Diet Cost
Grower 1	26.95	$158.57	$156.80	14.08	$144.84	$159.42	35.86	$137.47	$157.70
Grower 2	27.92	$158.57	$149.51	13.08	$157.49	$153.22	37.66	$137.47	$151.35
Finisher 1	28.65	$158.57	$140.98	9.79	$186.92	$146.86	25.03	$136.13	$145.32
Finisher 2 w/o Paylean-9®	19.23	$158.57	$138.52	6.57	$186.92	$142.36	8.27	$157.26	$143.64
Finisher 2 w/ Paylean-9®	26.62	$164.10	$168.11	16.92	$186.92	$168.72	21.01	$137.47	$175.06
Gestating Sow	9.66	$182.31	$138.16	0.90	$209.50	$143.40	32.25	$157.87	$131.47

[b] Based on prices ($.lb) from Feed Ingredient Weekly, October 2007: DDGS = $0.06, Corn = $0.06, SBM = $0.13, Limestone = $0.05, DiCalcium Phosphate = $0.28, Vit. Premix = $0.85, Lysine HCL = $0.99, DL-Methionine = $1.30, Grease = $0.24, L-threonine = $1.20, L-tryptophan = $22.50, and Paylean® = $26.00

In assessing the validity of total diet cost results with respect to the fractionated DDGS and Iowa DDGS, fractionated DDGS shows a higher total diet cost with lower inclusion rates. Due to the higher amino acid availability in fractionated DDGS samples, a lower inclusion rate for the DDGS is necessary to meet the amino acid constraints while maintaining proper metabolizable energy levels. At a lower inclusion rate it replaces SBM in the diet. This creates a higher overall cost for a diet since currently DDGS is priced substantially lower than soybean meal. The higher inclusion rate for Iowa DDGS creates a lower overall diet cost at its optimal level, but this cost does not account for negative impacts high inclusion levels of DDGS have on carcass value in swine. If Iowa DDGS is evaluated at the same inclusion level that is optimal for fractionated DDGS, the diet cost will be higher. A producer wishing to feed greater than 20% of the diet composed of DDGS should include a discount factor in the calculations.

Despite low inclusion levels of fractionated DDGS in the swine diet, its shadow value is comparable to that of Iowa DDGS at higher inclusion levels. In addition, when sulphur amino acid constraints were relaxed, higher maximum in-

Table 9. A 50 MGY Ethanol Plant Model[c]

	W/O Fractionation	With Fractionation
Annual Ethanol Capacity (MGY)	50,000,000	55,000,000
Corn Required (bushels)	17,857,143	20,676,692
Operating Cost ($/gallon)	$0.61	$0.53
Iowa DDGS Yield (lbs/bu)	17.4	
Fractionated DDGS Yield (lbs/bu)		12.5
Bran Yield (lbs/bu)		3.4
Germ Yield (lbs/bu)		4.4
Revenues	Plant Totals	Plant Totals
Ethanol	$100,000,000	$110,000,000
Iowa DDGS	$18,332,143	
Fractionated DDGS		$13,928,665
Bran		$2,284,750
Germ		$4,608,093
Total Revenues	$118,332,143	$130,821,507
Corn Cost	$59,464,286	$68,853,384
Operating Costs	$30,500,000	$29,150,000
Total Costs	$89,964,286	$98,003,384
EBITDA	$28,367,857	$32,818,123
Net Income	$28,367,857	$32,818,123

Increased Net Income from Fractionation Technique = $4,450,266

Present Value (PV) of Increased Annual Revenue = $38,945,481

[c] Based on prices: Corn =3.33 $/bushel, Ethanol = 2.00 $/gal, Iowa DDGS = 118.00 $/ton, Fractionated DDGS = 107.78 $/ton, Bran = 65.00 $/ton, and Germ = 101.30 $/ton

clusion levels of the fractionated DDGS are possible that replaced more corn and SBM in the diet. Germ has substantially higher levels of energy and digestible phosphorous than both Iowa DDGS and fractionated DDGS, but lysine and other amino acids are not increased proportionately. Its high energy content allowed for high optimal inclusion levels in both grower and gestating sow diets.

The 50 MGY ethanol plant spreadsheet model showed that fractionation technology results in greater ethanol yield and higher revenue from the feed byproducts. Despite lower inclusion levels, fractionated DDGS has higher economic value than Iowa DDGS and should increase net revenue for the ethanol plant producers. So long as the increase in capital cost is less than $38 million, the plant's overall profitability will improve.

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