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Overview of the Ethanol Industry and Production of DDG/S
(A Nutritionist's Perspective)

Matthew L. Gibson, Ph.D.
Kip Karges, Ph.D.

Dakota Gold Marketing
Dakota Gold Research Association
4506 N. Lewis Ave.
Sioux Falls, SD 57104
(605) 965-6273
MGibson@DakotaGoldMarketing.com

Summary

The modern fuel ethanol industry is experiencing explosive growth. This growth is resulting in a concomitant increase in both the consumption of corn and the supply of Dried Distillers Grains with Solubles (DDG/S). This paper explores some of the intricacies of the ethanol industry, production of DDG/S, new technologies in ethanol production, and the resulting change in by-products from these new technologies.

The Ethanol Production Process

Modern ethanol production can be described by its ultimate use: either potable or fuel. Both processes are remarkably similar, in general (Figure 1). Simplistically, whole corn is ground into a meal, water is added, the resulting mash is cooked (to gelatinized the starch), enzymes are added to cleave free glucose from the starch, yeast is added, and the mix is allowed to ferment. During this fermentation, two main products are formed: ethanol and CO_2. The CO_2 is (usually) scrubbed and vented to the atmosphere. The fermented mash is distilled to recover the ethanol. The resultant whole stillage is dried into the feed product Dried Distillers Grains with Solubles (DDG/S).

Even thought the two processes are, essentially, identical, the ultimate goal of these two industries is widely divergent. For example, the potable ethanol industry is highly concerned with organoleptic characteristics of the end-product – primarily taste. To achieve different taste profiles, the potable distillers use many techniques such as varying the "mash bill" (essentially, the grain mixture), altering fermentation times (and conditions), aging, as well as many others which are both proprietary and beyond the scope of this discussion. The fuel ethanol industry is focused on one goal: conversion of starch into the greatest amount of ethanol, as quickly and as efficiently as possible.

Regardless of the goal of each industry, one thing is clear: differences in the ethanol production process result in differences in the DDG/S produced. Some of these differences will be reviewed later in this paper.

Fuel Ethanol Industry

The current state of the fuel ethanol industry can best be characterized by the phrase "explosive growth." Even though ethanol has been used intermittently as an automotive fuel (or fuel additive) for over 100 years, the total production never significantly exceeded 1 billion gallons through 1995. Since then, however, production has virtually quadrupled (Figure 2).

The reasons for this explosive production increase are myriad and beyond the scope of this paper; certainly many market forces play an economic role. However, the uses of ethanol as a fuel are well-documented and worthy of mention.

Ethanol and DDG/S

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Renewable Fuel

Fuel ethanol is certainly garnering tremendous attention as a source of renewable fuel in the form of E-85. Each of the “Big 3” (B3) USA automakers has vehicles designed to run on this fuel. These vehicles are denoted as Flex Fuel Vehicles (FFV’s). In fact, one of the B3 currently has a national ad campaign based on the slogan “Live Green, Go Yellow” with the “Green” implying an environmentally-friendly life-style and the “Yellow” indicating that the fuel comes from corn.

The reason E-85 is considered a renewable fuel is simple: the fuel consists of 85 % ethanol and 15 % petroleum gas. FFV’s are simple to manufacture. In fact, they appear and operate identical to their “petroleum” counterparts with just a few simple modifications made at the factory which allow them to burn fuel which contains a range of ethanol from 0 up to 85 %. Also, E-85 supplied through normal consumer outlets and the pumps are identical – both factors negate any sort of additional infrastructure needed to supply product to end-user consumers.

Other countries also use ethanol as a source of renewable automotive fuel – the prime example being Brazil. In that country, about 1/3 of their cars run on the azeotrope (~ 95 % ethanol and ~ 5 % water) while about 2/3 of their cars run on 22 % “ethanol” (azeotrope, actually) and 78 % petro gas.

Octane Booster

Gasoline obtained at the pump is not really a single molecule. Rather is it a blended of components – each of which is intended to serve a unique role (or combination of roles). Ethanol is one such component commonly used as an octane booster .

Ethanol has a standard blending octane value of 113. Thus, it is a very effective blend component for increasing octane of various blends. In fact, most petro gas which contains 10 % ethanol will have the "next higher" octane grade rating. For example, an 87 octane "Regular" grade gas which is blended with 10 % ethanol will be boosted to the 89 octane "Premium" grade.

Oxygenate

Improving and maintaining air quality is one of the area under the jurisdiction of the Environmental Protection Agency (EPA). Starting with the Clean Air Act Amendments of 1990 (and, possibly before), several pieces of legislation have mandated oxygenate molecules be added to gasoline blends. Although the legal aspects of air quality are beyond the scope of this discussion, suffice it to say that this area has received much attention in the past and will continue to do so for the foreseeable future. One way to improve air emissions from vehicles is to include oxygenate molecules.

Several oxygenate molecules are available for use as the oxygenate component of gasoline blends. However, for all practical purposes, this role is filled by only two: Methyl Tertiary Butyl Ether (MTBE) and ethanol.

Although MTBE has not been legislated out of gasoline fuel on the national level, several states have implemented measures to limit its use within their borders. And, at the present, the use of MTBE as an oxygenate is apparently on the decline nationwide leaving ethanol as the only logical choice.

Energy Balance

Shrill detractors of the ethanol industry certainly make for colorful news coverage. For example, phrases such as "...using corn to make gas when millions are starving" are unquestionably intended to strike an emotional chord with the American public.

One area which has received the glaring light of public attention – especially in recent months and weeks – is the energy efficiency of ethanol conversion from corn. In this time of Middle-East turmoil, the claims – "...it takes more oil energy going into the process than comes out as ethanol" – receives more than its share of attention.

However, when reviewing objective measures of energy balance for the production of ethanol from corn in modern, fuel ethanol distilleries, this claim just does not stand up to serious examination. Many reasons exist for this. Improved agronomic practices for corn production and tremendous advances in fermentation technology are the two main reasons. The energy balance is currently equal to 1.77 for dry-grind technology ethanol production (ASPEN PLUS ® Model; Department of Energy, Argonne National Labs). That is, 1.77 BTU's are obtained in ethanol energy for every 1.00 BTU's of energy input. To be fair to the critics, this figure is greatly improved compared with previous eras. However, as this figure continues to improve, criticism for energy balance will lose its relevance.

Wet-mill vs Dry-grind

One area which deserves mention are the two types of facilities which produce fuel ethanol: "wet-mill" vs "dry-grind" operations. The main reason for mention of this distinction is this: the last wet-mill operation was commissioned in 1995. The entirety of growth experienced since that time has occurred in dry-grind operations. The significance of this observation (for animal producers) is that the co-product generated from dry-grind production is DDG/S. Thus, the recent growth of dry-grind ethanol has generated a concomitant growth in supply of DDG/S (Figure 3).

Local Economic Impact

The effect of ethanol production on the local economy is profound, as well. A study by Karges (2006), estimated that the value of corn increases between 300 – 350 % through the production of ethanol. This value benefits the ethanol producer, certainly, but it also benefits the corn farmer by providing a higher price for his corn. Further, this increase in corn value has a direct impact on the local economy as it creates jobs – both directly and indirectly – in the form of manufacturing and support.

Other Information Resources

For further insight into the fuel ethanol industry and FFV's, many excellent resources are available from industry organizations such as: (1) the Renewable Fuels Association (RFA) at www.EthanolRFA.org; (2) the American Coalition for Ethanol (ACE) at www.Ethanol.org; and (3) the National Ethanol Vehicle Coalition (NEVC) at www.E85Fuel.com.

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Feed Products

In the feed industry, confusion reigns with respect to the products available from corn milling and ethanol production facilities. There are primarily two types of corn processing facilities, currently, in operation. A brief review of the two is necessary to understand the feed products. Both types begin with the whole corn kernel.

Wet-milling corn processors subject the whole corn to a dilute sulfur dioxide "steep" process for several hours. From there, the corn is ground and milled into various fractions – mainly, bran, starch, protein, oil, and others. The main feed products from wet-milling operations are: steep liquor, bran, germ meal, gluten meal, and gluten feed.

Dry-grind ethanol producers basically process the whole kernel through the entire operation. The resulting feed product is primarily DDG/S. In effect, any other feed products are really "products of convenience" from the post-distillation evaporation processes.

Another difference in wet-mills vs dry-grind operations is in the feedstocks used for production. Obviously the wet-millers are using corn to generate <u>corn</u> oil, <u>corn</u> starch, high-fructose <u>corn</u> syrup, etc. However, dry-grind ethanol producers may use any source of starch (such as any of several grains, grits, screenings, etc.) to produce fuel ethanol.

The Association of American Feed Control Officials (AAFCO, 2006) requires the majority grain to be declared on the label of DDG/S. That is, DDG/S resulting from fermentation of a mixture of 49 % grain sorghum and 51 % corn will be labeled exactly the same as DDG/S from 100 % corn fermentation.

Market Considerations

Traditionally, DDG/S was used primarily as a protein source for ruminants. As such, it more or less tracked the SBM markets. As more product has become available – and the quality has improved for use in non-ruminants – DDG/S is becoming an important source of energy, as well.

In reviewing the price of DDG/S over the past 5 years, it generally ranges around 115% the price of corn (Table 1). And, when considering the annual FOB Minnesota spot price, DDG/S will average between \$ 70 and \$ 90.

As has been observed, DDG/S production has experienced dramatic growth. Further, this growth curve is expected to remain steep for at least the next 5 – 6 years. Despite aggressive predictions, the growth of the market is exceeding those expectations. For example, the total production of DDG/S for crop-year 2005 – 2006 is certainly expected to exceed 10 million tons; production will be in excess of 1 million tons per month by the 4th quarter. Earlier predictions – though aggressive – showed the production to reach 12 million tons per year in 2008.

Although many alternative uses of DDG/S are being pursued, for all intents and purposes, the stark reality is that almost all DDG/S will be fed to livestock. Thus, market development in all species of livestock will become crucial sooner than later. An understanding of DDG/S nutrition is vital to the continued success of both the ethanol and livestock industries.

Nutrient Considerations

The DDG/S of today is quite different than that produced just a few short years ago. Old "book values" may or may not be appropriate for use in modern poultry diets.

As noted, the dry-grind ethanol industry has experienced rapid evolution. Also, as more DDG/S has become available and has received more attention from the feed industry, some producers have made serious investments into improving DDG/S to the point where it is an acceptable feedstuff for all species of livestock (and pets!). And, due the rapid growth in this industry, there is a tremendous "data void" that needs to be filled in order to effectively use the product.

When polling nutritionists about DDG/S, the biggest concerns today seem to be centered on nutrient quality and product variability as well as physical factors such as flowability. Several factors are notable and should be discussed individually.

<u>Mycotoxins:</u> Mycotoxins are (unfortunately) not destroyed during either the fermentation or heating processes. And, like other nutrients, in general, they are concentrated up 3-fold during the ethanol process. Although they can be easily (and cheaply) quantified using ELISA technology in a corn sample, only HPLC is approved for quantifying naturally-occurring mycotoxins in DDG/S. (To be fair, there is one supplier who has a GIPSA approval for ELISA detection of Aflatoxin in DDG/S;

however, this procedure was validated using samples "spiked" with exogenous aflatoxin – not naturally-occurring mycotoxins.)

Two points should be noted. (1) Although mycotoxins can be easily quantified in a corn sample, a good, representative sample of corn is very, very difficult to obtain from a bulk shipment. (2) HPLC technology is costly and difficult.

In addition to the difficulties of detecting mycotoxins, the USA has experienced two years of corn production with high – if regional – mycotoxin contamination.

Rapid mycotoxin quantification in DDG/S is an area which is receiving much attention; it needs it.

Plant-to-Plant Variation: Due to wide variances in technology and processes, DDG/S coming from plants within close proximity to each other may be quite variable. Even DDG/S coming from one plant may be quite variable on a day-to-day basis. A study by Robinson examined DDG/S from several sources. He clearly demonstrated that DDG/S may vary widely for certain nutrients; even those nutrients with similar mean values may likely have widely divergent variability between sources (Table 2).

Energy Variability: Several factors contribute to the differences in ME values. Certainly, the "New" technology product has more energy than "Old" technology product (Table 3). Nutritionists should be aware that both products are still widely available. More discussion will follow about "New-New" technology products derived from bio-refining operations linked to dry-grind plants. However, from an energy standpoint, these products are different as well. Care should be taken that proper values are used for diet formulation.

Protein Variability: Many factors influence protein (and amino acid) content and digestibility in DDG/S. Corn protein is the primary contributor to DDG/S protein. As corn protein has decreased in recent years (Figure 4), so has the resulting DDG/S protein. Care should be taken to obtain accurate values for amino acids from your supplier.

Additionally, amino acid digestion has received much scrutiny. Ergul found that color was highly correlated with lysine digestibility (Table 4). Obviously, product which is darker has undergone more extensive Maillard non-enzymatic browning.

Phosphorus Availability: Even though the level of phosphorus may be variable in DDG/S, the digestibility is quite variable. Although the reasons are not exactly clear, Amezcua, Parsons, and Noll found wide variances in phosphorus availability (Table 5). The apparent mechanism seems to be linked to heating of the product – with a possible destruction of phytic acid. Obviously, in today's poultry market, this is not necessarily a desirable characteristic as it also indicates lower lysine digestibility.

Probably a "happy medium" is to find product which has high lysine digestibility along with acceptable phosphorus availability.

Variation in Fat Values: Fat levels will vary along with other nutrients as discussed previously. However, many nutritionists also consider the fat in DDG/S to be identical to corn oil. Analysis indicates this is not so. The fat in DDG/S has lower linoleic acid and higher omega-3, the iodine value is lower and the FFA content is higher. (Table 6).

New Technologies

As noted, the production of ethanol in dry-grind facilities is undergoing rapid technological evolution. And, as should be clearly evident at this point, any alteration of the ethanol process will result in changes to the resultant DDG/S. Some new technologies which have recently appeared in the marketplace are of particular note – especially, due to their profound changes on the resulting DDG/S.

BPX™

A new technology which completely revolutionizes ethanol production has recently been introduced. The technology is named BPX™. Essentially, the process allows production of ethanol without "cooking" the mash to gelatinize the starch. The changes on the resultant DDG/S – although not completely understood – are profound. The BPX™ product exhibits greatly improved physical characteristics such as higher density and easier pelleting. Most importantly, the product exhibits enhanced flowability.

Bio-Refining

Until recently, all product going into a dry-grind ethanol production facility has essentially become DDG/S through the process. Now, three fully-commercialized dry-grind facilities have implemented true dry-milling operations in front of the ethanol facility. The whole corn is milled into several fractions which can then be directed into several different production streams (Figure 5).

The "endosperm" stream – actually, a "corn-starch-enriched" stream is what ends up in the fermenter. That is, some of the bran and some of the germ – the non-fermentables – are removed from the whole kernel before fermentation. The advantages to ethanol production are fairly obvious. What is less obvious are the changes to the resultant co-product.

The co-product – a true DDG – has very high levels of protein (and amino acids, obviously) along with lower levels of fat and phosphorus. Research indicates that the energy value is quite good (Table 3). This is probably due to the removal of the bran fraction which dilutes the ME in "normal" DDG/S.

As the corn is milled prior to fermentation, the "germ enriched" fraction also becomes available as a feedstuff for animal production. As expected this product is high in fat and phosphorus. As the germ fraction contains the most desirable proteins in the corn kernel, the amino acid profile is quite desirable in spite of a fairly low crude protein level. As the product has not been "steeped" (as in a wet-mill), these protein fractions contain all the soluble fractions. Also, as this corn has not been through fermentation, the oil is in its "native" state.

"Oil from Syrup"

One final new technology that deserves mention is the "oil from syrup" process. At least two companies are introducing technology to the ethanol industry for removing the oil from the syrup process stream prior to drying into DDG/S. The uses for this oil are obvious: biodiesel, primarily, and feed, secondarily. Although not yet in wide-spread operation, the process is easy to implement and is quite inexpensive to operate.

Nutritionists are cautioned to note that the resulting DDG/S will be lower in fat.

Conclusion

The fuel ethanol industry is experiencing explosive growth in both volume and technology. The DDG/S from this production will be fed. Although the poultry industry has been slow to adopt the use of DDG/S, there is a tremendous opportunity for exploiting the plentiful resource.

References

References are available from the authors upon request.

Figure 1. The Dry-Grind Ethanol Process Broin, 2006.

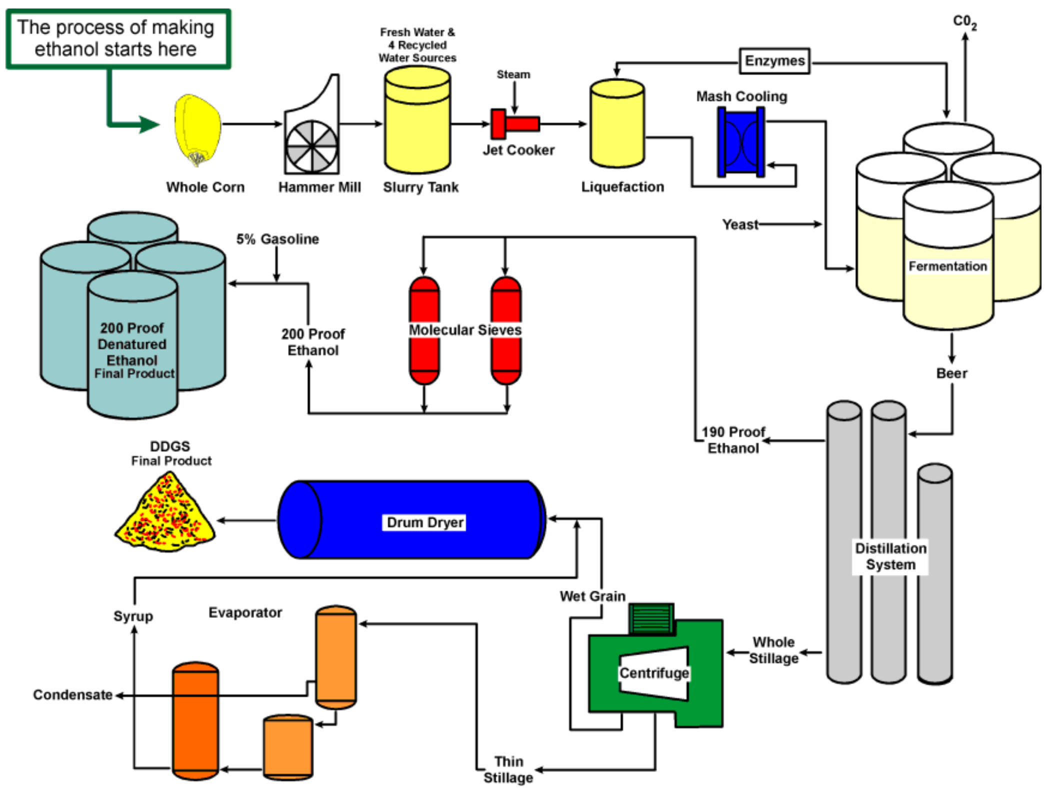

Figure 2. Ethanol Production – USA. ACE, 2006.

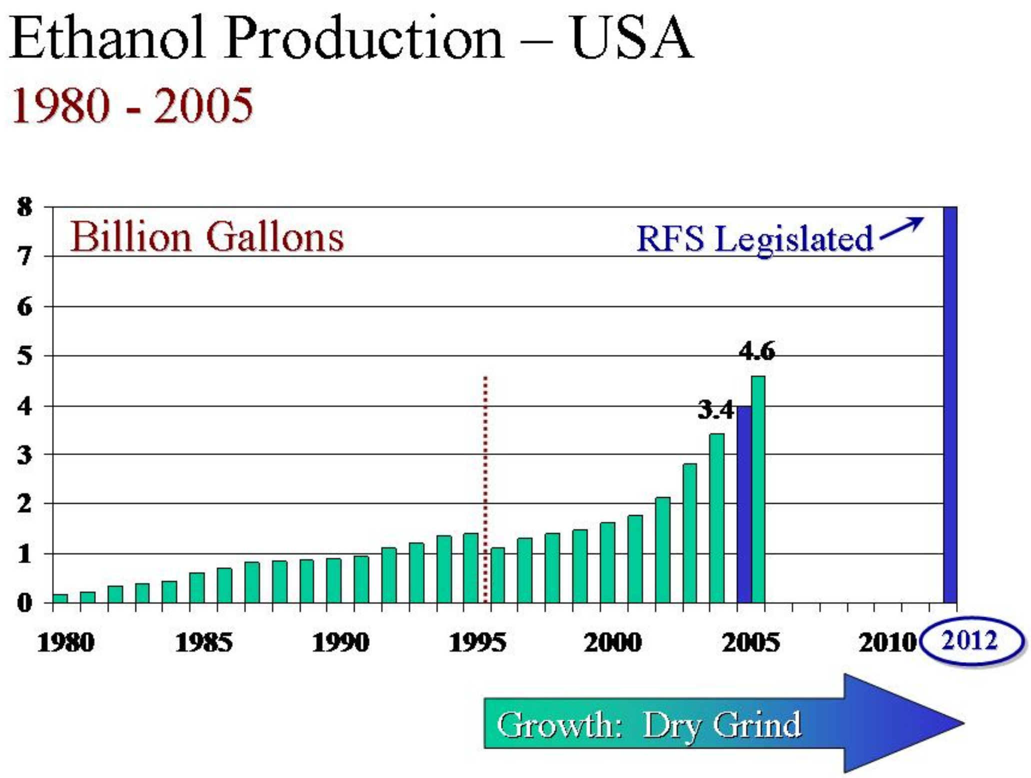

Figure 3. DDG/S Production – USA. ACE, 2006.

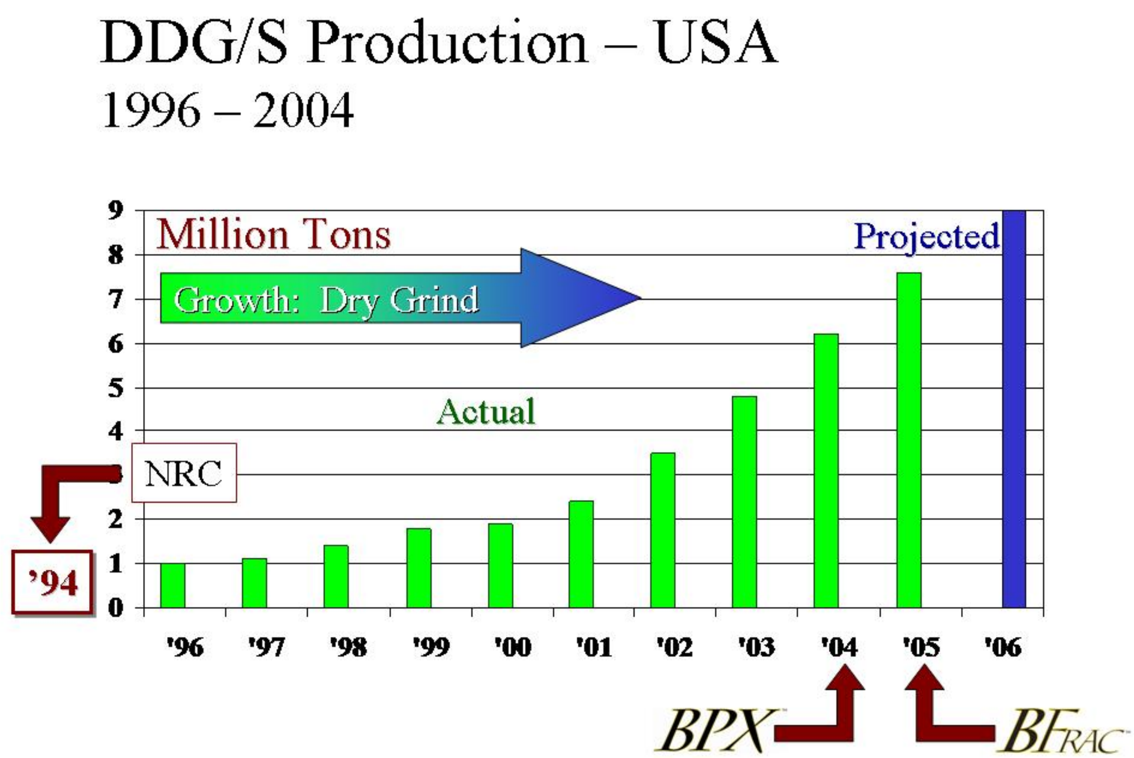

Table 1. Minnesota Spot Price ($/Ton) – Corn and DDG/S. DGM, 2006.

	Corn	DDG/S
2002	70	80
2003	76	90
2004	81	100
2005	61	71
2006	64	75

Table 2. DDG/S Source-to-Source Variability[1]. Robinson, 2004.

	Source	
Nutrient	Industry-wide	Dakota Gold
Crude Protein	30.1 ± 2.6	30.7 ± 1.2
Fat	11.5 ± 3.5	11.9 ± 0.7
ADICP	28.9 ± 11.7	8.2 ± 2.3
NE_L	1.93 ± 0.14	2.19 ± 0.04
Phosphorus	0.88 ± 0.14	0.70 ± 0.10

[1] Mean ± SD

Table 3. ME (kcal/lb) of Various Distillers Products. NRC, 1994 & DGRA, 2006.

Ingredient	Type	Metabolizable Energy
DDG/S	"Old" Technology	2,480
DDG/S	"New" Technology	2,750
DDG	Bio-Refined / High-Protein	2,650

Figure 4. Corn Protein – Crop Years '03/'04 → '04/'05. DGRA.

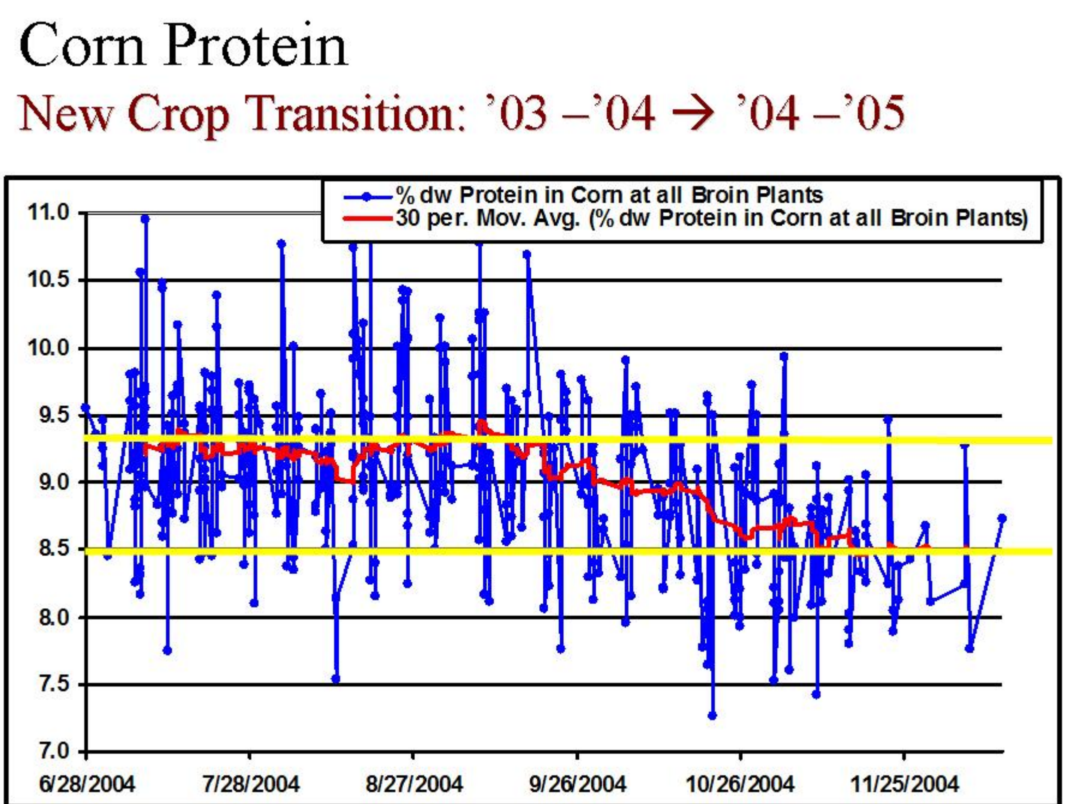

Table 4. Correlations between Color and Amino Acid Digestibility. Ergul, 2003.

Item	Hunter L*	Hunter b*
LYS	.67	.77
CYS	.67	.74
THR	.51	.58

Table 5. Phosphorus Availability of DDG/S. Amezcua, Parsons, Noll.

Experiment	DDG/S Description	Availability, %
1	Native	69
2	Low Digestible Lysine	102
2	Low Digestible Lysine	82
2	High Digestible Lysine	75
3	Native	75
3	Autoclaved	87

Table 6. Fatty Acid Profiles. NRC & DGRA.

Item	Corn[1]	DDG/S[2]
C16:0	11	13
C18:1	24	29
C18:2	59	51
Ω3	0.7	2
Ω6	58	52
Unsat:Sat	6.5	4.6
Iodine Value	125	110
Free Fatty Acids	0 ?	10

[1] NRC
[2] DGRA

Figure 5. Bio-Refining & Ethanol Production Process. Broin, 2005