CHAPTER 5

Emerging Technologies in Ethanol Production and Nutritional Composition of the High Protein Corn Co-Products Produced

Introduction

THE U.S. ETHANOL INDUSTRY IS CONTINUING TO EVOLVE where dry-grind ethanol plants are becoming biorefineries to not only improve ethanol yield, but also create a more diversified portfolio of corn co-products with potentially higher value for the domestic and international market. Several previous attempts were made to implement front-end fractionation technologies to enhance ethanol yield and create new co-products, but these process technologies were difficult to optimize ethanol and co-production efficiencies and are no longer used. However, beginning in 2005, the predominant new technology is back-end oil extraction from thin stillage, and is being used by the majority of dry-grind ethanol plants today. The processes, chemical composition and energy value of distillers corn oil is discussed in detail in Chapter 4.

Today, much of the focus of new engineering technologies being implemented in some dry-grind ethanol plants involve: 1) corn fiber separation for cellulosic ethanol production, 2) enhanced corn oil extraction methods, and 3) production of high protein (greater than 40 percent) corn co-products.

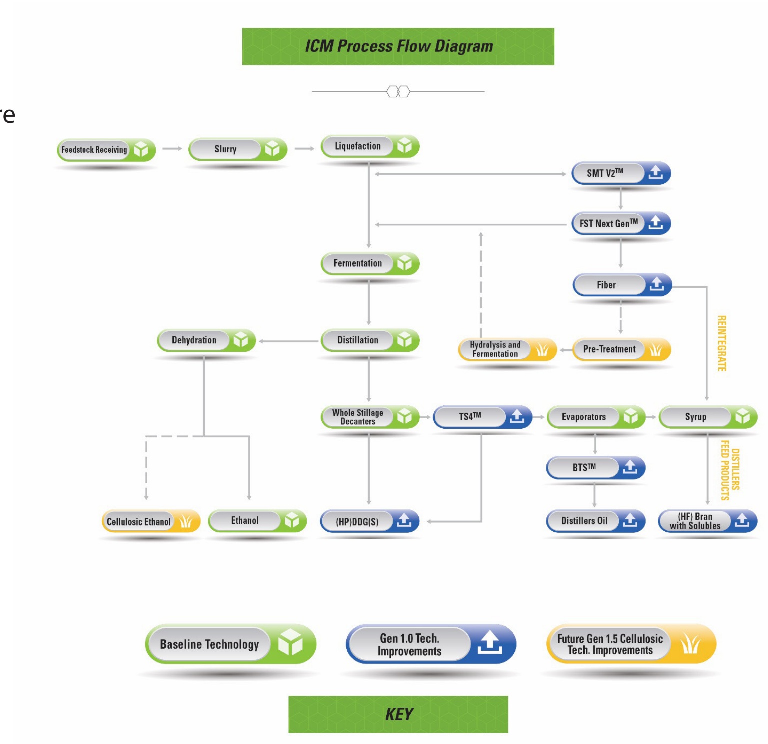

Figure 1. Overview of ICM Selective Milling Technology (SMT), Fiber Separation Technology (FST), Thin Stillage Separation System (TS4) and Grain Fiber to Cellulosic Ethanol Technology (Gen 1.5) in the ethanol and co-product production of dry-grind ethanol plants

Brief Description of New ICM, Inc. Process Technologies (www.icminc.com/products)

Four new processes have been developed by ICM, Inc. (Figure 1) that can be added to existing dry-grind ethanol plants to improve ethanol yield, corn oil yield and produce high-protein distillers dried grains (HP-DDG).

Selective Milling Technology™ (SMT)

This process uses newly designed proprietary milling equipment that allows ethanol plants to improve ethanol (up to 3 percent) and corn oil extraction (up to 25 percent) yields, while reducing energy usage (by about 40 percent) and improving operational efficiency of dry grind ethanol plants. The addition of SMT to an existing dry grind ethanol and co-product production process increases the amount of starch available for conversion to ethanol, improves oil recovery and recovers a higher proportion of fiber for other ICM process applications including Fiber Separation Technology™ (FST) and ICM Generation 1.5 processes. Currently, 26 ethanol plants around the world are using the SMT process.

Fiber Separation Technology™ (FST)

Fiber Separation Technology™(FST) is follows SMT, and is designed to remove fiber prior to fermentation of corn starch to ethanol. By removing the fiber before fermentation, ethanol plants are able to concentrate the amount of fermentable starch in fermenters and increase the capacity for ethanol production and throughput. As a result, ethanol plants that install FST technology achieve up to 15 percent greater ethanol production capacity, up to 30 percent greater corn oil separation, reduced natural gas use and have the capability of producing high fiber or high protein (40 percent) co-products.

Thin Stillage Separation System™ (TS4)

The ICM TS4 technology has several design configurations that allows separation of the stillage after fermentation into high-value components including protein, solubles and corn oil. This system improves plant operation efficiencies by increasing dryer and evaporator capacity, improving centrifugation and oil separation, increasing throughput, and reducing energy and water consumption of the ethanol plant.

Generation 1.5 – Grain Fiber to Cellulosic Ethanol Technology™ (Gen 1.5)

In addition to using ICM SMT and FST technologies, the implementation of Gen 1.5 allows ethanol plants to produce an additional seven to 10 percent ethanol from corn fiber, and improve oil extraction by up to 20 percent. The system allows ethanol plants to add up to $3 more value per gallon for ethanol produced under current U.S. government cellulosic ethanol incentives. Furthermore, corn fiber is much easier to handle than bulky crop residue, which significantly reduces the capital cost of producing cellulosic ethanol. Use of this process technology results in the production of high protein (40 percent) DDGS.

Brief Description of New Fluid Quip, LLC Process Technologies (http://fqptech.com/proven-technologies)

Three new processes have been developed by Fluid Quip LLC (Figure 2) that can be added to existing dry-grind ethanol plants to improve ethanol yield, corn oil yields, 50 percent purity protein, pure fiber and clean sugars.

Selective Grind Technology (SGT™)

The SGT System is installed in the mash cook process to expose more starch for conversion to ethanol and to shear open the germ to release more corn oil. This process is

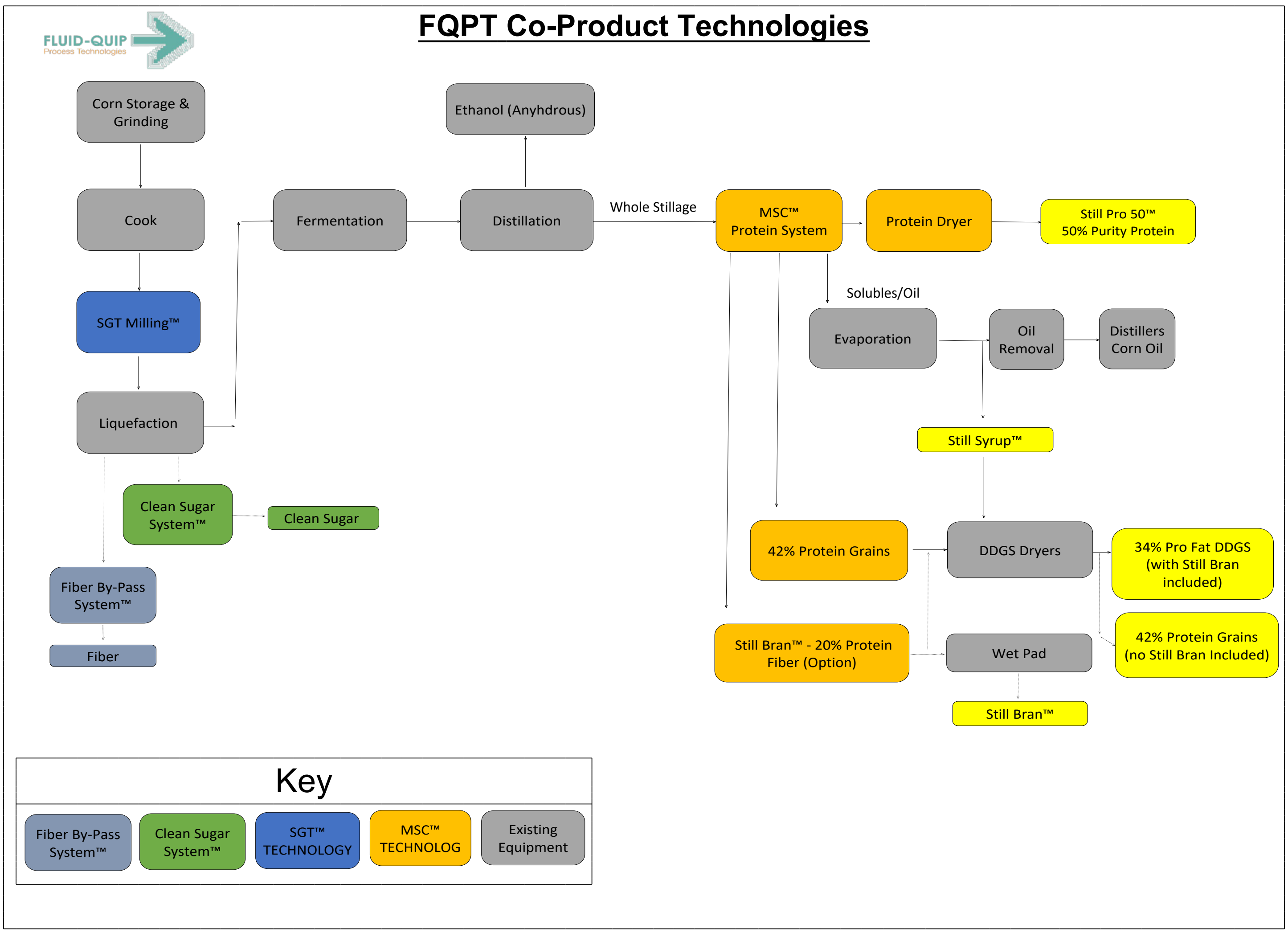

Figure 2. Overview of the process used to separate protein from thin stillage in the production of Still Pro 50™

designed to optimize particle size for maximum ethanol and corn oil yield, resulting in increases in ethanol yield (up to 3.5 percent), increases of corn oil (up to 30 percent) yield.

Maximized Stillage Co-Products™ (MSC)

Fluid Quip's MSC process is designed to separate multiple product streams from whole stillage. MSC produces Still Pro 50™, a 50 percent purity protein product that is a unique blend of spent brewer's yeast and corn gluten meal. Use of this system improves operation efficiencies of dry-grind ethanol plants by removing backset solids and impurities allowing increasing oil yields (up to 30 percent), and ethanol throughput gains (up to 10 percent). The MSC™ protein technology system can be adjusted to produce varying amounts of Still Pro 50™ while meeting typical nutrient specifications in the remaining DDGS for the export market.

Clean Sugar Technology (CST™)

The CST™ System produces an equivalent sugar quality to that of a corn wet mill process. CST™ not only produces an industrial sugar stream, but also yields a high-value corn oil stream and can produce valuable animal feed products including a high-purity protein stream.

Brief Description of Rayeman Compression Dryer System (www.rayemanelements.com)

The Raymen Compression Dryer is unique compared to conventional rotary drum dryers used in the majority of ethanol plants. As the wet DDGS enter the dryer, two patented and specially designed electrically heated screws intermesh with one another to create designated compression points that press water out of the grain. As this occurs, low temperature heat is created due to the shearing and compressing of the grains from the rotating screws, and vaporizes water within the grains at various flash points throughout the process. Use of this process conserves energy used in the co-product drying process, eliminates burning of the co-product, reduces carbon emissions and has a lower capital and operation cost compared with conventional dryers.

Nutrient Composition of New High Protein Corn Co-Products

The most important point to remember when considering purchasing and using any of the new high protein corn co-products is the nutritional composition and energy values are unique and vary among these co-products. Furthermore, these new co-products are being branded with unique names to distinguish each one from the others. Therefore, caution should be used, and generalizations of the protein and nutritional composition should be avoided when comparing the nutritional value of each of these co-products for various animal species.

There are limited nutrient composition data on the new high protein corn co-products being produced, except for Still Pro 50™, because processes are still being optimized in the ethanol plants using these various new technologies. Therefore, feed ingredient purchasers are encouraged to contact the producers and marketers of these co-products to obtain the most current nutritional information.

As shown in Table 1, the high protein distillers grains (HP-DDG) produced using current ICM technologies contains less crude protein, greater crude fat and phosphorus, and a different amino acid profile than previously produced HP-DDG (NRC, 2012). Studies are underway to determine metabolizable energy (ME) content of ICM HP-DDG in growing pigs and broilers, but based on ME content of previously produced HP-DDG for swine, it is expected the new HP-DDG will contain greater ME content for swine and poultry compared with medium-oil (seven to nine percent crude fat) DDGS. It is important to recognize results from previous studies evaluating the use of HP-DDG in diets for all species may not be applicable to the new ICM HP-DDG because of different nutritional characteristics.

Even less is known about the nutritional composition of FST Fiber+Syrup because it has only been produced in one corn ethanol plant in Brazil for a short time. It is not considered to be a high protein co-product because of its lower crude protein content (25.8 percent), but its nutritional composition is comparable in crude protein, crude fat, NDF and amino acid content to some sources of conventional DDGS. Furthermore, the phosphorus content in FST Fiber+Syrup is the highest (1.34 percent) among all co-products shown in Table 1, which can provide significant cost savings in swine and poultry diets (if it has high digestibility and bioavailability as in DDGS) by reducing the need for inorganic phosphate supplementation in these diets. Studies are underway to determine the ME, standardized ileal digestible amino acids and standardized total tract or bioavailable phosphorus content of this co-product for swine and broilers.

Purestream 40 has less crude protein (42 percent) than HP-DDG and Still Pro 50™, but has greater lysine, methionine, arginine, leucine and isoleucine content than in HP-DDG. Furthermore, the recently determined ME content (swine) of Purestream 40 is greater than Still Pro 50™, medium-oil DDGS and soybean meal.

Still Pro 50™ has been the most extensively researched among all of the new corn co-products. This co-product has the greatest crude protein content of all high protein co-products, and is comparable to soybean meal. As a result, the amino acid content of Still Pro 50™ is greater than found in all other high protein co-products, but has less arginine, isoleucine, lysine, phenylalanine and tryptophan than soybean meal. The ME content (swine) of Still Pro 50™ appears to be slightly less than medium-oil DDGS but about 100 kcal/kg greater than soybean meal. The phosphorus content in Still Pro 50™ is comparable to Purestream 40, and greater than DDGS, soybean meal and HP-DDG.

All of these new corn co-products are low in calcium and sodium, but relatively high in phosphorus content compared to other grains and soybean meal. Sulfur content in HP-DDG and Still Pro 50™ is greater than conventional DDGS, and may be a limiting factor for using high (greater than 20 percent) diet inclusion rates of these co-products in ruminant diets.

While all of the new corn co-products can be used as an excellent source of energy, digestible amino acids, and

Table 1. Nutritional composition of new high protein corn co-products (dry matter basis)

dry matter basis	HP-DDG (ICM)[1]	HP-DDG (NRC, 2012)	FST Fiber+Syrup (ICM)[2]	Purestream 40[3]	Still Pro™[4]	Medium-Oil DDGS (NRC, 2012)	Soybean meal (NRC, 2012)
Moisture %	8.8	8.8	10.0	10.7	6.8	10.7	10.0
Crude protein %	44.2	49.7	25.8	42.1	53.4	30.6	53.0
Crude fat %	8.6	3.9	7.8	9.4	5.8	10.0	1.69
NDF %	36.0	36.9	32.9	34.8	39.5	34.1	9.1
ADF %	17.5	22.6	9.3	15.8	20.0	13.5	5.9
ME6, kcal/kg	ND5	4,092	ND	4,275	3,766	3,801	3,660
Arg7 %	1.80 (72-79)	1.78 (85)	1.29	2.10 (87)	2.41 (81)	1.38 (81)	3.83 (94)
Cys %	1.02 (69-74)	0.90 (78)	0.72	0.91 (75)	1.75 (73)	0.49 (73)	0.78 (84)
His %	1.16 (66-72)	1.17 (79)	0.60	1.15 (82)	1.44 (80)	0.83 (78)	1.42 (90)
Ile %	1.52 (68-75)	2.01 (80)	0.57	1.62 (82)	2.12 (75)	1.19 (76)	2.38 (89)
Ile:Lys	1.13	1.50	0.66	1.05	0.98	1.18	0.72
Leu %	4.95 (81-84)	6.78 (86)	1.27	5.14 (89)	6.68(85)	3.64 (84)	4.02 (88)
Leu:Lys	3.69	5.06	1.46	3.36	3.08	3.60	1.22
Lys %	1.34 (47-56)	1.34 (69)	0.87	1.53 (76)	2.17 (61)	1.01 (61)	3.29 (89)
Met %	0.80 (79-83)	1.02 (86)	0.53	0.88 (87)	0.95 (84)	0.64 (82)	0.73 (90)
Phe %	2.29 (77-80)	2.65 (84)	0.63	2.32 (86)	2.67 (81)	1.53 (81)	2.67 (88)
Thr %	1.90 (60-67)	1.74 (75)	0.80	1.66 (75)	2.57 (70)	1.11 (71)	2.07 (85)
Trp %	0.38	0.26 (82)	0.30	0.31 (80)	0.40 (81)	0.22 (71)	0.73 (91)
Val %	2.19 (69-75)	2.32 (78)	0.93	2.15 (81)	2.73 (74)	1.56 (75)	2.48 (87)
Val:Lys	1.63	1.73	1.07	1.40	1.26	1.54	0.75
Ash %	3.0	2.6	7.3	2.8	3.9	4.5	7.0
Ca %	0.01	0.02	0.08	0.03	0.03	0.09	0.37
P %	0.80	0.39	1.34	0.91	1.00	0.67	0.79
S %	0.86	0.82	0.66	0.48	0.51	0.54	0.44
Na %	0.07	0.07	0.54	0.12	0.06	0.34	0.09

[1]Data from HP-DDG sources used in recent swine feeding trials conducted at the University of Minnesota. Values in parentheses are standardized ileal digestibility (swine) determined by Rho et al. (2017).

[2]Data from FS Bioenergia (Brazil)

[3]Data from Purestream 40 used in a recent feeding trial conducted at the University of Minnesota

[4]Data from United Wisconsin Grain Processors, Flint Hills Resources and Fluid Quip, LLC for Still Pro 50™

digestible phosphorus in diets for all animal species, the relatively high leucine, isoleucine and valine content of DDGS and high protein co-products may limit inclusion rates for swine, poultry and fish diets if high amounts of synthetic lysine, threonine and tryptophan are used to reduce the amount of soybean meal used in these diets. Excessive leucine relative to lysine interferes with the utilization of isoleucine and valine and may reduce feed intake and growth rate in pigs. It is unknown if these effects occur in poultry and various species of fish. Research studies are underway to determine if supplementing diets containing high protein corn co-products with synthetic isoleucine and valine are effective when adding these co-products at high (greater than 30 percent) dietary inclusion rates.

Summary of Studies Evaluating Animal Performance When Feeding HP-DDG Produced from Front-end Fractionation

Several studies have been conducted to determine the nutritional value and growth performance of feeding HP-DDG produced from front-end fractionation processes (Table 2). The majority of studies have been conducted for swine and dairy cattle, but only a few studies have been conducted for aquaculture (rainbow trout), broilers and layers and no studies have been published on feeding HP-DDG to beef cattle. The only study relevant to the HP-DDG produced using current ICM processes is by Rho et al. (2017). Because of the differences in energy and nutrient composition of the new ICM HP-DDG compared with previously produced front-end fractionation HP-DDG co-products, caution should be used when evaluating the animal responses from these previously published studies.

Summary of Studies Evaluating Nutritional Value of Still Pro 50™

One of the unique characteristics of Still Pro 50™ is it contains a substantial amount of spent yeast compared with HP-DDG, Purestream 40 and DDGS. Preliminary estimates suggest that Still Pro 50™ contains 29 percent spent yeast compared with 10 percent yeast in DDGS. Therefore, yeast contribute a significant amount of protein and amino acids to this co-product, along with beneficial compounds derived from yeast cell walls (mannans, β-glucans and nucleotides) which have been shown to have beneficial health effects for various food animal species (Shurson, 2017). The mannan content of Still Pro 50™ is about three percent and the β-glucan content is about 8.4 to 8.8 percent (Shurson, 2017). Therefore, in addition to serving as a high quality energy, digestible amino acid and phosphorus source, it may also provide animal health benefits. Preliminary data on amino acid (swine and poultry) and protein (ruminants) digestibility of Still Pro 50™ are shown in Table 3 and 4. See Table 1 for amino acid content and concentrations of other important nutrients in Still Pro 50™.

Conclusions

Several new high protein co-products are becoming available for domestic and export market use. Preliminary data indicate that although the protein and amino acid content is substantially greater in these co-products compared with conventional DDGS, and the amino acid digestibility and metabolizable energy content varies among co-products. Research needs to be conducted to determine maximum diet inclusion rates and performance benefits of feeding these co-products to swine, poultry, fish and ruminants.

Table 2. Summary of published studies on nutritional value and animal performance from feeding diets containing HP-DDG produced from front-end fractionation processes

Species	Reference
Aquaculture	Overland et al. (2013)
Beef cattle	None
Dairy cattle	Kelzer et al. (2007); Mjoun et al. (2009); Christen et al. (2010); Maxin et al. (2013a, b); Swanepoel et al. (2014)
Broilers	Batal (2007); Kim et al. (2008); Applegate et al. (2009); Rochelle et al. (2011);
Layers	Batal (2007); Kim et al. (2008); Tangendjaja and Wina (2011)
Swine	Widrymattereretal.(2007);Widrymattereretal.(2008);Gutierrezetal.(2009a,b);Andersonetal.(2012);Kimetal.(2009); Jacelaetal.(2010);Seaboltetal.(2010);aandRagland(2012);Petersenetal.(2014);Rojoetal.(2016);Rhoetal.(2017)

Table 3. Metabolizable energy and amino acid digestibility of Still Pro 50™ for swine and poultry		
Nutritional Component	Swine	Poultry
ME, kcal/kg (dry matter basis)	3,766	3,542 (TMEn)
Standardized ileal digestibility (swine) or true ileal digestibility (poultry) of amino acids %		
Arginine	81	94
Histidine	80	90
Isoleucine	75	90
Leucine	85	94
Lysine	61	81
Methionine + cystine	79	88
Phenylalanine	81	92
Threonine	70	87
Tryptophan	81	90
Valine	74	88

[1]Data were obtained from unpublished University of Illinois experiments, sponsored by Fluid Quip and Flint Hills Resources

Table 4. Rumen and intestinal digestibility of protein in Still Pro 50™	
Measure	percent as-fed basis
Soluble protein	28.7
Rumen degradable protein	26.1
Rumen undegradable protein	73.9
Intestinal digested protein	63.8
Intestinal digested protein as percent of undegradable protein	86.4
Total tract digested protein	89.9
Intestinal undigested protein	10.1

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