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# Analysis of fractionation in corn-to-ethanol plants

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# Analysis of fractionation in corn-to-ethanol plants

by

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Program of Study Committee:
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# ABSTRACT

As the dry grind ethanol industry has grown, the research and technology surrounding ethanol production and co-product value has also increased. One piece of technology to increase dry grind ethanol co-product value is of fractionation, both front end (before fermentation) and back end oil extraction (after fermentation) Front-end fractionation is pre-fermentation separation of the corn kernel into 3 fractions. The endosperm fraction is high in starch and is the only stream that enters the ethanol plant. The non-fermentable portion of the endosperm stream is carried into a product called high protein DDGS. The bran, or high fiber, stream is separated out and sold as an animal feed product, particularly to ruminant animals. High value oil is extracted out of the germ stream leaving a high protein co-product, corn germ meal. These 3 co-products have a very different composition than traditional DDGS from a corn ethanol plant. Furthermore, there are several possible fractionation processes; each produces a different set of co-products. Installing this technology allows ethanol plants to increase profitability by tapping into more diverse markets, and ultimately could allow for an increase in profitability.

An ethanol plant model was developed to evaluate fractionation technology and predict the change in co-products based on the compositions of the endosperm, bran, and germ streams, of the DDGS alone in the case of back end oil extraction. The model runs in Microsoft Excel and requires inputs of whole corn composition (proximate analysis), amino acid content, and weight to predict the co-product quantity and quality. User inputs include saccharification and fermentation efficiencies, plant capacity, and plant process specifications including front-end fractionation and backend oil extraction, if applicable. This model provides plants a way

to assess and monitor variability in coproduct composition due to the variation in whole corn composition.

Additionally the co-products predicted in this model are entered into the US Pork Center of Excellence, National Swine Nutrition Guide feed formulation software. The following information on the ethanol co-products can be included into the formulations: amino acid profile, crude protein, neutral detergent fiber, crude fiber, and metabolizable energy. This allows the plant user and animal nutritionists to evaluate the value of new co-products from fractionation equipment in existing animal diets.

# CHAPTER 1: GENERAL INTRODUCTION

## INTRODUCTION

The dry-grind ethanol industry has grown largely because of the renewable fuel standard which created a demand and incentive for investments into the ethanol industry. A traditional ethanol plant converts ground corn starch into ethanol, and carbon dioxide while the non-starch portion is carried into a product called dried distillers grains with solubles (DDGS). In order to improve plant efficiency and ultimately the economics of individual plants, new technologies have been developed.

Two of these technologies are backend oil extraction and front-end corn fractionation. Backend oil extraction takes oil out of the DDGS product after fermentation. Front-end fractionation separates the corn kernel into 3 streams. Only the high starch portion of the kernel enters the ethanol plant. The non-fermentable products of this stream are carried into a DDGS product, but it has a much higher protein compared to the traditional DDGS. The other two streams are high in the corn bran and in corn germ, both able to be utilized as animal or human food products.

When these technologies are installed the non-starch nutrients are modified compared to the traditional DDGS product. In the case of backend fractionation, the DDGS product has a much lower oil content, but higher protein. Front-end fractionation creates 3 new products with unique compositions compared to traditional DDGS. These 3 unique compositions allow for the plant to diversify its co-products, and break into new markets.

## LITERATURE REVIEW

Corn-based ethanol production has increased significantly in the last 10 years due largely to the Renewable Fuel Standard (RFS), which is under the administration of the

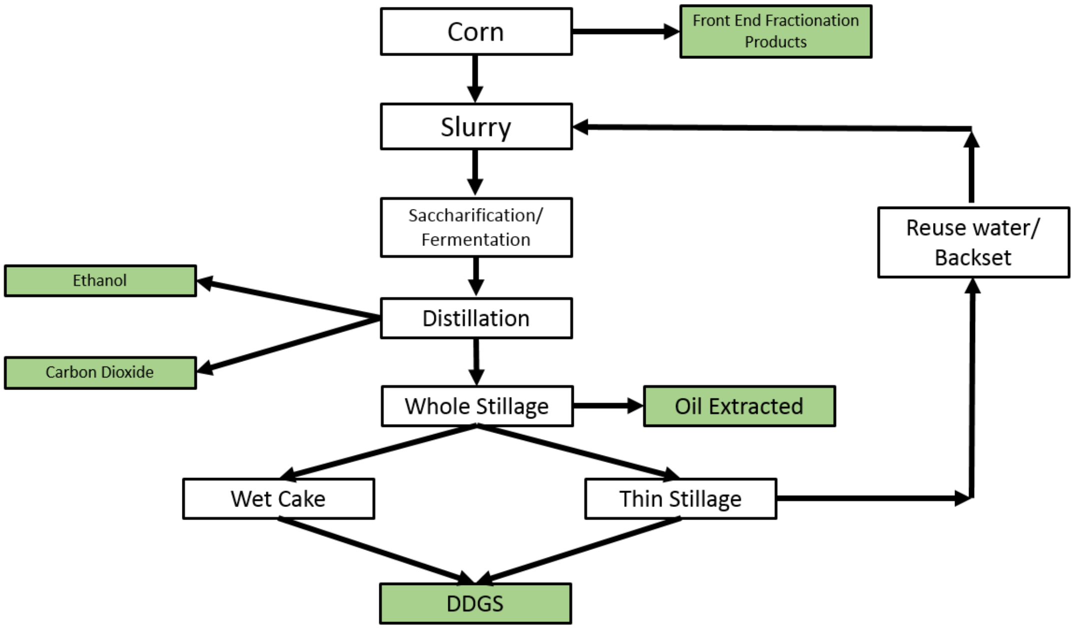
United States Environmental Protection Agency (U.S. EPA). The RFS originated with the Energy Policy Act of 2005. It mandated the amount of ethanol to be blended into the nation's fuel supply. (*Energy Policy Act of 2005* 2005) The RFS was expanded in 2007 with the passage of the Energy Independence and Security Act. The 2007 Act specified the inclusion rates of alternative fuels produced through various methods (starch-based ethanol, cellulosic ethanol, biomass based diesel, and other advanced fuels) in the U.S. fuel supply yearly from 2008 to 2022. The mandate for starch-based (corn) ethanol inclusion increased annually, with a cap of 15 billion gallons annually to be achieved in 2015. This policy has incentivized investments in the corn ethanol industry, thereby encouraging market growth. (Dinan, Gecan, and Austin 2014) As a result, the total number of corn ethanol facilities increased from 81 in 2005 to 213 facilities in 2015, 138 of which are located in the Corn Belt (Renewable Fuels Association 2014)

In the U.S., corn ethanol is produced via one of two methods, wet grind or dry grind processing. Wet grind ethanol plants soak whole corn kernels in water acidified with sulfur dioxide ($S0_2$) at about .12-.20%. This soaking occurs prior to processing and functions to soften the kernel and facilitate separation of the kernel into the starch, fiber, gluten, and germ components. (Warner and Mosier 2008) The starch portion comprises over 70% of the kernel on a dry matter basis; it is the substrate for fermentation resulting in ethanol production. (R L Belyea, Rausch, and Tumbleson 2004) The germ portion of the kernel is desired for its high oil content. Oil extraction from the germ leaves germ meal, which, when mixed with the fiber portion of the kernel, yields corn gluten feed, an animal feed ingredient. (O'Brien and Woolverton 2009) The gluten portion of the kernel is high in protein and is sold as corn gluten meal. (Bothast and Schlicher 2005) The diversity and value of co-products produced via wet grind ethanol processing is high; however, there are relatively few wet grind plants operating in the U.S. because they require high capital investment, and very large scale to be successful.

More than 80% of operational corn ethanol facilities in the U.S. are dry grind and, because of this large percentage, they are the focus of the review. (US Department of Energy 2013) The traditional dry grind process is depicted in Figure 1. A hammer mill or roller mill is used to grind corn, increasing the accessibility of the starch. Ground corn is then mixed with water forming a mixture called a slurry. The slurry goes through a jet cooker, which heats the slurry and begins to break apart starch polymers. Alpha-amylase and glucoamylase enzymes are added to the slurry to cleave these bonds in starch molecules releasing free glucose, a process referred to as saccharification. The free glucose is fermented by yeast, producing ethanol and carbon dioxide ($CO_2$). When fermentation nears or reaches completion, distillation is used to collect ethanol. The remaining solid is referred to as whole stillage. Whole stillage is generally split into two products, thin stillage and wet distillers grains. Some of the thin stillage is sent back into the reuse water of the plant and added to the slurry for the next batch. (Kwiatkowski et al. 2006) The remaining thin stillage is sent through a series of evaporators and ultimately produces syrup called condensed distillers solubles. Wet distillers grains in addition to condensed distillers solubles can be sold wet as an animal feed, but in most cases the two products are combined together dried into a products called dried distillers grains with solubles (DDGS). (Kim et al. 2008) DDGS is sold for an animal feed and is considered an inexpensive, high-protein feed ingredient for animal nutrition. (R.L. Belyea et al. 1989) In a typical dry grind ethanol facility, every bushel of corn (56 lbs.) yields approximately 2.8 gallons of fuel ethanol and 17 lbs. of DDGS. (Iowa

Renewable Fuels Association 2014), but corn composition will alter these quantities somewhat.

**Figure 1- Dry grind ethanol process**



In 2014, 14.3 billion gallons of ethanol and over 370 million tons of DDGS were produced. (Renewable Fuels Association 2015a) To produce these products U.S. plants processed 5.2 billion bushels of corn in 2014. (USDA Economic Research Service 2015) Corn is the largest expense for a dry grind plant, linking plant profitability tightly to its cost. The high volatility of corn prices (ranging anywhere from $2.00 to just over $8.00 per bushel over the past 10 years) has resulted in tight profit margins for the industry. (NASDAQ 2015) This has increased the importance of co-products’ contribution to the economic stability of ethanol plants. (Renewable Fuels Association 2015b)

## Ethanol Plant Technologies:

In order to increase plant revenue, research has gone into developing new processes that generate high-value co-products from dry grind corn ethanol facilities. One of these processes, back-end oil extraction, allows for recovery of about 30% of the oil found in corn (taking out this 30% of corn oil is equivalent to about .7 lbs of oil per bushel entering the plant) from the DDGS prior to drying. (N. Singh and Cheryan 1998)(Iowa Renewable Fuels Association 2014) The extracted corn oil, called distillers corn oil (DCO), can be sold for biodiesel or as an animal feed. In 2014, 90% of U.S. ethanol plants use dry grind ethanol plants had this backend oil extraction technology installed. (Iowa Renewable Fuels Association 2014)  At nearly $540 a ton, corn oil is more valuable than $170 a ton DDGS. (Hartman 2015)

Another process, less commonly employed, is front-end fractionation. This process add-on to a dry grind facility uses a series of milling techniques to separate the kernel into 3 streams—germ, endosperm and bran—in lieu of traditional whole kernel grinding. The endosperm stream contains the starch and enters the facility’s pre-existing ethanol process. (Gustafson and Jason 2010; Moss 2013a; Lin et al. 2011) Between 1.2 -1.4 lb oil is extracted from the germ stream per bushel of corn processed. (Technologies 2015) This oil can be sold as a food grade corn oil, because it is taken out prior to fermentation, or it can be sold for biodiesel production. The remnants of this germ stream constitute corn germ meal, which is sold as an animal feed ingredient. The high-fiber bran stream is sold as a ruminant feed. (Babcock, Hayes, and Lawrence 2008) Despite a high capital cost, installing front-end fractionation technology allows a facility producing traditional DDGS to diversify and produce more valuable co-products.

### Variability in Ethanol Co-Products:

The adoption of new, alternative plant processes changes the composition of ethanol co-products and increases the plant-to-plant variability in DDGS. (R.L. Belyea et al. 1989; V. Singh et al. 2005) This variation results from these processes isolating certain nutrients either before or after fermentation. When oil is spun out, less oil is carried through to the final product. This changes the composition of the DDGS. These compositional changes alter the nutritional value of the DDGS. (Murthy et al. 2006) In the case of front-end fractionation, the final DDGS from fractionation have reduced fiber and oil contents, and higher protein content relative to traditional DDGS. (V. Singh et al. 2005)

Variability in DDGS composition results from processing differences among plants, but there is also variability among batches produced at the same plant.  The latter variability can often be attributed to variability in the input corn composition. (R L Belyea, Rausch, and Tumbleson 2004) This variation can be seen in Figure 2, which includes data collected on corn protein by the Iowa State University Iowa Grain Quality Initiative. This data shows 4 different Iowa counties, and includes data spanning the past 13 years. Variability is evident among different Iowa locations in the same year and among years at the same Iowa location. (Iowa Grain Quality Initiative 2015)

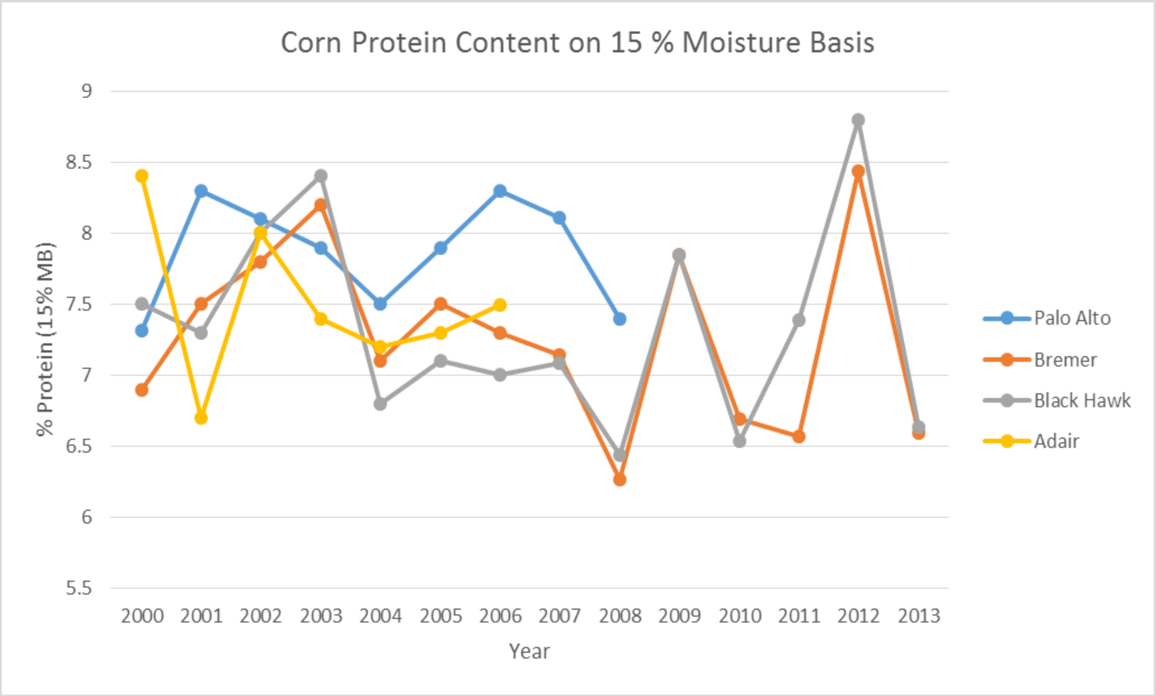


**Figure 2 Protein content of corn harvested from 4 Iowa counties, 2000-2013. Results are presented as a percentage of total kernel weight in 15% moisture grain.**

Finally, plant efficiency also has a large impact on DDGS nutrient variation. Older plants tend to produce DDGS with higher starch, reflecting lower fermentation efficiencies. As the industry grew and evolved over time, plants became more efficient and were able to more completely convert input starch to ethanol. (Babcock, Hayes, and Lawrence 2008) These conversion efficiencies can range anywhere between 93-98%. (Marine 2009; Mei 2006)

### Ethanol Plant Models:

The co-products produced from dry-grind corn ethanol facilities that have adopted new processing technologies (like front-end fractionation) are different from conventional DDGS. These different products provide an opportunity for plants to break into different markets, and potentially to increase financial stability despite fluctuations in input costs and ethanol value. (Lin et al. 2011) Due to a high cost of purchasing and installing front-end fractionation equipment, this opportunity exists only if front-end fractionation co-products collectively are of higher value than traditional DDGS. Another likely scenario is that a plant may want to produce more ethanol annually—this can be accomplished, but at the expense of more corn, labor, enzyme, water and other inputs. The additional ethanol may be profitable for a plant, but the cost of these additional plant inputs needs to be examined. Modeling a situation, such as either example just mentioned, allows for examination of interdependent relationships among facility processes. The plant is able to simulate and analyze multiple scenarios to estimate the profitability of facility improvements or process modifications. (Wood, Rosentrater, and Muthukumarappan 2014) Modeling can also provide a way to predict changes in nutrient composition of co-products, which is necessary to assess their feed value.

Table 1 lists ethanol plant models currently available in the literature, as well as the model characteristics. Existing models account for variations in corn composition; alternative process adoption, such as back-end oil extraction or front-end fractionation; and final DDGS composition data. The inclusion of the first two factors is important to accurately model final DDGS composition.

**Table 1-(Kwiatkowski et al. 2006; Hofstrand 2006; Mei 2006; Rajagopalan et al. 2005)**

|  |  | Software |  |  |  |
|---|---|---|---|---|---|
|  | Corn Composition as Input | Excel | Other | Additional Process Addition (oil extraction, pre-fermentation fractionation) | DDGS Composition Data |
| USDA (Kwiatkowski) | Yes, adjustable | Yes | Aspen Plus ® and Super Pro Designer ® Version 5.5 | No | No |
| ISU Extension Ag Decision Maker | No | Yes | No | No | No |
| Fan Mei (Washington University) | Yes | Yes | Aspen Plus ® | No | No |
| Rajagopalan | No | No | Aspen Plus ® | Yes | Yes, assumed protein in DDGS 28% DMB |

The table characteristics listed in the table are those, which can impact the utility of the tool for various purposes. Allowing corn composition as an input is an important factor because, as stated previously and evidenced in Figure 2, it is variable and is a significant determinant of ethanol yield. It is also used to predict the non-fermentable nutrients that carry into co-products. The software used to run the model is an important consideration for model utility, as some users may not have access to specialized software. The ability to examine the inclusion of additional processes (e.g., backend oil extraction or front-end fractionation) in the model enables comparison of an existing plant with and without one of these processes. Including this piece into a model allows for a plant to better understand the value of installing one of these processes. Finally, the composition of DDGS or other co-products is important for assigning a feed value to that product.

The ISU Extension Model is free and runs in MS Excel. It is easy to use and focuses on rough financial calculations. It is updated regularly with industry average statistics including current ethanol, corn, DDGS, and natural gas prices. It also makes assumptions on the amount of ethanol and DDGS produced from one bushel. (Hofstrand 2006) The Mei model contains a very detailed mass and energy balance of a dry-grind ethanol plant. This includes energy expenditure from each piece of equipment. (Mei 2006) The Kwiatkowski et al. model calculates the energy used and ethanol produced from a 40 million gallon per year plant. It assumes an average DDGS produced per bushel of corn. This allows the model to predict a quantity of DDGS produced, but assuming an average composition does not account for corn variability. Ultimately this model evaluates the costs associated with the dry grind process. (Kwiatkowski et al. 2006) Similar to the Kwiatkowski et al. model, the Rajagopalan et al. model evaluates the energy use; ethanol produced, and assumes a co-product quantity that is produced. The Rajagopalan model contains a scenario for front-end fractionation. (Rajagopalan et al. 2005) None of these models contain an option for backend oil extraction.

### Importance of DDGS Composition:

For ethanol co-products that are fed to animals, value comes from the product on an animal nutrition standpoint. Animal nutritionists formulate diets with various ingredients to create a balanced diet for the animals in question. Creating a balanced diet ensures an animal remains healthy, and is as productive as possible for the producer. Animal nutritionists balance diets using different factors including fiber content, amino acid composition, energy, and crude protein amount. (Jurgens et al. 2012) Knowing the nutritional composition of co-products allows for more accurate use in feed rations. For example, when formulating swine diets, one amino acid, lysine, is of primary concern. Crude protein and energy value are also important factors in formulating swine diets, while crude fiber limits the productivity of monogastric animals. Because of high of fiber, DDGS are typically limited to 30% DDGS in a diet. (Lee 2011) Examining the amino acid, protein, energy, and fiber amount of these new co-products can allow these products to be fed in animal diets at higher amounts than this 30%, which would ultimately give more value to the feed products. (V. Singh and Rausch 2001)

The model developed in the current study allows the user to adjust fermentation and saccharification efficiencies, add plant process and ultimately compare co-product value. The model takes the quantity and composition of whole corn, which can be gathered in a matter of seconds, by well-calibrated near-infrared units, and traces these nutrients through the dry grind ethanol process. These nutrients are traced into the co-products, which vary based on the plant process installed. These process additions include backend oil extraction and frontend fractionation. Focusing on the potential value from ethanol coproducts, this model addresses variation in DDGS resulting from process additions and corn composition variability. It also addresses new co-product generation from backend oil extraction (oil) and front-end fractionation (oil, germ meal, bran meal). The currently available models do not address variations in DDGS composition or composition of new products. Understanding this variation is important from an animal nutrition perspective. The potential value of these new co-products in animal diets is given using the connected feed formulation software. The ethanol feed co-products are inputted into feed formulation software, and allows nutritionists to view ethanol co-products alongside other ingredients currently used in formulations.

## THESIS ORGANIZATION

This thesis is organized into three sections. The first is a general introduction and literature review covering: ethanol plant technologies, variability in ethanol co-products, ethanol plant models, and importance of DDGS composition. The second part of the thesis is research entitled “Development of a mass balance model of a dry grind ethanol plant” which involves the development of a model to be used to predict ethanol yield, and ethanol co-product quantity and quality. The third section of this thesis is research entitled “Evaluating front-end fractionation products” which looks to give a value to new ethanol co-products from using front-end fractionation technology on an animal nutrition perspective. The results from this research are prepared for publication by the American Association of Cereal Chemist (AACC) in *Cereal Chemistry*.

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# CHAPTER 2: DEVELOPMENT OF A MASS BALANCE MODEL OF DRY GRIND ETHANOL PLANT, WITH OPTION TO INCLUDE FRONT-END CORN FRACTIONATION

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## ABSTRACT

Growth in the dry grind ethanol industry has increased research into alternative processing technologies, including back-end oil extraction and front-end fractionation. The addition of alternative processing technologies to an existing ethanol plant results in the production of more diverse, high-value co-products (relative to traditional, dry grind DDGS). More products may increase overall profitability for an ethanol plant. An ethanol plant model was developed to evaluate impacts of both back-end oil extraction and front-end fractionation technologies, specifically to predict the nutritional changes among co-products based on technology installed. The model runs in Microsoft Excel and requires inputs of whole corn composition (proximate analysis) and amino acid content. These can be obtained either by Near Infrared Spectroscopy (NIRS) or traditional wet chemistry methods. Component percentages plus grain weight predict the co-product quantity and quality. Additional user inputs include saccharification and fermentation efficiencies, plant capacity, and the presence or absence of alternative processing technologies. For example a traditional plant processing 60,000 bushels of corn per day would produce just over 504 tons of DDGS. A plant with front end fractionation processing the same amount of corn a day would produce 245 tons of DDGS, 34 tons of bran, and 151 tons of germ. The co-products predicted in this model are entered into the U.S. Pork Center of Excellence National Swine Nutrition Guide feed

formulation software. This allows the plant user and animal nutritionists to evaluate the nutritive value of new co-products as animal feed ingredients, including consideration of dietary essential amino acids for specific livestock diets. This model is a tool intended for individual ethanol plants to assess and monitor variability in co-product composition due to the variation in whole corn composition, resulting in value-addition for the plant and more accurate use of novel co-products as feed ingredients.

## INTRODUCTION

Fuel ethanol production has increased significantly over the past 10 years due largely in part to the Renewable Fuel Standard (RFS) that originated from the Energy Policy Act of 2005.(*Energy Policy Act of 2005* 2005) The RFS is administered by the United States Environmental Protection Agency (EPA) and mandates the amount of ethanol that must be blended into the US fuel supply (*Energy Policy Act of 2005* 2005) This policy has created a large market for fuel ethanol production. The RFS was expanded upon by the Energy Independence and Security Act of 2007, which set the required inclusion rates of alternative fuels (starch-based ethanol, cellulosic ethanol, biomass-based diesel, and other advanced fuels) in the U.S. fuel supply yearly from 2008 to 2022. The mandate for starch-based (corn) ethanol inclusion increased annually, with a cap of 15 billion gallons to be achieved in 2015. (*Energy Independence and Security Act of 2007* 2007) Up to the cap, mandate encouraged investments into corn-based ethanol plants and infrastructure.

Corn-based ethanol is produced using one of two methods, wet and dry grind processing. Compared to facilities that implement wet grind processing, dry grind corn ethanol plants have experienced more rapid growth since the RFS because they require lower capital investment. Currently 89% of corn ethanol facilities operate using dry grind processing. (Renewable Fuels Association 2015c) In dry grind processing, whole corn is ground and mixed with water and enzymes to form a slurry. Alpha amylase and glucoamylase enzymes convert the starch portion of the kernel into glucose during saccharification. Yeast fermentation of the resultant glucose yields ethanol and carbon dioxide. (Bothast and Schlicher 2005) Ethanol is distilled off leaving whole stillage. This whole stillage is generally centrifuged into two products, thin stillage and wet cake. A portion of the thin stillage is recycled back to the slurry, sometimes called backset. The remaining thin stillage and the wet cake are carried through the process and dried into a product called dried distillers grains with solubles (DDGS). (Rajagopalan et al. 2005) Each bushel of corn can produce 2.8 gallons of ethanol and about 18 lbs of DDGS. (Renewable Fuels Association 2015b) Figure 1 shows the corn ethanol production process and co-product generation.

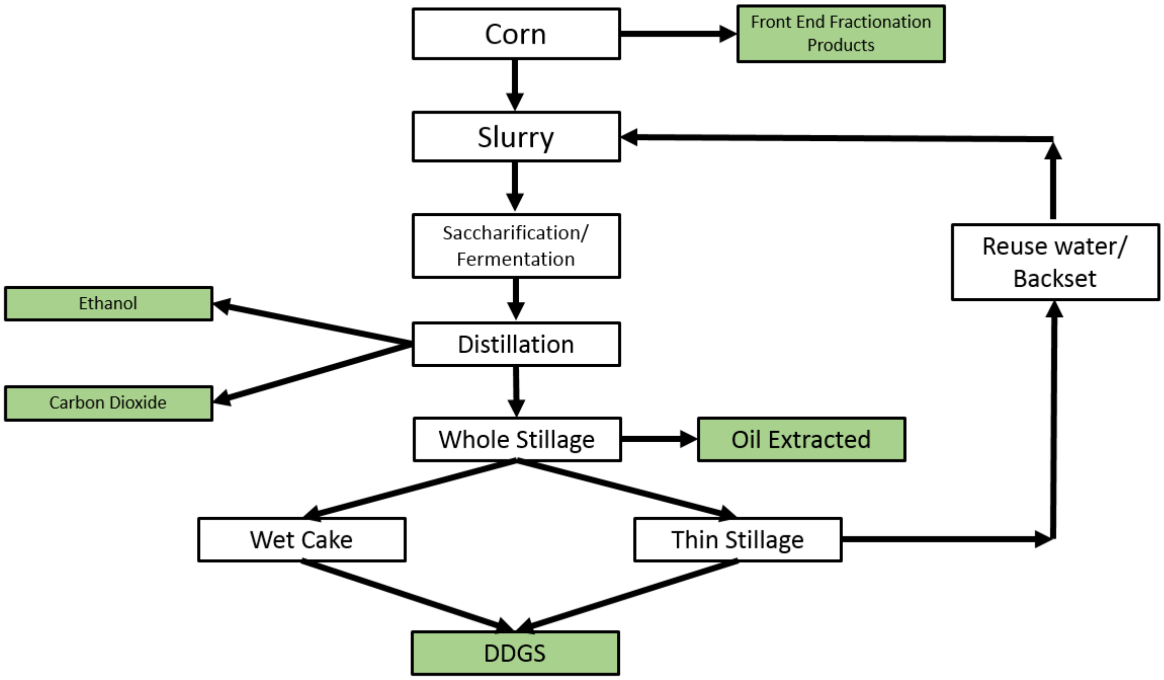


*Figure 3 dry grind ethanol process*

The DDGS from ethanol production are sold as an animal feed product. DDGS provide an important source of income for ethanol plants, ranging from 7%-25% total profit over the past 10 years. (Hofstrand 2006) The International Feed Directory classifies them as a high protein feed ingredient. (National Research Council 1982) This product is generally less expensive than other high-protein ingredients for livestock feed. One downside to using DDGS in livestock feed formulations is that, in monogastric animals, DDGS have a reduced digestibility compared with corn because of a higher percentage of crude fiber. (Stein and Shurson 2009) A more pressing concern is that DDGS typically have variable nutrient composition making it difficult for animal nutritionists to formulate diets. One source of variation is from variation in corn composition. This variation can be seen in figure 2, which includes data from the Iowa State University -Iowa Grain Quality Initiative showing corn protein composition. This data shows 4 different counties, and includes some data for these counties for the past 13 years. Looking at this data, one can see variation between different locations in the same year, and variation between years at the same location. (Iowa Grain Quality Initiative 2015) In addition to macronutrient variation, there is some variation between amino acids found in corn and those found in DDGS. Research has been done to evaluate changes in amino acids during the dry grind process. Results of this study indicated that approximately 20% of DDGS protein comes from yeast. (Han and Liu 2010) Understanding amino acid composition of DDGS is important because of its importance to animal nutrition. Another source of variation in DDGS is a result of differences among individual ethanol plant processes. (R L Belyea, Rausch, and Tumbleson 2004) As the ethanol industry matured, more research went into increasing profitability. This can be done a by modifying plant processes and implementing new technologies with goals of decreasing energy inputs, increasing ethanol production, and increasing the diversity and value of co-products. (Taylor et al. 2001) A side effect of these novel processes is often compositional alterations to DDGS.

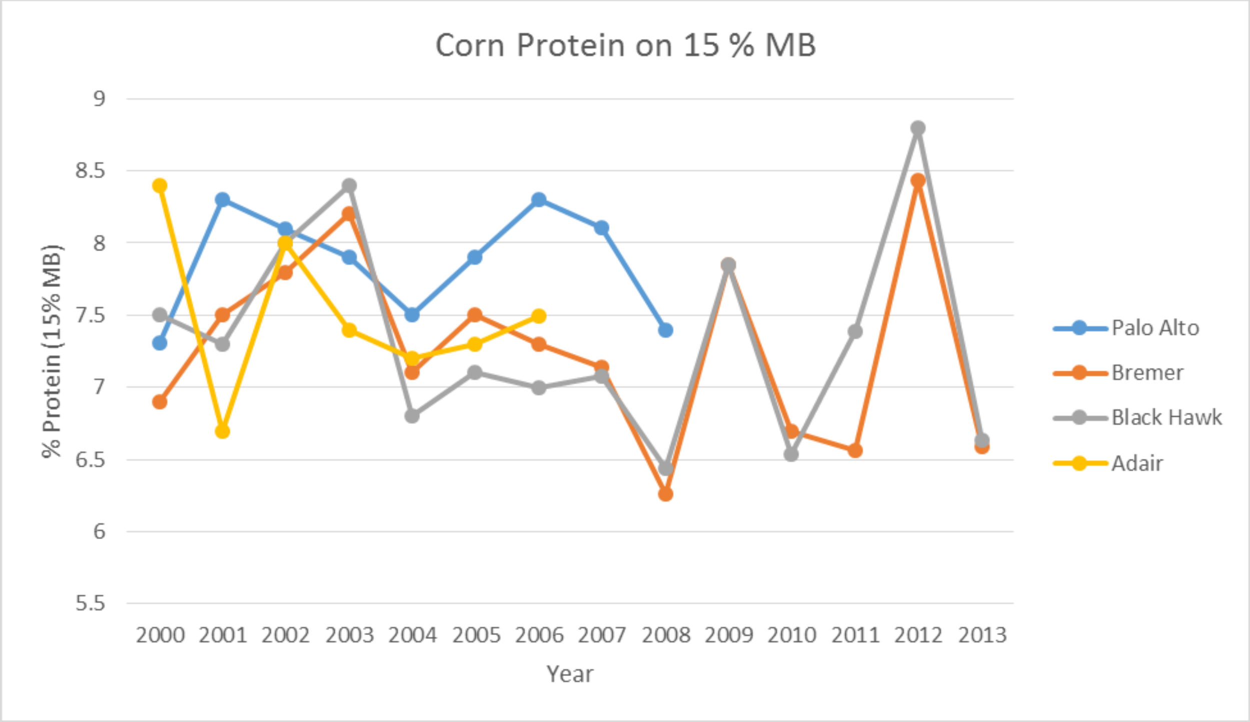


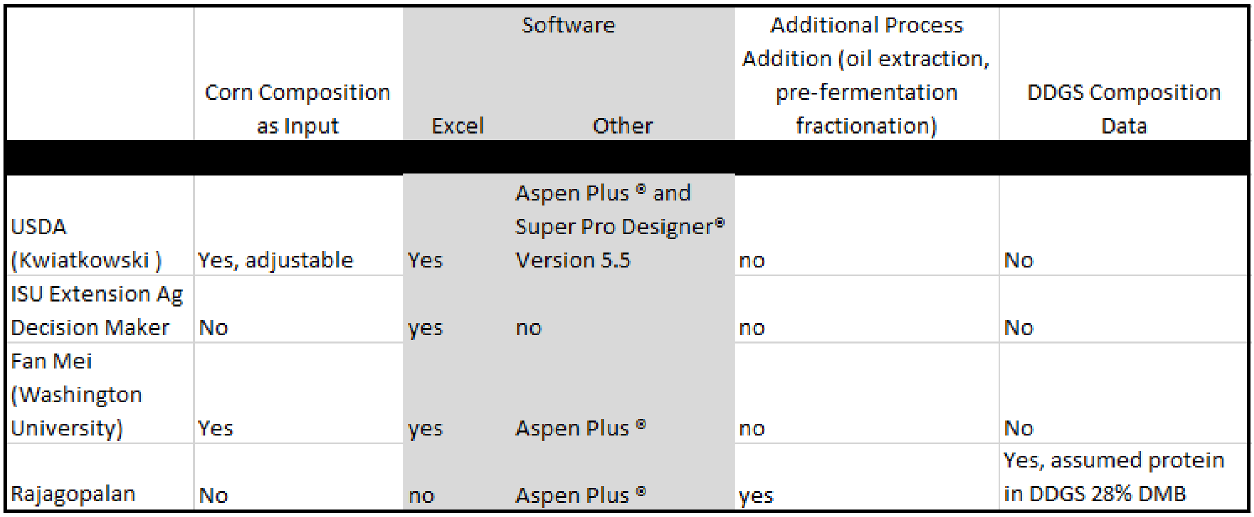
*Figure 4 -Corn proteins Composition from 4 Iowa Counties 2000-2013*

One common technology to increase co-product value is corn oil extraction. Backend oil extraction is considered “bolt on” process, meaning that it can be added to an existing plant without large infrastructure changes. Corn oil extraction is done post fermentation, but prior to drying. (Shurson and Alghamdi 2008) Corn oil is more valuable than traditional DDGS. Additionally, removing oil decreases the amount of energy needed by the DDGS dryer. (*A Guide to Distiller’s Dried Grains with Solubles (DDGS)* 2012) Removing oil through corn oil extraction also reduced the oil in the final DDGS product. This lower oil content (5.5%) alters the nutritional value compared to traditional DDGS (10.5%). (Herkelman 2012)

Front-end fractionation is another bolt on technology that separates the corn kernel into 3 streams prior to entering the ethanol plant. These three streams are bran, germ, and endosperm. (Gustafson and Jason 2010) This process is similar to the first steps of dry corn mills for flour, grits and hominy. Each stream produces co-products that differ from traditional DDGS. The endosperm stream is the largest at roughly 90% of the total mass. It is high in starch and is the only stream to enter the ethanol plant. After ethanol plant processing there is a DDGS co-product, which is of high protein, 30%-42% compared to 25% for traditional DDGS. (Moss 2013b) The bran stream is high in fiber and is sold primarily as a ruminant feed product. Oil is extracted from the germ stream and can be sold as food grade oil, or as oil for animal feed or biodiesel production. (*Fractionation Technology Review for Corn Dry Mill Ethanol Plants Report* 2008) The remnants of the germ stream after oil removal are also sold as a high quality livestock feed ingredient called corn germ meal. (Murthy et al. 2006) Ultimately, front-end fractionation can allow plants to diversify co-products, save energy by sending fewer products through the fermenter and dryer, and increase plant profitability. (*Fractionation Technology Review for Corn Dry Mill Ethanol Plants Report* 2008)

Process modeling can be used to examine interdependent relationships among existing facility processes and including potential bolt-on processes. This allows plants to simulate and analyze multiple scenarios to estimate the profitability of facility improvements or process modifications. (Wood, Rosentrater, and Muthukumarappan 2014)

*Table 2- Available models in the literature* (Rajagopalan et al. 2005; Kwiatkowski et al. 2006; Mei 2006; Hofstrand 2006)



| | Corn Composition as Input | Software | | Additional Process Addition (oil extraction, pre-fermentation fractionation) | DDGS Composition Data |
|---|---|---|---|---|---|
| | | Excel | Other | | |
| USDA (Kwiatkowski ) | Yes, adjustable | Yes | Aspen Plus ® and Super Pro Designer® Version 5.5 | no | No |
| ISU Extension Ag Decision Maker | No | yes | no | no | No |
| Fan Mei (Washington University) | Yes | yes | Aspen Plus ® | no | No |
| Rajagopalan | No | no | Aspen Plus ® | yes | Yes, assumed protein in DDGS 28% DMB |

The available models in the literature are detailed in Table 1. The inputs highlighted in the table are those, which can impact the utility of the tool for various purposes. Variable corn composition is included in two of the models. This is an important factor to include because the nutrients in corn determine the amount of ethanol that can be produced, and the nutrient composition of the resultant DDGS. Evaluating additional processes involves the inclusion of either backend oil extraction or front-end fractionation into the model. Including new technologies is important for the ability to compare an existing plant that may be looking to install one of these technologies. Modeling would allow a plant to better understand the value they would receive from installing one of these processes. The software used to run the model is important to the intended user of the model, as some users may not have access to software other than MS Excel.

The ISU Extension Model is a free model that runs in MS Excel and is easy to use. It is used to do rough financial calculations. It is updated regularly with industry average statistics. (Hofstrand 2006) The Mei model contains a very detailed mass and energy balance of a dry-grind ethanol plant. (Mei 2006) The USDA model developed Kwiatkowski models the energy used, ethanol produced from a 40 million gallon per year plant. It assumes an average DDGS produced per bushel of corn. Ultimately this model evaluates the costs associated with the dry grind process. (Kwiatkowski et al. 2006) Similar to the Kwiatkowski model, the Rajagopalan model evaluates the energy use, ethanol produced, and assumes a co-product quantity that is produced. The Rajagopalan model is improved because it contains a scenario for front-end fractionation. (Rajagopalan et al. 2005)

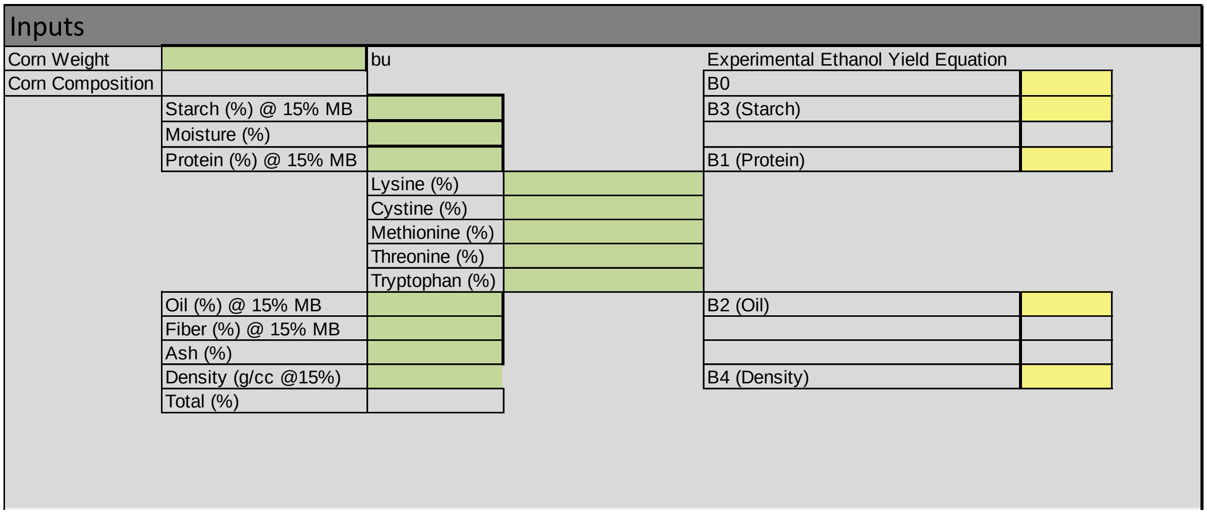
The model developed in the current study addresses areas that existing models are lacking, particularly in that it allows the user to adjust plant efficiencies and add plant process specific to individual facilities.  Ultimately, this enables comparison of co-product value under different processing scenarios at an individual facility. The co-products from using new technologies, like front-end fractionation, are very different compared to conventional DDGS. These different products provide an opportunity for plants to break into different markets, and potentially increase resistance to fluctuations in input cost and ethanol value. (Li et al. 2010) Due to a high cost of purchasing and installing front-end fractionation equipment, this opportunity only exists if front-end fractionation co-products are of collectively higher value than traditional DDGS. The developed model works to both predict production quantity and quality and to give value to ethanol plant co-products from front-end fractionation.

## Materials and Methods

This model was developed using Microsoft Excel 2013 (Microsoft Corporation, Redmond, WA) and runs using the Visual Basic code. It is divided into 3 input worksheets.

These include “Corn”, “Plant Operation”, and “FEF, Yeast”. The model also contains an output page for the ethanol plant. The co-products on this outputs page are outputted into the feed formulation library of feeds in the ration balancing software.

### Inputs-Corn Worksheet:



Inputs

| | | | | | |
|---|---|---|---|---|---|
| Corn Weight | | bu | | Experimental Ethanol Yield Equation | |
| Corn Composition | | | | B0 | |
| | Starch (%) @ 15% MB | | | B3 (Starch) | |
| | Moisture (%) | | | | |
| | Protein (%) @ 15% MB | | | B1 (Protein) | |
| | | Lysine (%) | | | |
| | | Cystine (%) | | | |
| | | Methionine (%) | | | |
| | | Threonine (%) | | | |
| | | Tryptophan (%) | | | |
| | Oil (%) @ 15% MB | | | B2 (Oil) | |
| | Fiber (%) @ 15% MB | | | | |
| | Ash (%) | | | | |
| | Density (g/cc @15%) | | | B4 (Density) | |
| | Total (%) | | | | |

### Corn Composition:

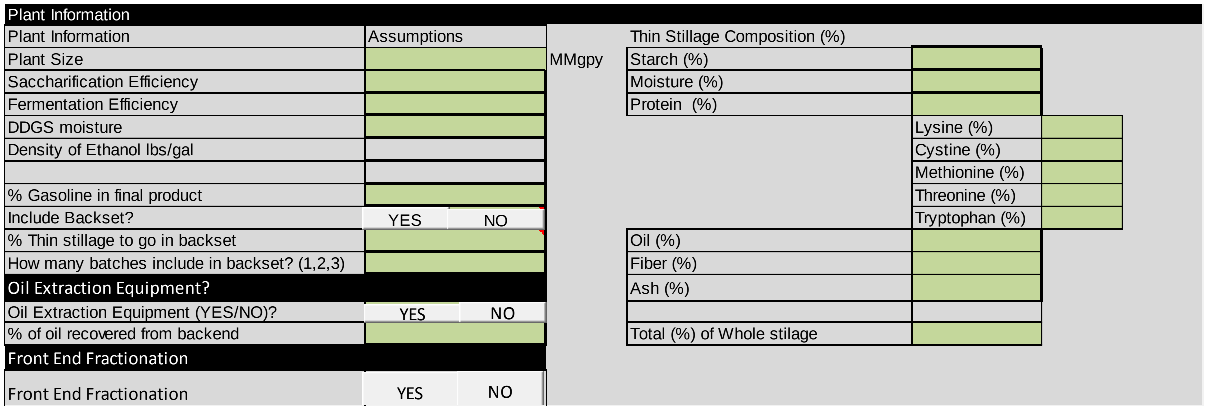
The user of the model inputs corn composition values on a 15% moisture basis (starch, protein, oil, fiber, and ash) as well as nutritionally important amino acids (Lysine, Cystine, Methionine, Threonine, Tryptophan) and grain density (units of grams/cubic centimeter, g/cc).

### Iowa Grain Quality Initiative Equation:

An experimental ethanol yield equation was developed by the Iowa Grain Quality Initiative (Iowa State University, Ames, IA). This equation uses proximate analysis of whole corn at 15% moisture basis to predict the yield of ethanol in gallons per bushel. It was intended for use with rapid near infrared spectroscopy (NIRS) but could be used with chemically determined values as well. The equation can be seen in equation 1. It uses the previously inputted corn composition data, and coefficient values for each proximate that are published in the original document. (Burgers, Hurburgh, and Jane 2009) These coefficient values can be updated on an input page in the model setup if new published information becomes available. The predicted value appears on the output page.

$$Ethanol\ Yield\ \left(\frac{gal}{bu}\right) = B_0 + B_1 * \%Protein + B_2 * \%Oil + B_3 * \%Starch + B_4 * Density\ \left(\frac{g}{cc}\right)$$ (Equation 1)

**Inputs-Plant Operation Worksheet:** The "Plant Operations worksheet" has a wide list of inputs so each user can customize the analysis to reflect current plant operations.



Plant Information

| Plant Information | Assumptions | | |
|---|---|---|---|
| Plant Size | | | MMgpy |
| Saccharification Efficiency | | | |
| Fermentation Efficiency | | | |
| DDGS moisture | | | |
| Density of Ethanol lbs/gal | | | |
| | | | |
| % Gasoline in final product | | | |
| Include Backset? | YES | NO | |
| % Thin stillage to go in backset | | | |
| How many batches include in backset? (1,2,3) | | | |
| Oil Extraction Equipment? | | | |
| Oil Extraction Equipment (YES/NO)? | YES | NO | |
| % of oil recovered from backend | | | |
| Front End Fractionation | | | |
| Front End Fractionation | YES | NO | |

| Thin Stillage Composition (%) | | | |
|---|---|---|---|
| Starch (%) | | | |
| Moisture (%) | | | |
| Protein (%) | | | |
| | Lysine (%) | | |
| | Cystine (%) | | |
| | Methionine (%) | | |
| | Threonine (%) | | |
| | Tryptophan (%) | | |
| Oil (%) | | | |
| Fiber (%) | | | |
| Ash (%) | | | |
| | | | |
| Total (%) of Whole stilage | | | |

## Plant size:

The amount of corn in bushels (bu) as well as the size of the plant in million gallons produced per year (Mmgpy). These are both inputs provided by the user. This allows the outputs to be scaled up with the amount of corn and size of the plant.

## Ethanol Production:

To calculate a theoretical ethanol yield, an estimation of the facility's saccharification and fermentation efficiencies are entered into the model as an input. These values can be inputted if known by a plant, if one or both are not known they can be entered in at 100%.

These efficiencies account for non-converted starch, which then would be carried through to the DDGS.

The conversion from starch to glucose found in equation 2. (Karuppiah et al. 2008)

$$\text{1 lb Starch} \rightarrow \text{1.1 lb Glucose} \qquad \textit{(Equation 2)}$$

Including the saccharification efficiency, a model input, the amount of glucose is calculated in equation 3.

$$\text{Corn Starch * 1.1* Saccharification Efficiency= Glucose} \qquad \text{(Equation 3)}$$

The chemical conversion from glucose to ethanol and carbon dioxide is found in equation 4. (Karuppiah et al. 2008)

$$\text{1 lb glucose} \rightarrow \text{.51 lb ethanol+ .49 lb } CO2 \qquad \text{(Equation 4)}$$

Including the fermentation efficiency is displayed in equation 5.

$$Gallons\ of\ Ethanol\ Produced = \frac{(Glucose * Fermentation\ Efficiency * .51)}{Density\ of\ Corn} \qquad \text{(Equation 5)}$$

**Backset Calculation:**

The backset is the portion of the thin stillage that is recycled into the slurry of the next batch. Including the backset calculations was important to account for the solids that remain in the reuse water of a plant. In the model there is a yes/no question to include backset. Additionally an option to choose how many backset batches to include, meaning how many batches will this batch of corn nutrients stay in the reuse water, the maximum being 3. The thin stillage stream breakdown is inputted. This thin stillage is defined in this case as the water and solids that spun out during the centrifugation process. The whole stillage is defined as the product that is dumped from the fermenter. (Kwiatkowski et al. 2006; Kim et al. 2008) The “Thin Stillage % in Backset” box is included to calculate the percent of the thin stillage that remains in the reuse water. Equation 6 is used to calculate the amount of a nutrient in the thin stillage.

$$\text{Nutrient in the Backset} = \frac{\%\ \text{Thin Stillage of Whole Stillage}}{1 - \%\ \text{Moisture Thin Stillage}} \times \text{DM Total weight whole stillage} \times \%\ \text{nutrient in thin stillage} \ast \%\ \text{Backset of Thin Stillage}$$

(Equation 6)

The amount of each nutrient that is carried through to the DDGS is the amount of whole stillage less the backset. This is calculated in equation 7.

$$\text{Nutrient in DDGS} = \text{Nutrient in Whole Stillage} - \text{Nutrient in Backset}$$ (Equation 7)

The weight of each nutrient in the slurry, the mixture that enters the fermentation tanks, must be accounted for prior to fermentation. These nutrients are what enters the fermenter. It is assumed that the backset starch is fermented, and the amino acids are not transformed in the process. The backset is added in via equation 8.

$$\text{Nutrient in Slurry} = \text{Nutrient in Backset} + \text{Nutrient in corn}$$ (Equation 8)

Figure 3 depicts how a nutrient moves through the model. Each nutrient is listed to the right the step in the corn to ethanol process. If the nutrient is converted or extracted, the corresponding letter to the changed nutrient is displayed in bold and underlined.

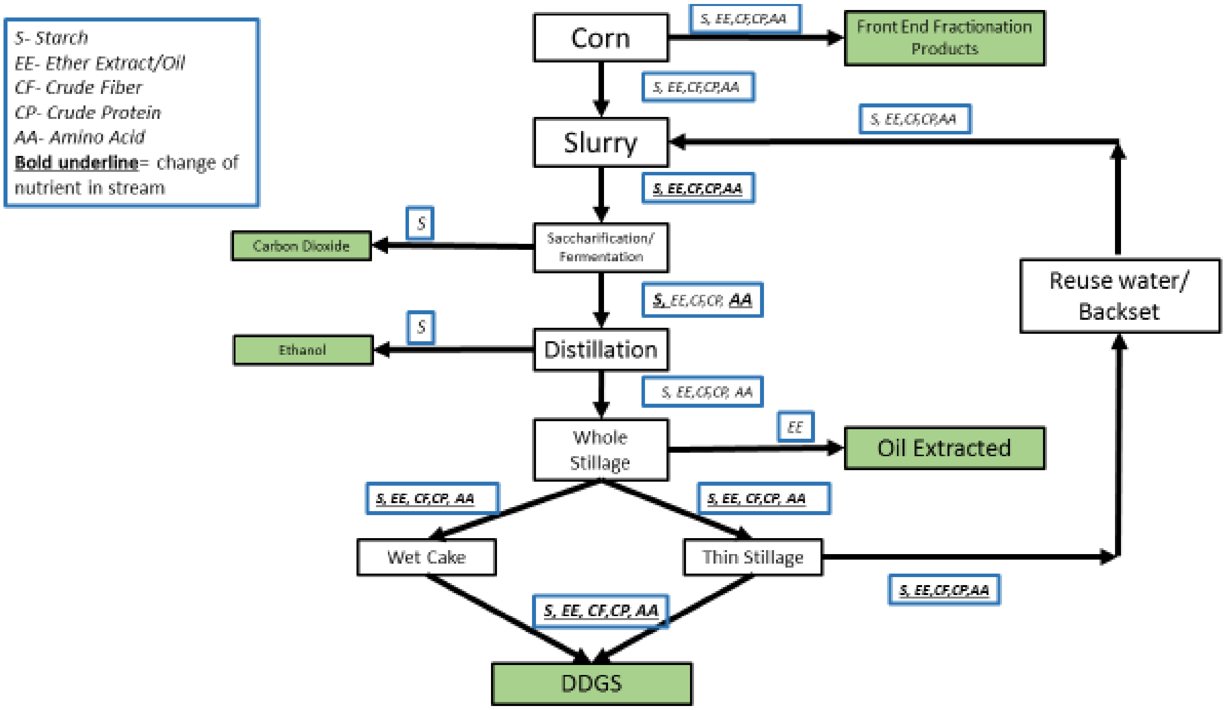


*Figure 5- Nutrients traced through the model*

**Backend Oil Extraction:**

Backend oil extraction is used as a variable input in the model. The user can select to include this process through a yes/no on the inputs tab. The percent of total corn oil known to be recovered is inputted and used to calculate the amount of oil that is taken out and sold as corn oil. This is displayed in equation 9. The remaining oil is carried through the process to the DDGS as displayed in equation 10.

$$Extracted\ Oil = (\%\ oil\ in\ corn * corn\ weight + backset\ oil) * percent\ oil\ recovery$$

(Equation 9)

$$Oil\ in\ DDGS = (\%\ oil\ in\ corn * corn\ weight + backset\ oil) - Extracted\ Oil$$ (Equation 10)

## Inputs-Front End Fractionation Yeast Worksheet:

### Yeast Contribution:

Yeast has a high protein content, and contains high amounts of amino acids. To evaluate the amino acid contribution from the yeast to the DDGS during the dry grind ethanol process, the equation developed by Han and Liu ($Y=AX_1+BX_2+C$) was used. The user inputs the % amino acid of total protein for each amino acid in both the corn and yeast added. The published coefficient values in the model are available to be changed by the model user if the equation is updated. The Han and Liu Yeast equation is listed in equation 11. (Han and Liu 2010)

$$Y = AX_1 + BX_2 + C \qquad \text{(Equation 11)}$$

Y= % amino acid of total protein in downstream product

X1= % amino acid of total protein in ground corn

X2= % the amino acid of total protein in the yeast

A= fixed parameter showing the extend of corn contribution

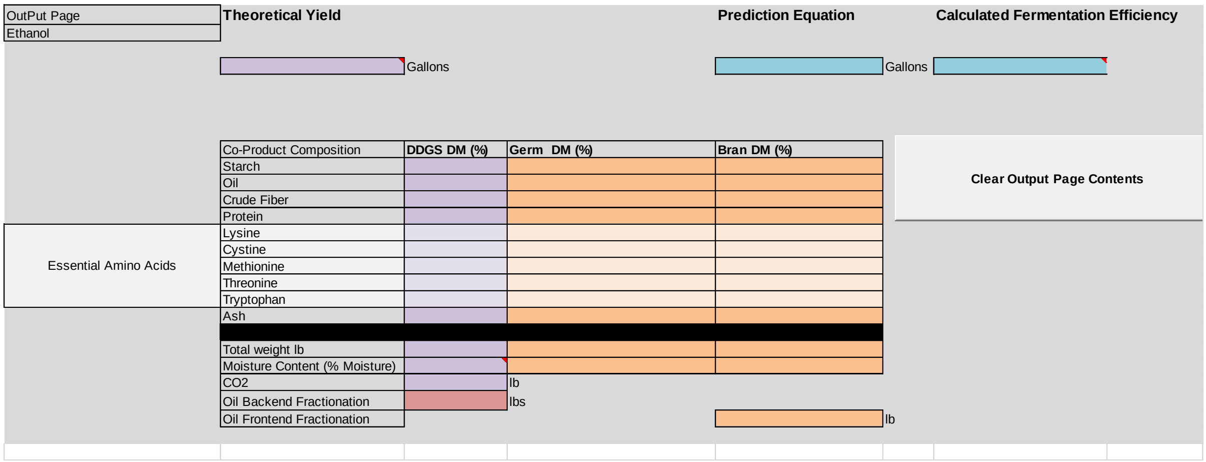
B= fixed parameter showing the extent of yeast contribution

C= a fixed value parameter showing the Y intercept

### Front-end Fractionation:

Front end fractionation is modeled using known information of how each nutrient separates into each of the three streams this information comes from the fractionation machine manufacturers. The model user has a choice to include this technology or not through a yes/no checkbox. The stream breakdowns of each nutrient are entered in as a percent of whole corn that is separated into the germ, endosperm, and bran streams. Stream breakdowns can be changed to reflect operations. Knowing these amounts, each nutrient is traced through the model and ends up into the correct output product.

## Output Page:



OutPut Page
Ethanol

**Theoretical Yield** Gallons
**Prediction Equation** Gallons
**Calculated Fermentation Efficiency**

**Clear Output Page Contents**

Essential Amino Acids

| Co-Product Composition | DDGS DM (%) | Germ DM (%) | Bran DM (%) | |
|---|---|---|---|---|
| Starch | | | | |
| Oil | | | | |
| Crude Fiber | | | | |
| Protein | | | | |
| Lysine | | | | |
| Cystine | | | | |
| Methionine | | | | |
| Threonine | | | | |
| Tryptophan | | | | |
| Ash | | | | |
| | | | | |
| Total weight lb | | | | |
| Moisture Content (% Moisture) | | | | |
| CO2 | | lb | | |
| Oil Backend Fractionation | | lbs | | |
| Oil Frontend Fractionation | | | | lb |

The output page displays all the model outputs in one place. It is organized by color. Purple values are displayed for all model runs, blue are only displayed if front end fractionation technology is not selected, orange is only displayed if front end fractionation technology is installed, and red is the backend oil extraction and is displayed only if this is selected.

## Ethanol Yield:

The top values of the outputs page involve ethanol production. The “Theoretical Yield” box calculates the yield based on stoichiometric equations, and inputted plant efficiencies. The “Ethanol Yield Equation” box uses the experimental equation developed by the Iowa Grain Initiative. The “Fermentation Efficiency” box uses both the theoretical yield using 100% efficiency and predicted ethanol yield equation to calculate plant efficiency for the starch conversion of the plant.

**Co-Product Outputs:**

All co-products compositions (DDGS, bran, germ) are given on a dry matter (DM) basis. The amounts of carbon dioxide emitted, and oil extracted both front-end and back-end are displayed in pounds below the product compositions.

**Feed Formulation Software:**

This ethanol plant model is connected with the US Pork Center of Excellence Feed Formulation software for swine. When the ethanol plant model is run, each product and its composition is automatically added to the library of feed on an as fed basis. This allows these products to be analyzed and compared to existing feeds, to determine how they fit into swine diets.

The metabolizable energy (ME), neutral detergent fiber (NDF), crude protein (CP) and Lysine are values that are important for formulating feeds. Values for NDF and ME are not given through proximate analysis. Predictions for these values from existing proximate analysis were developed to solve this problem. The ME values are calculated using the published ME prediction equation 12. (Anderson et al. 2012)

$$ME\left(\frac{kcal}{kg}\right) = .9 * (GE) - 29.95 * (\%TDF)$$ (Equation 12)

** % values on a dry matter basis*

To predict the ME, gross energy (GE) and total dietary fiber (TDF) amounts are needed. Using published data for corn DDGS and other corn co-products the ME, TDF, as well as NDF were predicted. The data in these articles includes a variety of DDGS products from multiple plant locations and companies, as well as a variety of corn co-products produced via corn dry and corn wet mills. (Kerr, Dozier, and Shurson 2013; Anderson et al. 2012) The software for regression calculations included Microsoft Excel 2013 and CAMO Unscrambler 10.1. The % TDF (equation 13) and the GE (equation 15) are intermediate calculations used to calculate the ME. The % NDF value (Equation 14) and ME value (Equation 12) are then inputted directly in to the feed library.

$$(\%TDF) = 3.63 * (\%\,Crude\,Fiber) + 6.96 \qquad \text{(Equation 13)}$$

** Developed in Microsoft Excel 2013, % values on a dry matter basis*

$$(\%\,NDF) = 4.84 * (\%\,Crude\,Fiber) + 3.05 \qquad \text{(Equation 14)}$$

**Developed in Microsoft Excel 2013, % values on a dry matter basis*

$$GE\left(\frac{kcal}{kg}\right) = 4189.17 + 19.98 * (\%\,Crude\,Protein) + 37.14 * (\%\,Oil) \qquad \text{(Equation 15)}$$

**Developed in CAMO Unscrambler 10.1, % values on a dry matter basis*

## Results and Discussion

Using a theoretical yield assumed to be 100% efficient and ethanol yield prediction equation; plant efficiency for the starch conversion can be calculated for the modeled plant. This provides a tool for a plant to discover its efficiency. For plants that have a known efficiency they can compare known efficiency to the predicted efficiency. Knowing efficiencies allows a plant to more accurately track their products both in and out of the plant.

The proposed model also adds improvements on currently available models in the literature. This improvement specifically comes in its ability for variation, and prediction of co-products from new technologies. It is adjustable which allows it fit a wide range of ethanol plants. It predicts ethanol yield, carbon dioxide emitted, and co-product composition. This helps to account for variation in corn nutrients and specifically how this variation affects nutrients in the DDGS. The potential to use this technology to evaluate new corn hybrids for ethanol and co-product yield, would help farmers and ethanol plants to make decisions. The ability to add and adjust both backend oil extraction equipment and front-end fractionation equipment allows the user to model these processes on the plant in question and see the value in these changes. This ability allows ethanol plants to decide if the technology should be purchased and installed. The largest change that can be seen from adding one of these plant processes is the change in co-product composition. There is significant value in knowing the composition of co-products from an animal nutrition standpoint. Because of high variation in DDGS, animal nutritionist must include a large factor of safety when formulating diets. Knowing the composition of the product can give nutritionists confidence in the product they are buying.

The ability to trace amino acids through the process as well as output DDGS proximate analysis, metabolizable energy (ME), and neutral detergent fiber (NDF) values to a feed formulation library is unique to this model. This capability is valuable to evaluate feedstuffs and formulate rations. Metabolizable energy, NDF, and amino acids are not included in proximate analysis but are important for nutritionists. Many livestock diets, such as swine, are balanced on amino acids, and limited by NDF. By outputting these co-products into the feed formulation software, nutritionists are able to compare ethanol co-products in a system they are familiar with, and additionally give value to these products.

**Table 3 Corn input composition for comparison model run (15% MB)**

| Corn composition | |
|---|---|
| | 15% MB |
| Starch | 64.0% |
| Protein | 8.8% |
| Lysine | 0.4% |
| Cystine | 0.1% |
| Methionine | 0.1% |
| Threonine | 0.4% |
| Tryptophan | 0.3% |
| Oil | 3.5% |
| Crude Fiber | 2.1% |
| Ash | 7.0% |

Table 3 and Table 4 display the model run at 4 different plant characteristics, traditional, backset, backend oil extraction and front-end fractionation. All 4 model runs used the same corn composition, and plant efficiencies. Looking at the output values the user can see how the different plant processes influence co-product composition. DDGS from traditional plants have much higher oil (13%) than a plant taking out 30% of the corn’s oil backend (7%). Front-end fractionation alters the ending oil content of DDGS further (5.5%) by separating out a large amount into the germ stream.

It is also worth noting there is a yield drop in ethanol production per bushel of corn (2.82 vs 2.93 gal/bu). This is due to incomplete recovery of total kernel starch; small amounts are lost to the germ and bran streams. However, because of the removal of germ and bran prior to fermentation, the contents of a fermenter in a facility using front-end fractionation will contain a higher proportion of endosperm and, therefore, fermentable starch. This allows the facility to process a larger quantity of corn over time, as the space normally occupied by bran and germ in the fermenter is displaced by additional starch, resulting in increased ethanol production over time.

**Table 4-Output from model comparison run**

[a] Values for previous batch run (15% MB) starch (65%), Protein (7%), Lysine (.36%), Cystine (.14%), Methionine (.09%), Threonine (.36%), Tryptophan (.31%), Oil (4.1%), Crude Fiber (3.1%), Ash (6%)

| Traditional | | Traditional (Backset) [a] | Backend Oil Extraction | Front-end Fractionation | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Plant Information | | | | | | |
| Saccharification Efficiency | 97.0% | 97.0% | 97.0% | 97.0% | | |
| Fermentation Efficiency | 99.0% | 99.0% | 99.0% | 99.0% | | |
| Backset? | No | Yes 1- batch | No | No | | |
| Oil Extraction | No | No | Yes | no | | |
| Front End Fractionation? | No | No | No | yes | | |
| | | | | | | |
| Output Page | | | | | | |
| Ethanol Yield (gal/bu) | 2.93 | 2.93 | 2.93 | 2.82 | | |
| Carbon Dioxide (lbs) | 18.7 | 18.7 | 18.7 | 18 | | |
| | | | | | | |
| | DDGS (% DM) | DDGS (% DM) | DDGS (% DM) | DDGS (% DM) | Germ (%DM) | Bran (% DM) |
| Starch | 9.00% | 8.00% | 9.50% | 9.40% | 30.00% | 18.00% |
| Oil | 13.00% | 12.00% | 7.00% | 5.50% | 3.00% | 2.00% |
| Crude Fiber | 8.00% | 7.00% | 8.40% | 5.20% | 8.00% | 14.00% |
| Protein | 33.00% | 29.00% | 35.20% | 27.80% | 24.00% | 6.00% |
| Lysine | 1.32% | 1.17% | 1.40% | 1.20% | 0.72% | 0.00% |
| Cystine | 0.19% | 0.17% | 0.20% | 0.10% | 0.29% | 0.18% |
| Methionine | 0.21% | 0.18% | 0.21% | 0.20% | 0.31% | 0.22% |
| Threonine | 1.28% | 1.13% | 1.40% | 1.20% | 0.58% | 0.31% |
| Tryptophan | 0.95% | 0.78% | 0.90% | 0.90% | 0.21% | 0.08% |
| Ash | 26.00% | 23.00% | 28.00% | | | |
| Moisture Content | 12.00% | 12.00% | 12.00% | 12.00% | 4.60% | 1.00% |
| Oil Extracted | | | 0.98 | 0.93 | | |

## Conclusions

A spreadsheet-based model was developed to track mass and nutrient balances through dry grind corn-to ethanol plants.  This model provides an improvement to existing models by allowing for variation in plant size and added plant technologies to evaluate ethanol yield, carbon dioxide and co-product quantity and quality. The ability for model user to compare co-product composition between technologies installed gives ethanol plant an idea of how technology changes can improve plant co-products. Furthermore these co-products can be evaluated in feed formulation software and compared against existing ingredients. This ability can give value to these new ingredients by determining potential value via inclusion in animal diets.

Trial runs with example data provides a tool to predict ethanol outputs. Table 4 displays these changes for 4 different model runs. The ethanol yield as well as the oil composition of these runs varies the most.  The ethanol yield drops slightly when frontend fractionation is installed, while the oil content varies between plant processes because of the incentive to remove and sell this high value product.

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# CHAPTER 3: VALUATION OF FRACTIONATION PRODUCTS

A paper to be submitted to *Cereal Chemistry*

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## ABSTRACT

Growth in the dry grind ethanol industry has increased research into alternative processing technologies, including back-end oil extraction and front-end fractionation. The addition of alternative processing technologies to an existing ethanol plant results in the production of more diverse, high-value co-products (relative to traditional, dry grind DDGS). More products may increase overall profitability for an ethanol plant. Using the Nelson model, front-end fractionation products were analyzed for the potential increase in overall value beyond the traditional dry grind process. Using one set of product prices as of May 15, 2015, and one set of assumptions on the separation in the front-end process, a plant with the technology installed would have a gross revenue increase of $0.25 per bushel of corn processed. The model additionally outputted feed co-product compositional values into a swine feed formulation software. The diets were formulated to meet minimum values for metabolizable energy (ME) (1500 kcal/lb.), crude protein (18% as fed), and lysine (.92% as fed) and maximum value of neutral detergent fiber (NDF) (16%). The example case had a 5% higher corn germ meal inclusion rate in the diet compared to traditional DDGS. It also showed an inclusion rate for corn germ meal from fractionation of 36% with a potential to reduce total feed cost by over $20 a ton. The potential inclusion of this product as well as corn bran and corn germ meal in swine diets could provide an increase in value for the products from front end fractionation, and add to the incentive for ethanol plants to install this technology.

## Introduction:

In 2014 the United States produced over 13 billion gallons of ethanol, compared to just 3.9 billion gallons in 2005. (Renewable Fuels Association 2015a) This rapid growth in ethanol produced was due to the implementation of Renewable Fuel Standard (RFS), which is under the administration of the United States Environmental Protection Agency (U.S. EPA). The RFS originated with the Energy Policy Act of 2005, which mandated the amount of ethanol to be blended into the nation's fuel supply. (*Energy Policy Act of 2005* 2005) The passage of the Energy Independence and Security Act of 2007 expanded the RFS further. The 2007 Act specified the inclusion rates of alternative fuels produced through various methods (starch-based ethanol, cellulosic ethanol, biomass based diesel, and other advanced fuels) in the U.S. fuel supply yearly from 2008 to 2022. The mandate for starch-based (corn) ethanol inclusion increased annually, with a production cap of 15 billion gallons annually to be achieved in 2015. This policy has encouraged market growth by incentivizing investments in the corn ethanol industry up to the cap. (Dinan, Gecan, and Austin 2014)

In the U.S., corn based ethanol is produced via one of two methods, wet grind or dry grind processing. Wet grind ethanol plants pre-soak corn in water acidified with sulfur dioxide ($S0_2$) at about .12-.20% of the water. This soaking process softens the kernel and the elevated acidity facilitates separation of the kernel into the starch, fiber, gluten, and germ components. (Warner and Mosier 2008) Starch is the component that is desired for conversion to ethanol. The germ portion of the kernel is desired for its high oil content; the oil is extracted leaving the germ meal. (O'Brien and Woolverton 2009) Germ meal mixed with the separated fiber portion of the kernel yields corn gluten feed, which can be sold as an animal feed ingredient. The gluten portion is high in protein and can be sold as corn gluten meal. (Bothast and Schlicher 2005)

In dry grind processing whole corn is mixed with water and enzymes to form a slurry. Alpha amylase and glucoamylase are added to convert the starch in the kernel into glucose during saccharification. Yeast fermentation of the resultant glucose yields ethanol and carbon dioxide.(Bothast and Schlicher 2005) Ethanol is then distilled off leaving whole stillage. This whole stillage is generally centrifuged into two products, thin stillage and wet cake. A portion of this thin stillage, or backset, is recycled back into the slurry of the next batch. The remaining thin stillage and wet cake are then combined and dried into a product called dried distillers grains with solubles. Each bushel of corn can produce 2.8 gallons of ethanol and about 18lbs of DDGS. (Renewable Fuels Association 2015b)

More than 80% of operational corn ethanol facilities in the U.S. are dry grind. The large increase in ethanol production over the past 10 years has primarily been that of dry grind plants. This translates into an increase in DDGS production. In 2014 35.5 million tons of DDGS were produced for the animal feed industry. Of the DDGS produced approximately 24 million tons are used domestically, while 11 million tons of DDGS are exported to foreign markets. (U.S. Grains Council 2015; Renewable Fuels Association 2015b) These DDGS give ethanol plants an additional source of revenue, contributing between 7-25% of revenue over the past 10 years. (Hofstrand 2006) Animal producers use DDGS as a feed ingredient because it is a low cost, high protein product.

One of the main issues with DDGS as a feed product is the high nutrient variation. Variation can occur between plants, and even between batches at the same plant. Plant to plant variation occurs because of differences in processing and plant characteristics. (Liu

2011) With 187 dry grind ethanol plants operating in 2014, the potential for plant-to-plant variation is very high. (Renewable Fuels Association 2015c) One of the reasons for variation between batches from the same plant is variation in corn composition. ( Belyea et al. 1989) This variation can be seen in corn composition data from Iowa State Extension- Iowa Grain Quality Initiative containing multiple Iowa counties from the past 13 years. The protein composition is graphed in figure-1 showing variation in corn protein composition among several county-wide test plots, across years. The variation in corn is reflected in DDGS variability, and ultimately hurts its use as a feed product. DDGS variability creates uncertainty, causing nutritionists to apply a safety factor to ensure that use of DDGS as an ingredient in feed formulations provides a diet with adequate essential nutrients. (Liu 2011) This safety factor hurts the inclusion rate in animal diets.

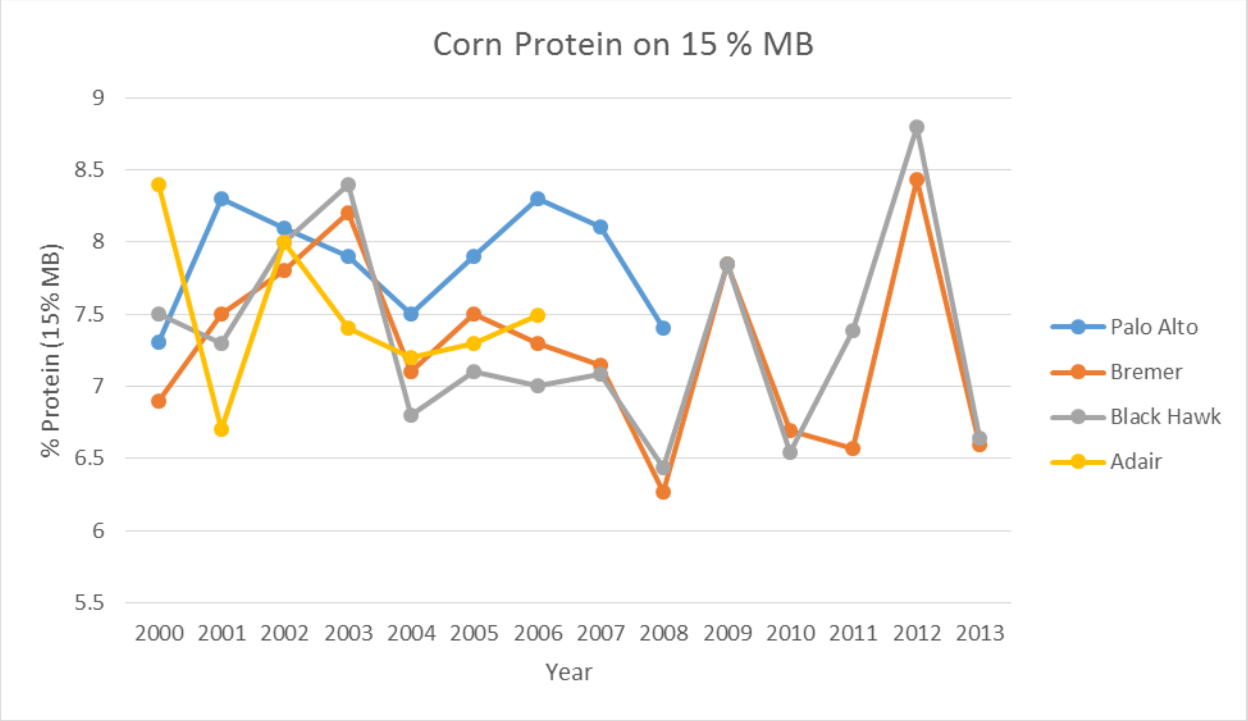

**Figure 1-Protein Composition of Corn from Various Iowa Counties 2000-2013** (Iowa Grain Quality Initiative 2015)

In addition to protein variation, the amino acid composition of the DDGS is of concern from an animal nutrition standpoint. Amino acid composition often is the limiting nutrient in animal diets. In swine diets, lysine is of the most importance. A product such as DDGS has a much lower lysine composition than other high protein feeds such as soybean meal. Soybean meal has roughly 3% lysine on an as fed basis, while DDGS ranges around .75%-1.00%. (Dahlke 2012)

When it comes to fiber, nutritionists prefer the values from the detergent system, neutral detergent fiber (NDF) and acid detergent fiber (ADF), over digested crude fiber. The NDF values include the structural components of the plant (hemicellulose, cellulose, lignin) while ADF consists of these same structural components without the hemicellulose portion. DDGS are typically limited in swine diets by the NDF value (~ 30%) while other high protein products, such as soybean meal, have lower values of NDF (9%). (Dahlke 2012)

As the ethanol industry matured, new technologies have been implemented to add additional revenue. One potential add on is front-end fractionation. Front-end fractionation creates products similar to those from wet milling. Front-end fractionation is a milling technique that separates the corn kernel into 3 streams- endosperm, bran, and the germ. This separation is done prior to entering the ethanol plant. (Gustafson and Jason 2010) The endosperm stream is the largest because corn is nearly 75% starch. This stream enters the pre-existing ethanol plant, and ultimately produces ethanol, carbon dioxide and a high protein but low protein quality DDGS product. (Moss 2013b) Oil can be extracted from the germ stream, and sold for a high value. Corn oil is valued at roughly $540 a ton, compared to $150 a ton for DDGS. (Hartman 2015) The remaining non-oil portion, called germ meal, is sold as an animal feed. (Murthy et al. 2006) Germ meal is used in monogastric diets because of its concentrated amino acid profile and low fiber content. (O’Brien and Woolverton 2009) The bran stream is also sold as an animal feed, primarily for ruminants because of its high fiber content. Despite a high capital cost, front-end fractionation can increase plant profitability by diversifying co-products, as compared to the single DDGS product produced from a traditional dry grind plant.

Modeling both the economics and mass balance of front-end fractionation at an individual ethanol plant provides a resource to evaluate if the benefits of this technology are significant enough to justify the capital investment required. In addition to bolstering understanding of the economic aspects of front-end fractionation, modeling the mass balance of the front-end fractionation also provides the user with a predicted nutrient composition of the co-products. This reduces the issue of DDGS uncertainty. Known nutrient compositions allow plants to appropriately market co-products for more accurate nutritional use in animals. This decreases the safety factor and increases confidence in using co-products in feed formulations, thereby securing co-product value. A plant model that incorporates both front-end fractionation and back end oil extraction (from the DDGS after fermentation) was developed. (Nelson 2015) This paper reports the application of that model to corn valuation and feed formulation.

## Materials and Methods:

The Nelson model was used to evaluate the potential value of products from front-end fractionation. This model predicts ethanol outputs (ethanol, carbon dioxide, feed co-products) based on variable whole corn composition, and plant technologies (front-end fractionation, backend oil extraction). (Nelson 2015) Additionally it connects into the U.S. Pork Center of

Excellence and the United States Soybean Board, National Swine Nutrition Guide formulation software. The feed co-products from the Nelson model are outputted into the currently existing feed library. This allows the user to formulate swine diets with the existing ingredients and evaluate new ingredients. (Dahlke 2012)

To validate the Nelson model for amino acid tracking, samples to determine stream composition data were obtained from a plant using front-end fractionation equipment. These samples were from the whole corn as well as the 3 streams from fractionation. The whole corn composition is given in table 5. Total protein was measured by Europhins Lab (Des Moines IA), amino acid data was determined by University of Missouri labs (Columbia MO).

**Table 5- Corn composition for amino acid validation**

| Corn composition | |
|---|---|
| Amino Acid | 15% MB |
| Lysine | 0.248 |
| Cystine | 0.128 |
| Methionine | 0.119 |
| Threonine | 0.239 |
| Tryptophan | 0.055 |
| Total Protein | 6.7 |

The model was run for this composition of corn, and the percent error between the predicted values and the actual values for each stream are given in table 6. The percentage amino acid composition values of the fractionation streams are not given for confidentiality reasons.

**Table 6- % relative error between actual values and Nelson model prediction values, for essential amino acids.**

| Actual | Lysine | Cystine | Methionine | Threonine | Tryptophan |
|---|---|---|---|---|---|
| Germ Meal | -1% | -11% | -4% | 1% | -1% |
| Bran | -12% | -15% | -16% | -4% | -11% |
| DDGS | 2% | 6% | 8% | 0% | -2% |

As expected the higher volume streams more concentrated in essential amino acids were better predicted than those that are low in protein and amino acids. Bran is not likely to be used as a swine feed ingredient. In general, the model slightly shorted the germ meal and over estimated the DDGS.

To evaluate the value from front end fractionation the potential value was calculated per bushel of corn processed. Additionally, swine diets were formulated to demonstrate how co-products from frontend fractionation could be included. Fractionation stream breakdown information, was obtained from Cereal Process Technologies, LLC (Overland Park KS) and entered into the Nelson model. The assumptions for whole corn composition and plant efficiencies can be seen in table 7. Five diets were run. The diets were formulated for the grow-finish swine diet specifications listed in table 9. These values are based on the Nutrient Requirement of Swine. (National Research Council Staff 1988) They include minimum inclusion levels of metabolizable energy (ME), crude protein, and lysine. The diets were also restricted to a maximum inclusion rate of neutral detergent fiber (NDF). The cost assumptions for the value per bushel as well as the cost assumptions found in the feed formulation software are found in table 9.

**Table 7- Corn composition and plant characteristic assumptions made in model run**

| Corn composition | |
|---|---|
| | 15% MB |
| Starch | 61.6% |
| Protein | 6.6% |
| Lysine | 0.26% |
| Cystine | 0.19% |
| Methionine | 0.17% |
| Threonine | 0.29% |
| Tryptophan | 0.06% |
| Oil | 3.6% |
| Crude Fiber | 2.5% |
| | |
| Plant Information | |
| Saccharification Efficiency | 97% |
| Fermentation Efficiency | 99% |
| Backset? | No |
| Backend Oil Extraction | No |
| Front End Fractionation? | Yes |

**Table 8-Diet Specifications**

| **Swine** | |
|---|---|
| Type | Grow-Finish |
| Weight | 100-130 lbs |
| ME min requirement (kcal/lb) | 1500 |
| Crude Protein (min requirement) | 18% |
| Lysine (min requirement) | 0.92% |
| NDF (max in diet) | 16% |

**Table 9- Cost assumptions: Soybean meal and DDGS in feed formulation software** (Dahlke 2012)**, Fractionated DDGS, Corn, Ethanol, Corn Oil** (Hartman 2015)**, Corn Germ Meal** (Feed Services Co 2015)**, Corn Bran** (USDA-MO 2015)

| Product | cost/ unit |
|---|---|
| Soybean meal | $325 / ton |
| Corn | $125 / ton |
| DDGS in FF software | $170 / ton |
| Fractionated Corn Germ Meal | $190 / ton |
| Fractionated DDGS | $170 / ton |
| Fractionated Corn Bran | $100 / ton |
| Ethanol | $3.50 / gallon |
| Corn oil | $540 / ton |

## Results and Discussion:

Corn composition values from table 7 were used along with the cost assumptions in table 9. Both a traditional model run along with a run with frontend fractionation, using the same input corn composition and plant efficiency assumptions found in table 7. Despite a drop in ethanol yield per bushel, the addition of co-products from frontend fractionation allowed this process to have an increase in gross revenue of $0.25 per bushel of corn. This value allows for a rough estimate of the value of installing and operating the equipment. Other economic factors to consider in future model expansion would be the capital cost of the equipment, the change in energy use from the plant.

**Table 10- Model outputs for traditional ethanol run and frontend fractionation run**

| Traditional | | | | Frontend Fractionation | | |
|---|---|---|---|---|---|---|
| | Amount | Value | | | Amount | Value |
| Ethanol | 2.82 gallons | $9.87 | | Ethanol | 2.78 gallons | $9.73 |
| DDGS | 16.4 lb | $1.23 | | DDGS | 11.1 lb | $0.94 |
| | | | | Corn Oil | .84 lb | $0.23 |
| | | | | Corn Germ Meal | 4.1 lb | $0.39 |
| | | | | Corn Bran | 1.1 lb | $0.06 |
| | | $11.10 | | | | $11.35 |

The 5 diet formulation results are in table 11. All diets had an option to include corn and soybean meal from the feed library. Diets 2-5 include the option to add a different ethanol co-product. (DDGS from feed library, fractionated DDGS, fractionated corn bran, fractionated germ)

In diet 5 the corn germ meal had a high amino acid profile. The higher lysine composition combined with lower composition of NDF allows for a 5% higher inclusion. It is important to notice the ability for the corn germ meal to replace a higher amount of soybean meal, which ultimately lowered the cost of the diet by $25 per ton compared to traditional DDGS. The high protein DDGS from the fractionation were limited by the lysine requirement in the assumed diet. While high in protein, this product had a lower lysine composition. Offering a combination of the coproducts in a single diet may further reduce feed costs.

The NDF value of the diet is of importance when analyzing these products. Monogastric animals cannot digest fiber, as efficiently as a ruminant animal and therefor to get enough energy in the diet, fiber must be limited. The diets, which included DDGS and corn-germ meal, were all limited by the maximum NDF requirement in the diet. If this maximum NDF is adjusted, the formulation for the DDGS in the diet would change as well.

**Table 11- Diet formulation run for each co-product, values and percent on an as-fed basis.**

| | Ingredients | % as fed | ME (kcal/lb) | Crude Protein (%) | Lysine (%) | NDF (%) | Cost/ton feed |
|---|---|---|---|---|---|---|---|
| Diet 1 | | | 1550 | 20% | 0.92% | 9.4% | $175.60 |
| | SBM | 72% | | | | | |
| | Corn | 29% | | | | | |
| Diet 2 | | | 1549 | 24% | 0.92% | 16% | $172.66 |
| | SBM | 25% | | | | | |
| | Corn | 44% | | | | | |
| | Corn DDGS (from software) | 31% | | | | | |
| Diet 3 | | | 1521 | 21% | 0.92% | 16% | $167.60 |
| | SBM | 22% | | | | | |
| | Corn | 21% | | | | | |
| | Fractionated Corn DDGS | 22% | | | | | |
| Diet 4 | | | 1500 | 20% | 0.92% | 16.0% | $178.41 |
| | SBM | 30% | | | | | |
| | Corn | 61% | | | | | |
| | Fractionated Corn Bran | 12% | | | | | |
| Diet 5 | | | 1551 | 19% | 0.92% | 16% | |
| | SBM | 18% | | | | | $147.09 |
| | Corn | 51% | | | | | |
| | Fractionated Corn Germ meal | 36% | | | | | |

## Conclusion

When making decisions about rather to install front-end fractionation technology the potential value is found in the nutrient value of the co-products. Using the Nelson model, front-end fractionation products were analyzed for the potential increase in value. A plant with the technology installed and operating according to the assumptions in this project could gain $0.25 per bushel of corn processed. The feed products were also evaluated for their potential inclusion in swine diets. Corn germ meal could be included at 5% higher rate than conventional DDGS, reducing the cost of the diet by over $20 a ton because of its high lysine composition. This along with the income potential from the high protein DDGS and corn bran stream provides the plant with more value of co-products compared to a traditional plant. The potential value in these additional co-products provides an incentive for dry grind plants to look further into the possibility of installing this technology. Further modifications to the model and iterations of formulations using a range of price combinations would provide a more precise analysis of operating parameters and equipment setups for front-end fractionation. The present conclusions are based on one set of operating parameters and prices.

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# GENERAL CONCLUSIONS

In part 1 a mass balance model was created to predict ethanol plant output. This model took into account input corn composition, plant efficiencies, as well as added plant processes including frontend fractionation and backend oil extraction. The model provides a tool for plants to better predict co-product composition, which can lead to higher confidence for animal nutritionist using feed co-products from ethanol production.

In part 2 of the research an analysis using the developed model was completed to estimate the value from including frontend fractionation. The results found that for the assumptions made, a plant with frontend fractionation would earn $0.22 per bushel of corn processed. This does not take into account the investment in the equipment or changes in the energy use of the plant. This research also found that high protein DDGS and corn germ meal from front-end fractionation could be included in swine diets. The DDGS could be included at a higher percentage, while the corn germ meal lowered the total cost of the diet by replacing a portion of soybean meal.

This research could be expanded upon through the addition of an economic, energy, or life cycle assessment of the processes. Additionally a sensitivity analysis for different market scenarios would be beneficial to ultimately show how installing frontend fractionation would allow plants to stand up to market fluctuation.

# APPENDIX

## ETHANOL PLANT MODEL USER MANUAL

The Ethanol Plant Model connected with the National Swine Nutrition Guide is a tool that both ethanol plants and animal nutritionists can use to determine co-product value. The inputs to the model are corn composition and plant characteristics, which after going through the model is outputted into the feed library in the formulation software. This allows the co-products from ethanol production to be analyzed for their replacement value in traditional feeds.

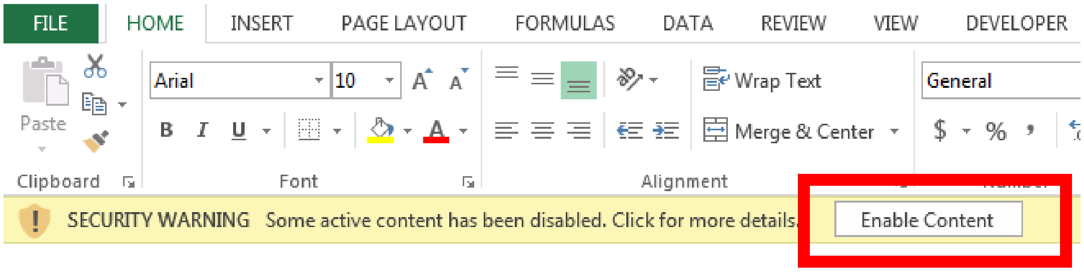
# Software Requirement:

- To run this model you will need Microsoft Excel. Additionally, the model runs on a program code, which requires the Macro setting to be enabled. **This can be done in one of the following ways.**

**1. Enable content when model opens.**

A. Select "Enable Content" in the security-warning banner at top of the spreadsheet.

-This will enable the Macros for the model to run.



SECURITY WARNING Some active content has been disabled. Click for more details.

**2. MS Excel 07 (And Later)**

A. Select 'File'
B. → "Options"
C. → "Trust Center"
D. → "Trust Center Settings"
E. → "Macro Settings"
F. → "Enable all Macros"

Microsoft does not recommend enabling all Macros, a warning message may appear. You must enable the macros to run the program.

**3. Earlier Versions of Excel**

A. Select 'Tools' from the menu bar
B. → 'Macro'
C. → 'Security'
D. → ' Low'

**Additionally you must select 2 Excel Add-Ins**

E. → Select 'Tools' from the menu bar
F. → 'Add-Ins'
G. Check 'Analysis Tool Pack' and 'Analysis Tool Pack-VBA'

→ If the program asks for a password enter "Arnold Ziffel" into the password box.

# Program Operation:

- The program may ask for a password when initially opened, this password is “Arnold Ziffel”
- There must be a value inputted in all input boxes in the model.
    - This includes “Inputs-Corn”, “Inputs-Plant Operation”, and “Inputs- FEF Info, Yeast” tabs.
- Navigate from page to page using the tabs on the bottom of the screen.
- Green boxes indicate a user input.

# “Inputs- Corn” Tab:

→Corn Weight

→Enter the number of bushels to be analyzed.

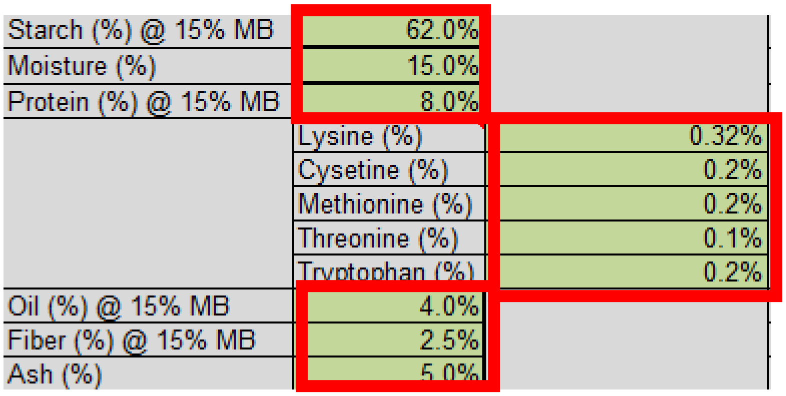
| | | |
|---|---|---|
| Corn Weight | 1 | bu |

→Corn Composition

→Enter the composition of corn at a 15% moisture basis. There should be a value in each of the green boxes.

*i* Amino Acids are a percent of total mass at 15% moisture.

*i* Density is measured in g/cc at 15% moisture basis.



| | | | |
|---|---|---|---|
| Starch (%) @ 15% MB | 62.0% | | |
| Moisture (%) | 15.0% | | |
| Protein (%) @ 15% MB | 8.0% | | |
| | Lysine (%) | 0.32% | |
| | Cysetine (%) | 0.2% | |
| | Methionine (%) | 0.2% | |
| | Threonine (%) | 0.1% | |
| | Tryptophan (%) | 0.2% | |
| Oil (%) @ 15% MB | 4.0% | | |
| Fiber (%) @ 15% MB | 2.5% | | |
| Ash (%) | 5.0% | | |

→Ethanol Yield Equation

*i* The ethanol yield equation is an equation to predict the amount of ethanol produced per bushel of corn based on the NIR proximate composition.

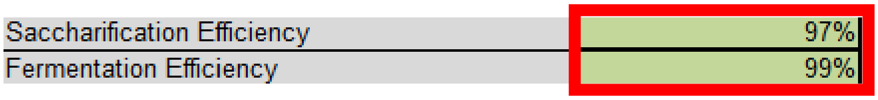
*i* The user can edit the coefficients of this equation when the equation is updated. Entering the corresponding B coefficient value into the green box to the left of each B value does this.

# “Inputs- Plant Operation” Tab:

1. Enter the plant size in Million gallons produced per year (Mmgpy)

| | | |
|---|---|---|
| Plant Size | 110 | Mmgpy |

2. Ether the Saccharification and Fermentation efficiencies.
    - Saccharification efficiency is the efficiency of converting starch to glucose.
    - Fermentation efficiency is the efficiency of converting glucose to ethanol.



| | |
|---|---|
| Saccharification Efficiency | 97% |
| Fermentation Efficiency | 99% |

3. DDGS moisture is the desired moisture content that the DDGS are dried to.

| | |
|---|---|
| DDGS moisture | 12% |

4. % gasoline in final product is the amount of gasoline put into the ethanol produced as a denaturant.

| | |
|---|---|
| % Gasoline in final product | 5% |

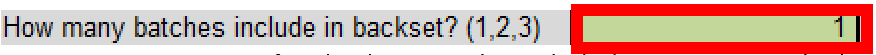
5. “Include Backset” is included for the user to adjust if reuse water should be included in the analysis.
    → To include the backset select the “yes” button.
    → If backset should not be included select “no”

Include Backset?

6. If backset is selected the user must input the % solids in backset. This is the amount of solids that exist in the backset water.

| | |
|---|---|
| Solid % in backset | 35% |

7. The user also must select how many backsets to include in the calculation. You may select 1, 2 or 3 batches to be analyzed.



| | |
|---|---|
| How many batches include in backset? (1,2,3) | 1 |

    → If no backset is to be included enter a 0 into the box.

8. “Backend Fractionation” is a process that can be added onto a plant in which oil is extracted after the fermentation process.
    → To include Backend Fractionation select the “yes” button.

→ If Backend Fractionation should not be included select “no

Backend Fractionation (YES/NO)?

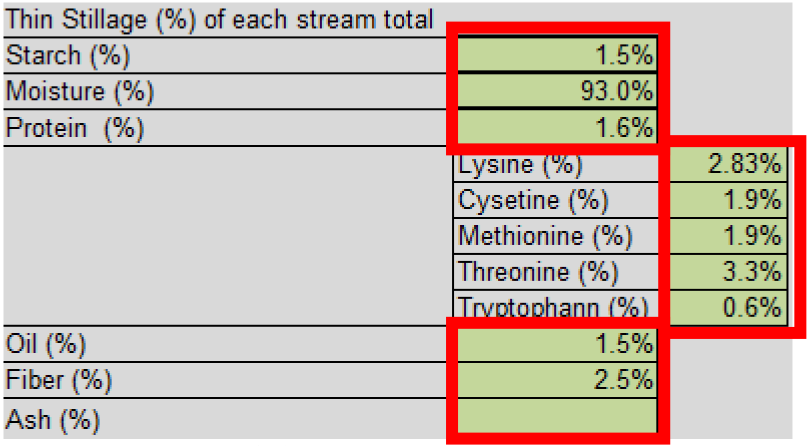
9. The % of oil recovered from backend is the % of oil that is extracted from the backend fractionation technology.

% of oil recovered from backend: 50%

10. “Front End Fractionation” is a process that can be added onto a plant in which the corn is broken down into streams prior to entering the fermentation process.
    - → To include Front End Fractionation select the “yes” button.
    - → To not include Front End Fractionation select the “no” button.

Front End Fractionation

11. The Thin Stillage % is the percent solids of the thin stillage stream. The inputs are based as a % of each stream total as is.
    - → Enter the values for thing stillage into corresponding boxes on an as is basis.



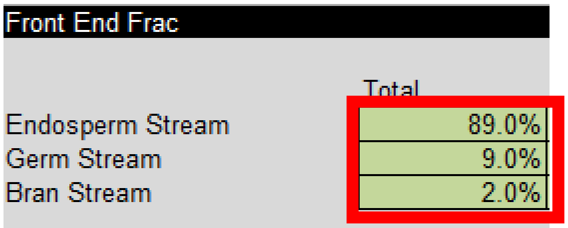
| Thin Stillage (%) of each stream total | | |
|---|---|---|
| Starch (%) | 1.5% | |
| Moisture (%) | 93.0% | |
| Protein (%) | 1.6% | |
| | Lysine (%) | 2.83% |
| | Cysetine (%) | 1.9% |
| | Methionine (%) | 1.9% |
| | Threonine (%) | 3.3% |
| | Tryptophann (%) | 0.6% |
| Oil (%) | 1.5% | |
| Fiber (%) | 2.5% | |
| Ash (%) | | |

12. The Total (%) of whole stillage is the amount of the stillage that is separated into the thin stillage.

Total (%) of Whole stilage: 30.0%

# “Inputs- FEF Info, Yeast” Tab:

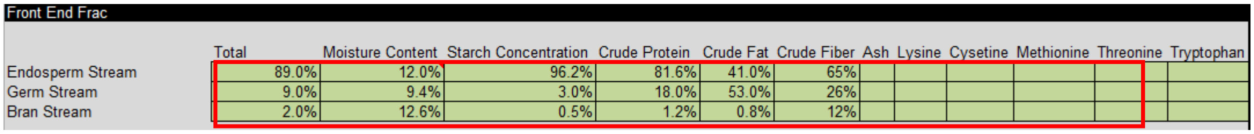
1. The Front end Fractionation information is an input for front-end fractionation. This information will be used if the user selects to include front-end fractionation on the “Inputs- Plant Operation” page.
    → The % values entered in the total column are the % of total mass that is separated into each of the 3 streams, Endosperm, Germ, and Bran.



Front End Frac

| | Total |
|---|---|
| Endosperm Stream | 89.0% |
| Germ Stream | 9.0% |
| Bran Stream | 2.0% |

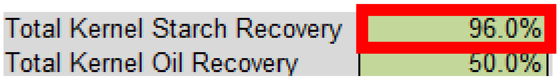
    → The remaining columns in the Front End Fractionation should be entered as % of the mass in each stream.



Front End Frac

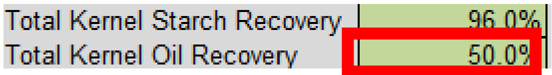
| | Total | Moisture Content | Starch Concentration | Crude Protein | Crude Fat | Crude Fiber | Ash | Lysine | Cysetine | Methionine | Threonine | Tryptophan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Endosperm Stream | 89.0% | 12.0% | 96.2% | 81.6% | 41.0% | 65% | | | | | | |
| Germ Stream | 9.0% | 9.4% | 3.0% | 18.0% | 53.0% | 26% | | | | | | |
| Bran Stream | 2.0% | 12.6% | 0.5% | 1.2% | 0.8% | 12% | | | | | | |

    → The “Total Kernel Starch Recovery” is the % amount of the total cornstarch that is recovered into the endosperm stream.



| | |
|---|---|
| Total Kernel Starch Recovery | 96.0% |
| Total Kernel Oil Recovery | 50.0% |

    → The “Total Kernel Oil Recovery” is the % amount of oil from the corn that can be recovered and extracted.

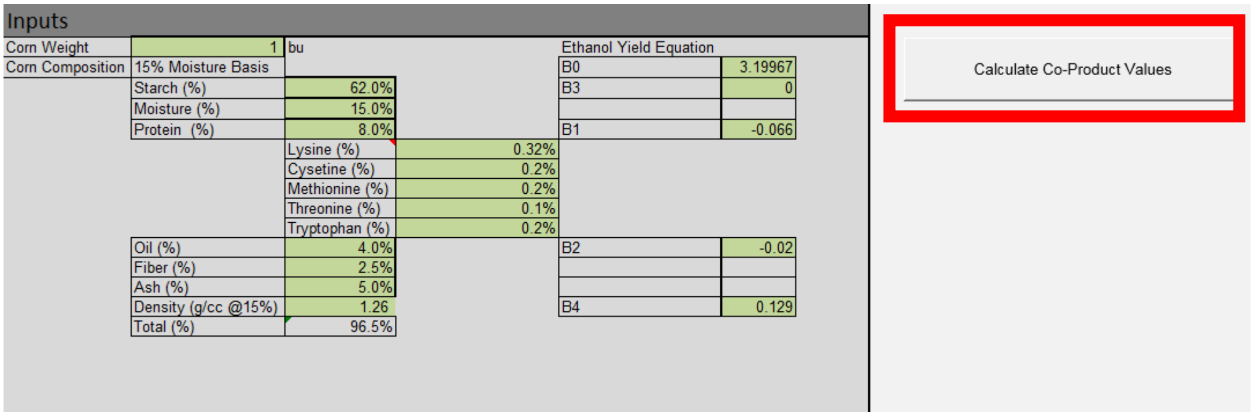


| | |
|---|---|
| Total Kernel Starch Recovery | 96.0% |
| Total Kernel Oil Recovery | 50.0% |

2. The Han and Liu is an equation that is used to evaluate the changes in amino acids during the fermentation process due to the effect of yeast.
    → The coefficients of the equation can be changed on the “Inputs –FEF Info, Yeast”. Entering the corresponding coefficient value into the green box does this.
    → The amino acid composition of the yeast is also important for the equation to work. This input value is a % of the amino acid in question of the total protein.

# Running the Model:

1. Once the inputs have been put into the model, to run the program click on the “Calculate Co-Product Values” button on the “Inputs-Corn” tab. This will run the model.
   - → “Inputs-Corn” Tab
   - → Click “Calculate Co-Product Values”

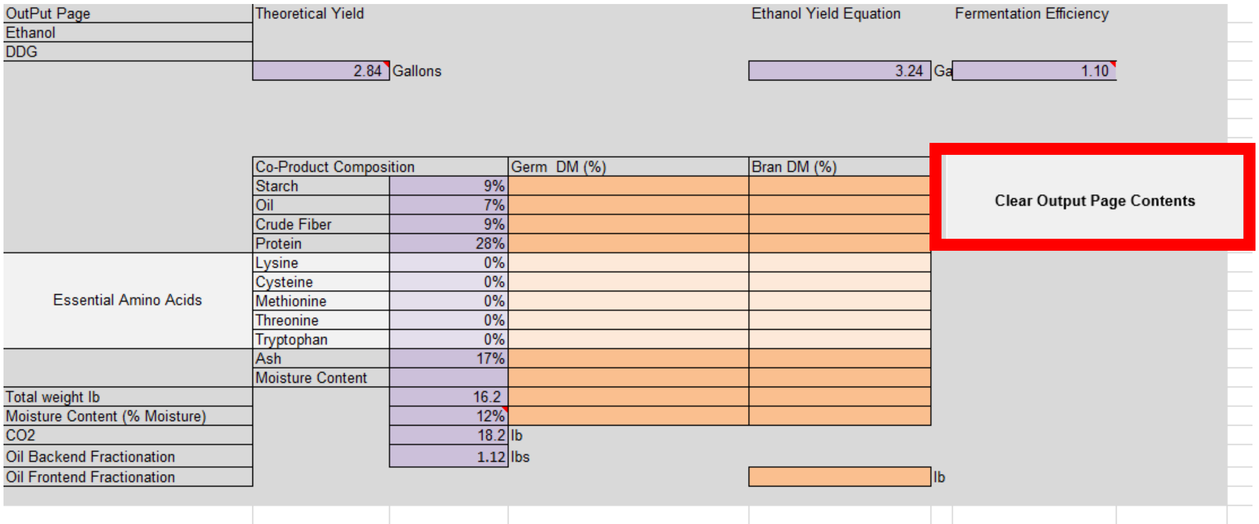


| Inputs | | | | | |
|---|---|---|---|---|---|
| Corn Weight | 1 | bu | | Ethanol Yield Equation | |
| Corn Composition | 15% Moisture Basis | | | B0 | 3.19967 |
| | Starch (%) | 62.0% | | B3 | 0 |
| | Moisture (%) | 15.0% | | | |
| | Protein (%) | 8.0% | | B1 | -0.066 |
| | | Lysine (%) | 0.32% | | |
| | | Cysetine (%) | 0.2% | | |
| | | Methionine (%) | 0.2% | | |
| | | Threonine (%) | 0.1% | | |
| | | Tryptophan (%) | 0.2% | | |
| | Oil (%) | 4.0% | | B2 | -0.02 |
| | Fiber (%) | 2.5% | | | |
| | Ash (%) | 5.0% | | | |
| | Density (g/cc @15%) | 1.26 | | B4 | 0.129 |
| | Total (%) | 96.5% | | | |

2. Once the button has been clicked, go to the “Output Page” tab to see results.

   To clear contents of outputs page:

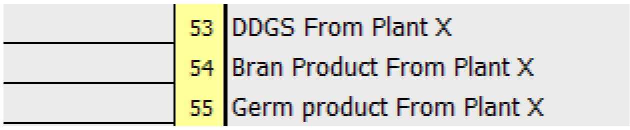
   →Click “Clear Output Page Contents”



| OutPut Page | Theoretical Yield | | | Ethanol Yield Equation | | Fermentation Efficiency |
|---|---|---|---|---|---|---|
| Ethanol | | | | | | |
| DDG | | | | | | |
| | 2.84 | Gallons | | 3.24 | Ga | 1.10 |
| | Co-Product Composition | | Germ DM (%) | Bran DM (%) | | |
| | Starch | 9% | | | | |
| | Oil | 7% | | | | |
| | Crude Fiber | 9% | | | | |
| | Protein | 28% | | | | |
| Essential Amino Acids | Lysine | 0% | | | | |
| | Cysteine | 0% | | | | |
| | Methionine | 0% | | | | |
| | Threonine | 0% | | | | |
| | Tryptophan | 0% | | | | |
| | Ash | 17% | | | | |
| | Moisture Content | | | | | |
| Total weight lb | | 16.2 | | | | |
| Moisture Content (% Moisture) | | 12% | | | | |
| CO2 | | 18.2 | lb | | | |
| Oil Backend Fractionation | | 1.12 | lbs | | | |
| Oil Frontend Fractionation | | | | | lb | |

# Accessing Feed Formulation Information:

1. To view calculated ingredients in the feed formulation software
    - → Select the “Feeds” tab
    - → Scroll down to feed identification number 53, 54, 55
    - *i* These three are the lines for the plant processes.
    - *i* The composition of these products is found by scrolling to the left.



| | |
|---|---|
| 53 | DDGS From Plant X |
| 54 | Bran Product From Plant X |
| 55 | Germ product From Plant X |