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# ***Risk, Infrastructure and Industry Evolution***

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*Edited by*

***Burton C. English***

*Department of Agricultural Economics  
The University of Tennessee  
Knoxville, TN*

***R. Jamey Menard***

*Department of Agricultural Economics  
The University of Tennessee  
Knoxville, TN*

***Kim Jensen***

*Department of Agricultural Economics  
The University of Tennessee  
Knoxville, TN*

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# Economic Feasibility Of Supplementing Corn Ethanol Feedstock With Fractionated Dry Peas: A Risk Perspective

Cole R. Gustafson, Scott Pryor, Dennis Wiesenborn, Abhisek Goel, Ron Haugen, and Andrew Wilhelmi<sup>1</sup>

## Introduction

North Dakota ranks 12<sup>th</sup> in national production of ethanol with four operational plants and three additional plants under construction (Renewable Fuels Association (RFA), 2007). Growth of the corn-based ethanol production has contributed to increased corn demand and prices. In North Dakota, ethanol plants face great feedstock supply risk as corn production in the region is highly variable due to the state's arid and northern climate.

Fractionated dry pea, or field pea (*Pisum sativum* L.), are a potential ethanol feedstock replacement alternative for corn. This interdisciplinary study develops an engineering process model of pea fractionation, quantifies fractionation process costs, and determines if pea fractions enhance corn ethanol fermentation. Results are used to form a stochastic simulation model of a typical 100 million gallon per year (mg/y) ethanol plant that evaluates the profitability and risk of using fractionated peas as a partial feedstock replacement for corn in the proportion of 10 percent in an effort to mitigate rising corn prices and supply risk.

## Background

An extensive body of research has been reported on the fractionation of peas for human consumption (Fedec, 2003; Owusu-Ansah and McCurdy, 1991). Dry peas can be fractionated by either wet milling or dry milling with air classification. Wet processing is used to produce more highly purified protein and starch, but this process is more difficult and requires higher amounts of energy for drying and refining of effluent streams. Dry milling is less expensive to build and operate, and is effluent free (Emami and Tabil, 2002; Nichols *et al.*, 2005).

Nichols *et al.*, (2005) investigated the actual ethanol yield of starch-enriched field peas in a laboratory setting and found the yield to be 0.48 g ethanol/g pea starch, which is 85 percent of the theoretical yield. Therefore, if the whole pea were used, and assuming 46 percent starch on a dry basis, and allowing for the typical efficiencies of conversion, production of 3.4 gallons of ethanol from 100 pounds of field peas could be expected. Although, the general ability of the pea starch to be fermented has been shown, no controls using ground corn were used for rate and yield comparisons. Further, cost estimates of the fractionation process were not provided.

Similarly, few economic models have embodied corn ethanol supply risk. Tiffany and Eidman (2003) developed a deterministic model to assess ethanol plant profitability and scale economies. Larson, English, and He (2008) examined the effect of alternative contracting mechanisms on ethanol plant feedstock supply risk. However, the focus was on a cellulosic ethanol plant and did not address increasing supply risk facing traditional corn ethanol plants.

The objective of this study is to test the hypotheses that pea fractions compete economically with corn, reduce corn ethanol plant supply risk, and lead to increased corn ethanol plant efficiency.

## Economic Corn Ethanol Plant Simulation Model

The economic corn ethanol plant simulation model is structured assuming the operation of the plant will be to maximize expected profit. Profit is set equal to gross revenue minus variable cost minus fixed costs. Gross revenue (GR) of an ethanol plant is modeled by summing the revenue from selling three outputs: ethanol, dry distillers grains with solubles (DDGS), and protein from the pea fractionation as follows:

$$\hat{G} \hat{R} = \hat{P}_1 \hat{Q}_1 + \hat{P}_2 \hat{Q}_2 + \hat{P}_3 \hat{Q}_3$$

where  $Q_1$  is the number of gallons of ethanol produced,  $P_1$  is price of a gallon of ethanol,  $Q_2$  is the quantity of DDGS produced,  $P_2$  is the price of DDGS,  $Q_3$  is the quantity of pea protein produced, and  $P_3$  is the price of pea protein sold. Ethanol,

<sup>1</sup> Gustafson is a Professor in the Department of Agribusiness and Applied Economics; Pryor is an Assistant Professor; Wiesenborn is a Professor in the Department of Agricultural and Biosystems Engineering; Goel is a Graduate Research Assistant; Haugen is a Farm Management Specialist in the Department of Agribusiness and Applied Economics; and Wilhelmi is a Graduate Research Assistant in the Department of Agricultural and Biosystems Engineering, all respectively, at North Dakota State University, Fargo, North Dakota.

DDGS, and pea protein prices are all stochastic. Variable costs (VC) of producing ethanol include:

$$\hat{VC} = \hat{W}_1 + \hat{W}_2 + E_1 + E_2 + L_1 + Y_1 + C_1 + H_1 + M_1 + M_2 + F_1$$

where  $W_1$  is cost of dry peas,  $W_2$  is the cost of corn,  $E_1$  cost of energy (both natural gas and electricity),  $E_2$  cost of enzyme,  $L_1$  cost of labor,  $Y_1$  cost of yeast,  $C_1$  cost of other chemicals,  $H_1$  cost of water,  $M_1$  miscellaneous expenses,  $M_2$  plant maintenance and repair expenses,  $F_1$  expenses related to licenses and fees. Fixed cost can be calculated as follows:

$$FC = D_1 + I_1$$

where,  $D_1$  is depreciation expense and  $I_1$  is interest expense on debt finance.

Distributions of net returns over variable costs were obtained from the iterations of the model for each pea supplementation strategy<sup>2</sup>. The variability of each random variable was simulated using Monte Carlo procedures in @Risk (Palisade Corporation, 2007). Five thousand iterations were conducted, at which the stopping criteria were satisfied. BestFit, a distribution estimation procedure contained in @Risk, (Palisade Corporation, 2007) was used to estimate the statistical distributions of these variables.

Empirical estimation of the model required specification of an engineering process model for the pea fractionation, determination of pea fractionation operating and investment costs, impacts of pea fractions on the efficiency of corn fermentation, and calibration of the pea/corn ethanol simulation model with local empirical data. Each of these is discussed in the following subsections.

<sup>2</sup>A detailed mathematical model, list of data sources, and summary statistics regarding distributions of stochastic variables is available from the senior author.

## Engineering Process Model

An engineering process model was developed to determine economic investment and operation costs of fractionating dry peas (Figure 1). The model consisted of 6 distinct steps resulting in 16 different product streams.

Detailed methods regarding construction of the engineering process model for fractionating field peas, equipment specifications, and model results are reported by Wilhelmi *et al.* (2007). The model indicates that 35,000 lb/h (dry basis) of peas are needed in this plant to replace 10 percent of the corn feedstock on a starch basis. A single-stage fractionation process produces 26,000 lb/h starch-rich fraction for blending with corn, and 11,000 lb/h protein-rich fraction.

## Process Cost Analysis

Two leading manufacturers of milling and air classification equipment provided detailed operating and investment cost information for the fractionating process. However, these companies provide equipment that is typically scaled for the food processing industry (13,000 lb/hr) which would not be of sufficient scale for a large ethanol plant. In order to process sufficient quantity of peas for a 100 mg ethanol plant operating with a 10 percent pea starch feedstock, the use of three parallel sets of pin mills and air classifiers were modeled. Operating and investment costs for a single unit were tripled to determine final pea fractionation costs for a plant that was capable of processing 35,000 lb dehulled peas/hr.

The cost of equipment for unloading, cleaning (including magnetic separator), destoning, and dehulling was estimated at \$1.6 million (Weber, 1987, with equipment cost indexing to 2006). Thus, total direct handling and fractionation equipment costs ranged from \$6.1 to \$7.0 million. A cost factor

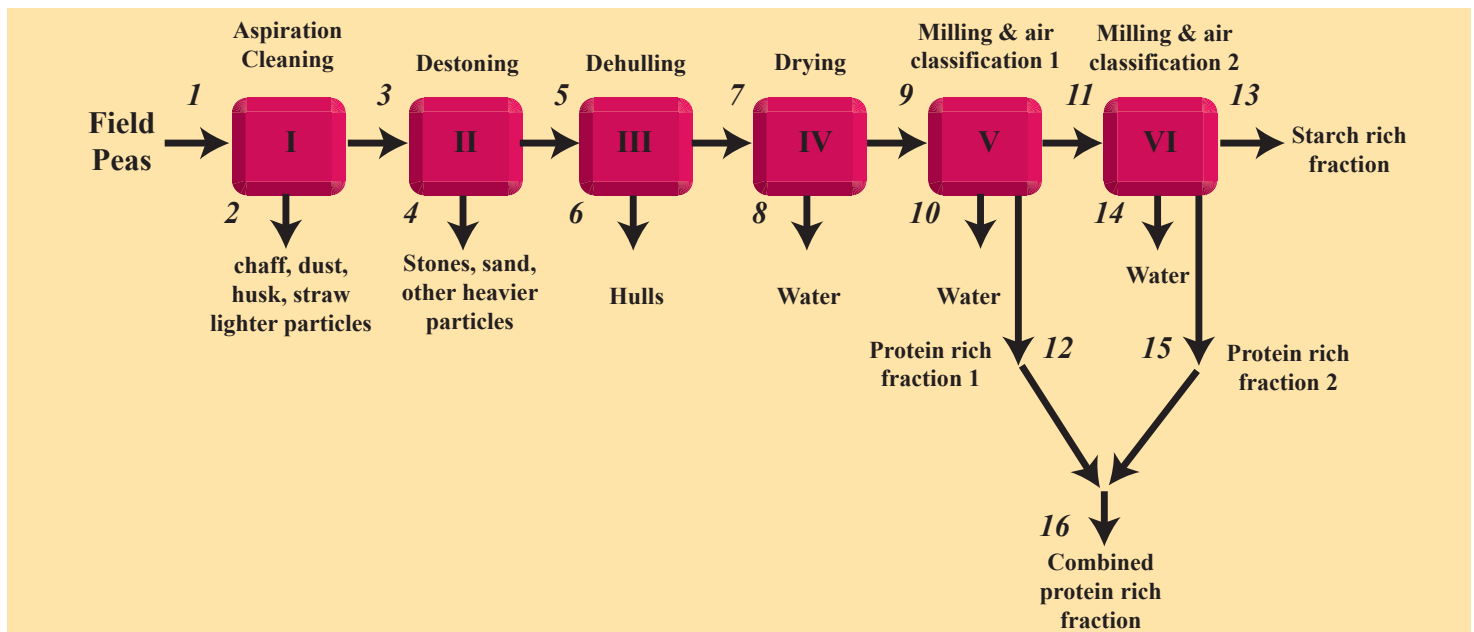


Figure 1. Process Diagram for Dry Fractionation of Field Peas

of 4.55 was used to extrapolate direct equipment cost to total plant costs (Peters, Timmerhaus, and West, 2003), which includes equipment installation, instrumentation, piping and electrical, buildings, yard improvements, service facilities, land, engineering and supervision, construction, contractor's fee, contingency and working capital. Thus, total fixed-capital investment for the pea-fractionation plant was estimated to be \$28 to \$32 million.

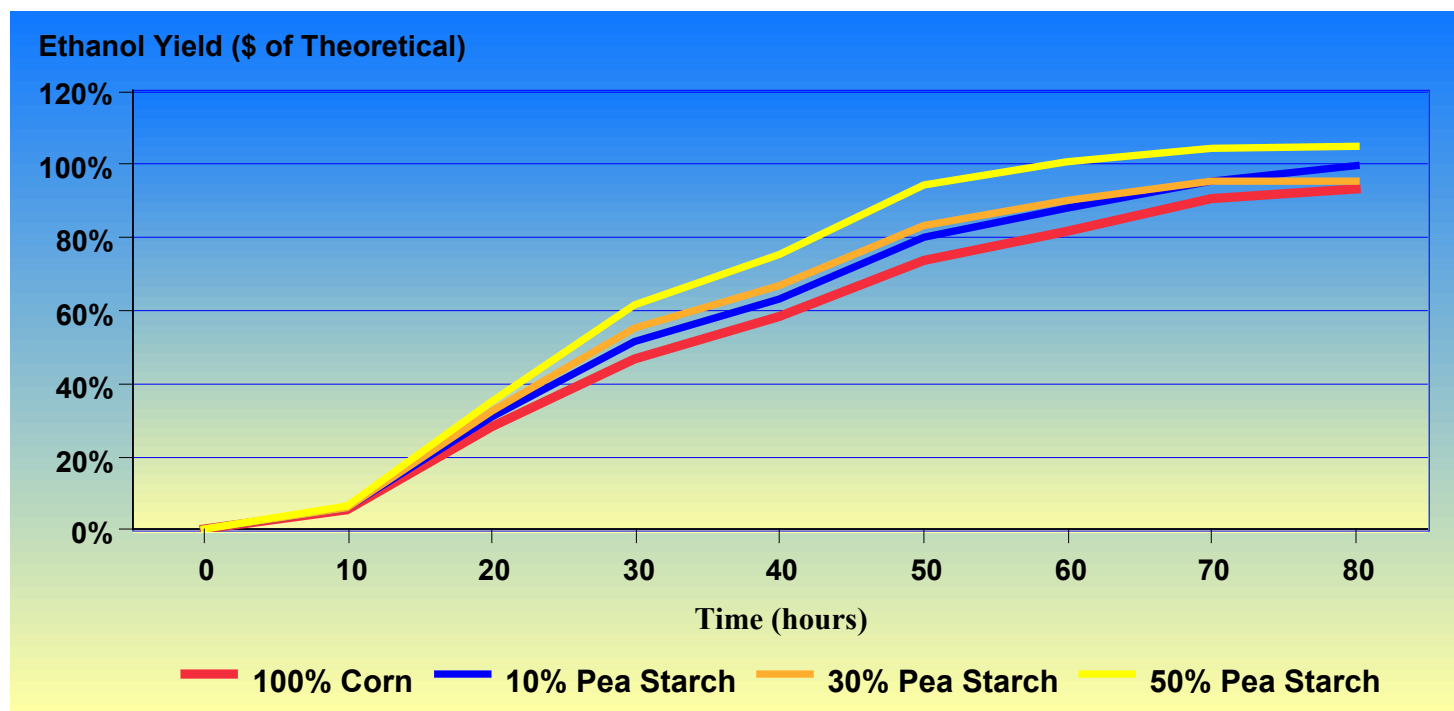
### Enhanced Fermentation Productivity With Pea Starch

Several fermentation trials were conducted to evaluate fermentation kinetics, rate, and final yields of supplementing corn feed stock with varying proportions of pea starch (Pryor, Lenling, and Wiesenborn, 2008). The laboratory-scale dry mill fermentation protocol used was a scaled-down process based on that reported by Singh *et al.* (2005). Figure 2 shows the estimated ethanol yields using a carbon dioxide evolution method from initial fermentation experiments with pea starch replacing a portion of corn feedstock. This simple evaluation method estimates ethanol production based on weight loss during fermentation. The weight loss is assumed to be carbon dioxide evolution which can then be related to ethanol production. The method tends to slightly overestimate actual ethanol production because of loss of other volatiles such as ethanol and water vapor; these losses are erroneously quantified as carbon dioxide evolution and contribute to higher ethanol production estimates. Several follow-up experiments were completed using analysis with High Performance Liquid Chromatography (HPLC) to con-

firm the trends found using this method (Pryor, Lenling, and Wiesenborn, 2008).

As seen in Figure 2, fermentation rates appear to be more rapid with increasing proportions of pea starch. Yields follow a similar trend although the mean yield for the 10 percent pea starch fermentations was slightly higher than that for a 30 percent supplementation. Although final yields between control and experimental treatments were not statistically different at the 95 percent confidence level ( $p=0.098$ ), fermentation rates are higher for pea-starch treatments and there is potential for reducing total fermentation times without negatively effecting yields. Reduced fermentation times could lead to increased ethanol plant capacity because more batches could be completed annually with a fixed sized plant.

The economics of a large-scale ethanol plant depends heavily on both rates and yields of ethanol from incoming feedstocks. Based on a 13 percent final ethanol concentration, a 0.5 percent difference in ethanol concentration would lead to a 4 percent change in annual capacity. Similarly, a difference of one or two hours in a 50-hour fermentation can have measurable consequences over the course of a year. Therefore, ethanol plant efficiency was assumed to increase 10 percent in this study when pea starch was substituted for 10 percent corn feedstock. This assumption of increased efficiency lowered per gallon cost of ethanol as investment costs were spread over greater production.



**Figure 2.** Estimated Ethanol Yields of Corn/Pea Starch Co-fermentation Based on Weight Loss Throughout Fermentation. Note: Ethanol yields are expressed as a percentage of yields expected if all starch present was fermented to ethanol.



## Calibration Of The Empirical Model With Local Data

A stochastic profitability model of a 100 mgy ethanol plant was constructed to simulate net profit of three alternative options of supplementing corn feedstock with fractionated dry peas in proportions of 0 percent, and 10 percent. Risks included in the model were variability in both output and raw material prices as well as feedstock supply uncertainty. In particular, prices of ethanol, DDGS, corn, and dry peas were stochastic as were production yields for corn and peas. The model is calibrated with local yield distributions, prices, and production cost information from central irrigated (corn) and western dryland (pea) regions of North Dakota.

Data used to calibrate the stochastic model were obtained from various sources. Monthly average inflation adjusted ethanol rack prices for the period 1982 to 2006 as reported by the Nebraska State Government Energy Office (2007) because North Dakota does not have an active market for ethanol. Ethanol produced in the plant is sold locally at this price as basis is negligible. Monthly average inflation adjusted wholesale cash prices of DDGS from 1981 to 2006 at Lawrenceburg, Indiana provided data to estimate the DDGS price distribution. Again, DDGS are sold locally so transportation costs and basis are assumed to be negligible. Monthly North Dakota corn prices were collected from historical National Agricultural Statistics Service (USDA-NASS, 2007) data from 1985-2007 to estimate the price distribution. However, given recently strong corn prices, the mean corn price was increased to \$3.50 in the base model. Moreover, a \$0.10/bu price increase reflecting basis change was added to incorporate the impact a new ethanol plant has on local corn prices (McNew and Griffith, 2005). Likewise, the pea price distribution was estimated in a similar manner with 2000-06 NASS data (earlier data were not collected), and the mean pea price increased to \$7.50/cwt, reflecting current market prices and parity with a corn price of \$3.50. The value of the enriched fraction of pea protein is assumed to equal soybean meal (Lardy, 2007). The prices of enzyme, yeast, chemicals, water, labor, management and quality control, maintenance, miscellaneous expenses, licenses, fees and insurance for a gallon production of ethanol were obtained from Tiffany and Eidman (2003).

Corn yield distribution was based on annual county-level production data for the period 1964- 2006 (USDA-NASS, 2007) from counties within 60 miles of the plants location (Jamestown, North Dakota). A plant located in this region of irrigated and dryland corn production could expect to source 77 percent of needed corn from the area (Johnson, 2007). The remainder is transported from eastern North Dakota at an additional cost of \$0.20/bu. In years when production surrounding the plant is below the historic average, additional corn is imported posing a supply risk to the ethanol plant. The value of corn supply risk is assumed to be the quantity of additional

corn needed to be imported multiplied by the additional transportation cost and prevailing price. The distribution of pea yields was also estimated with 1964-2006 NASS data from producing counties in North Dakota.

Technology, investment and financial assumptions regarding the ethanol plant were: 1) the cost of building a plant is assumed to be \$1.02 per gallon capacity for a 100 million gallon per year plant (Eidman, 2008), 2) the plant is capitalized with both equity (40 percent) and debt (60 percent), 3) the plant is expected to produce 2.75 gallons of ethanol and 18 pounds of DDGS per bushel of corn (Eidman, 2008), 4) the plant is expected to produce 5.30 gallons of ethanol per 100 pounds of dry peas (Nichols *et al.*, 2005), and 5) the plant life is expected to be 15 years (Tiffany and Eidman, 2003).

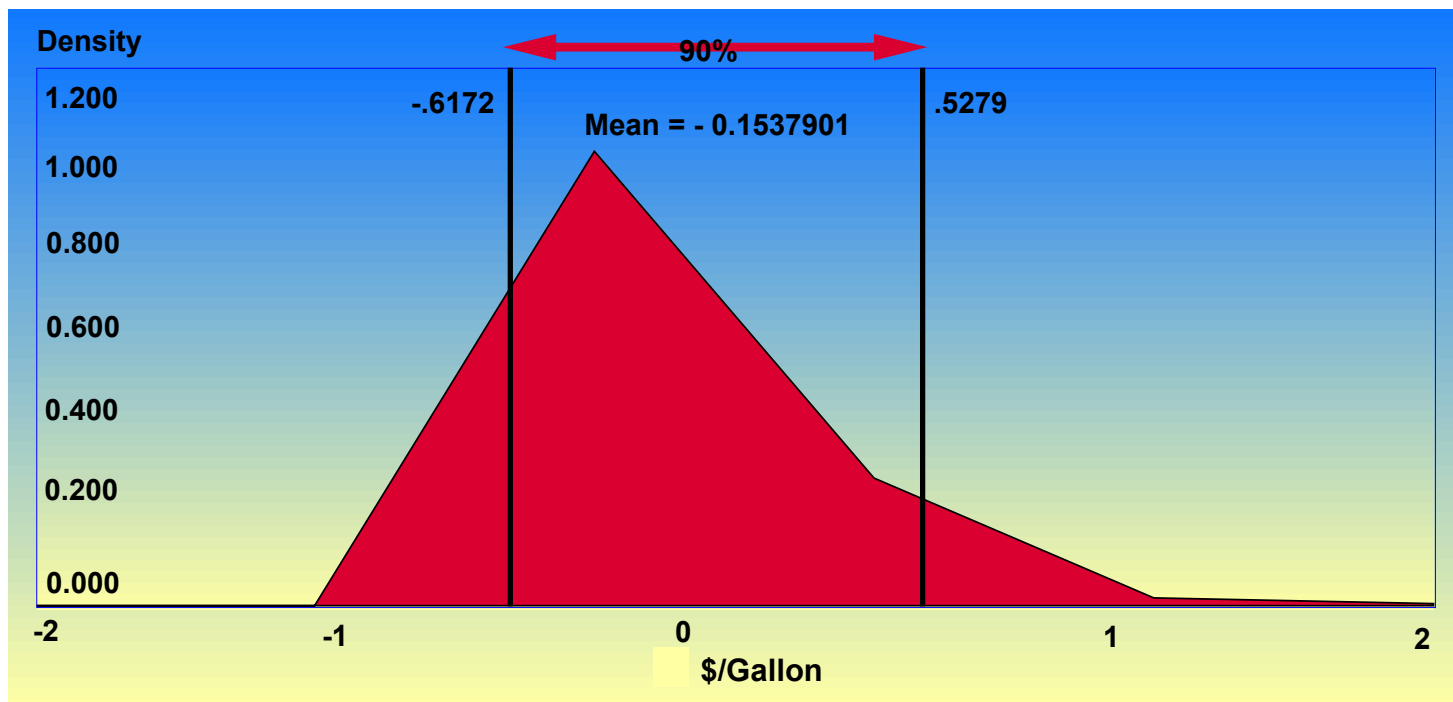
The substitution of dry peas for corn in the ethanol production process increases the rate of fermentation decreasing the time taken to produce ethanol. Therefore, the 100 mgy ethanol plant was assumed to have higher efficiency with production capability increasing to 110 mgy. The plant processing dry peas will have a higher output while additional capital cost is expected for the cost of pea fractionation equipment. In addition, the value of DDGS also changes with pea supplementation. The plant scenario producing ethanol with 10 percent of its corn being replaced with dry peas is expected to produce 2.03 per gallon of ethanol per bushel of dry peas, 2.59 gallons of ethanol per bushel of corn, and 17.37 pounds of DDGS per bushel of corn (Wihelmi *et al.*, (2007). Finally, estimated correlations between yields and prices of corn and dry peas were not included due to lack of significance. They were not expected to be significant given the local nature of this study.

## Economic Results

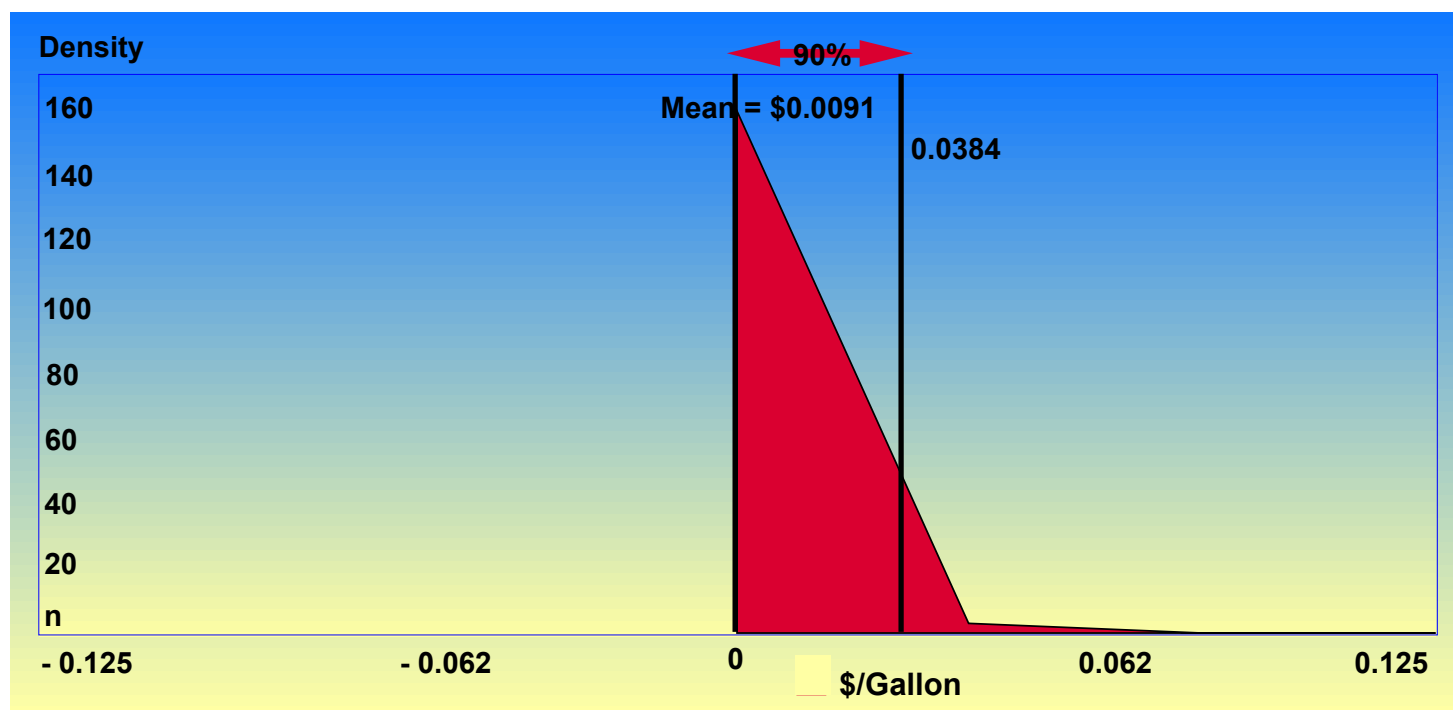
Economic results for the base 100 mgy ethanol plant located in central North Dakota that uses 100 percent corn for its feedstock is marginally unprofitable at a local net price ratio of corn (\$3.50/bu) and ethanol (\$1.38/gal).<sup>3</sup> When the plant is simulated stochastically, results show it is losing \$0.15/gal of ethanol produced after all variable and fixed costs of production are deducted. The net profit distribution in Figure 3 shows that the plant profit is expected to be from -\$0.61/gallon to \$0.52/gallon at a 90 percent of probability as depicted in the distribution of net income (Figure 3).

Inclusion of supply risk raises costs as the firm faces an expected corn supply risk of \$0.009/gal of ethanol produced on an on-going basis because local corn production in the surrounding region periodically falls below historical average as displayed (Figure 4).

<sup>3</sup>An enterprise budget detailing revenue, costs, and profit for both the 100 percent corn and 90 percent corn-10 percent pea scenarios that are input into the simulation models are available from senior author upon request.



**Figure 3.** Distribution of Ethanol Plant Net Income/Gallon, 100 Percent Corn Feedstock



**Figure 4.** Ethanol Plant Corn Supply Risk, 100 Percent Corn Feedstock

The distribution of the supply risk (Figure 4) showed the processor incurred additional hauling costs of \$0.009 gal/ethanol produced, on average, because corn production in the region periodically falls below historical average production. While corn is the largest cost item for an ethanol plant, this level of supply risk is negligible due to the plant's location in a region of irrigated corn production. The sensitivity of corn supply risk was tested by constraining local supply even

further with the assumption that only 50,000 bu. of corn was available locally instead of 70,000 bu. This raised corn supply risk an additional \$0.01/gal and reduced ethanol plant profitability from \$-0.14 to \$-0.15.

Profitability of the ethanol plant is highly sensitive to corn prices. When corn prices drop 40 percent to \$2.16/bu., ethanol plant profitability improves to \$0.412 per gallon. How-

ever, as corn prices increase 40 percent to \$5.04/bu., plant profitability quickly erodes to \$-0.70 per gallon. Breakeven corn price is just under \$3.24/bu. after all variable and fixed costs of production are deducted.

### Substitution Of Ten Percent Peas For Corn

Despite the assumption of increased plant efficiency, the replacement of 10 percent of the corn feedstock with pea starch leads to lower plant profitability. The investment cost of fractionation equipment to process the quantity of peas needed to replace 10 percent of the corn utilized in a 100 mg ethanol plant totals \$28 million. At present corn, pea, and investment prices, expected ethanol net income averages \$-0.43 per gallon of ethanol produced when 10 percent of the corn feedstock is replaced with peas. The large investment cost required due to use of three smaller processing mills are not offset by lower pea prices. The distribution of 10 percent pea net income is shown in Figure 5. The net profit distribution shows that expected profitability of the plant ranges from -\$0.91/gallon to \$0.27/gallon with 90 percent of probability.

Not only are expected profits lower, but the variability of profits increase due to more variable pea production and prices. The replacement of corn with 10 percent peas does partially mitigate firm supply risk as shown in Figure 6. Overall corn supply risk decreases by \$0.001 as dry peas are substituted for 10 percent of corn.

However, the displaced corn has a negligible impact on profits due to the higher total cost of using peas. Net income per gallon of ethanol produced with 10 percent peas is still highly sensitive to corn prices. At present corn and pea prices,

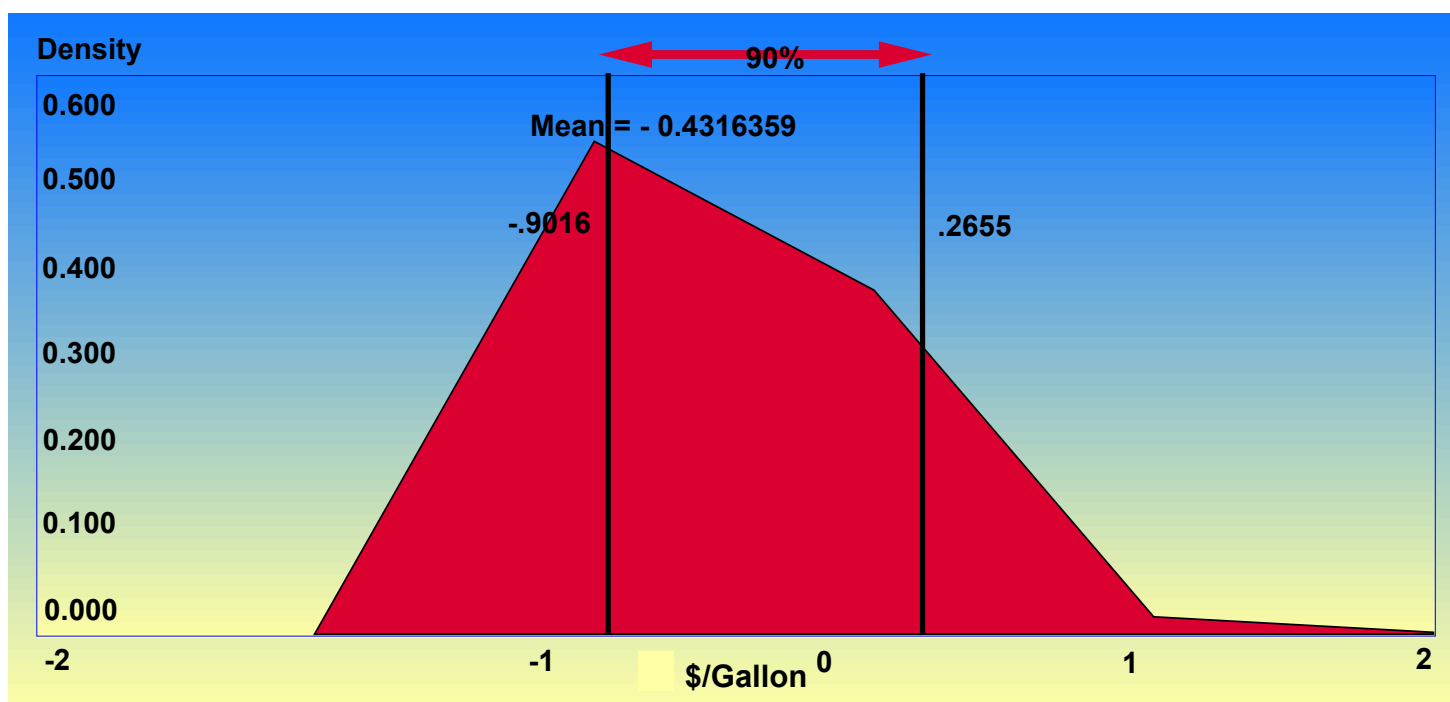
corn prices would have to rise to \$4.34 for peas to become breakeven with corn (e.g. point at which net income with 100 percent corn falls to \$-0.431).

Investment cost of fractionation equipment could be an important determinant of profitability. As noted earlier, commercial scale equipment to support a 100 mg ethanol plant is presently not available. Thus, a smaller pea fractionation system was replicated 3x to meet plant needs. As industry demand for larger fractionation equipment evolves, investment cost per dry weight of peas processed will likely fall, which in turn would increase plant profitability. To gauge the sensitivity of peas to fractionation equipment investment costs, additional model runs were performed assuming investment costs dropped 10-90 percent from the base cost of \$28 million. Results show that a 10 percent discount in pea fractionation investment cost has only a marginal impact on ethanol plant net income as profits only increase \$0.003/gal. Even a 90 percent drop in pea equipment investment raises net income only \$0.40/gal to \$-0.031/gal.

The viability of pea supplementation likely depends on potential changes in the feed value of the DDGS. Peas may have a positive benefit, because of enhanced lysine, which is the limiting amino acid for at least some feeds. It is unknown however whether lysine is influenced by fermentation.

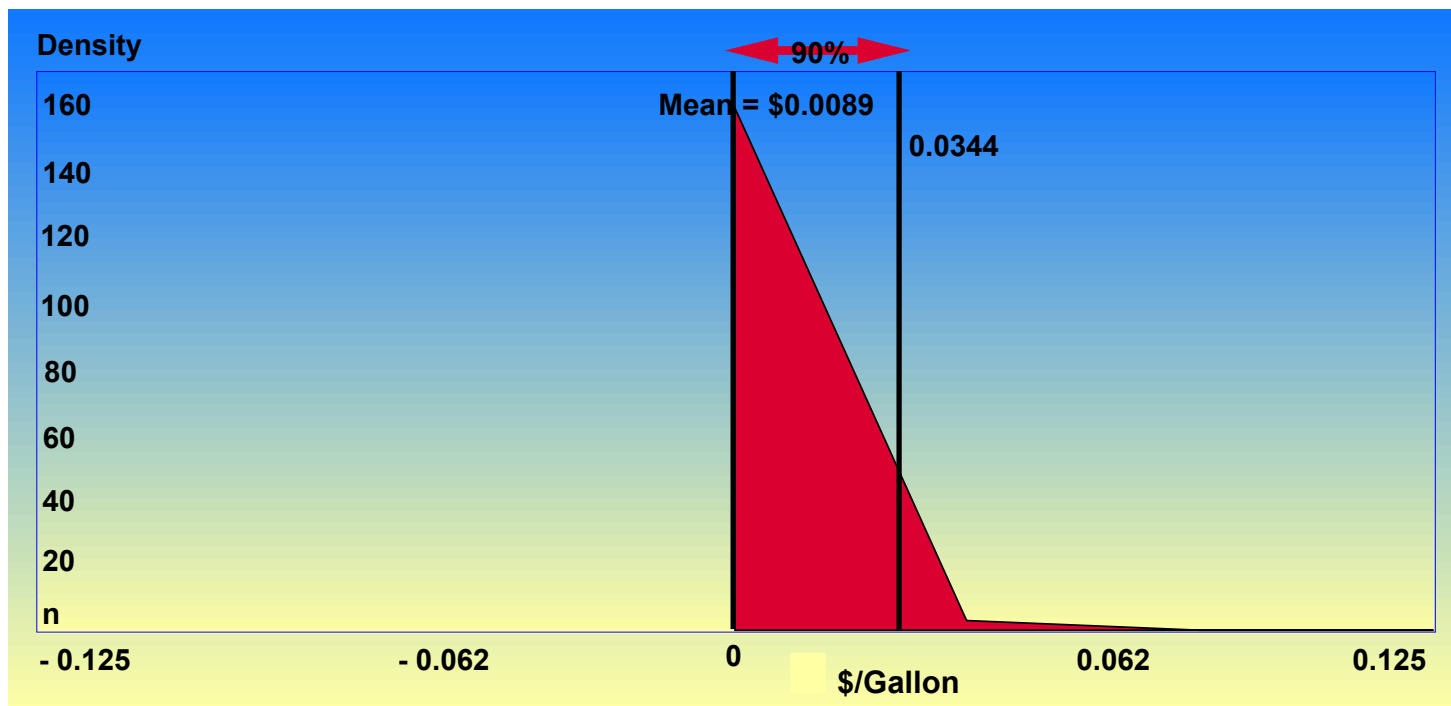
### Conclusions and Recommendations

Fermentation analyses in this study show that supplementing corn in a conventional dry-grind ethanol plant with a starch-enriched product from fractionated field peas should have neutral or slightly positive impact on ethanol production



**Figure 5.** Distribution of Ethanol Plant Net Income/Gallon, 100 Percent Corn Feedstock





**Figure 6.** Ethanol Plant Corn Supply Risk, 90 Percent Corn/10 Percent Peas

rates given similar initial starch loadings. The engineering and economic analyses show that the investment and power costs for dry milling and air classifying that is presently available is prohibitively expensive to be commercial. However, an even more significant factor is high pea feedstock prices, relative to corn. Corn prices would have to rise more than 20 percent before peas breakeven. An alternative approach not investigated is to mix whole or dehulled peas with corn without fractionation. One disadvantage of use of whole or dehulled peas is an increase in inert solids (protein and fiber) in the saccharification and fermentation steps. This feedstock dilution would likely reduce overall ethanol capacity instead of increase it as assumed in this study. The corn ethanol industry moved away from wet milling in recent years; however, the rapid growth in that industry has spurred the development of new wet-fractionation processes for all feedstocks, including corn.

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