

## **Novel Crop Biotechnologies & the US Ethanol Industry**

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IMBA Project 2005-9

Project period: 8/1/2004- 1/31/2006

**Final report** (covers period of 8/1/2004- 1/31/2006)

### **Executive Summary**

In recent years there has been a growing interest in technologies that augment the operations of both wet and dry mills. In order to evaluate a cross section of the available technologies a model representing not only the wet or dry mill, but the entire supply chain must be built. This project has developed such supply chain models and implemented them, first to test the effects of using specialty crops at the wet mill, and then to test a portfolio of technologies at the dry mill.

For the wet mill, a number of specialty corn varieties were chosen that allow for improved starch and ultimately ethanol production. Findings suggest that although these new technologies have the potential to positively impact the viability of ethanol production, the degree of impact varies. Moreover, it was found that supply chain concerns can become important to the adoption of crops specifically engineered to facilitate the ethanol and starch production process.

The wet mill industry is driven largely by food products instead of ethanol. As such ethanol technologies must be congruent with food needs. Accordingly, the analysis focuses on the likely costs of adopting new corn varieties in a system where a non-GM starch product is necessary. Findings suggest that costs in such cases can be large and may prohibit the adoption of new or specialty varieties except when value creation is very large.

The technologies that have been selected for the dry mill portion of the project include those that increase operating efficiency such as: improved yeasts/bacteria, corn varieties with improved ferment-ability characteristics and high  $\alpha$ -amylase corn varieties. Technologies that work within incumbent ethanol facilities and do not require significant supply chain coordination would appear to be most readily adopted, provided that the technology is robust. The adoption of specialty corn varieties, however, is inherently more complicated. Although costly segregation protocols are less relevant at the drymill, where the end product is not destined for human consumption, the value associated with new corn varieties is not always sufficient to encourage even the basal level of needed

supply chain coordination. As such, the adoption of such crops may be limited and the potential of these technologies may not be fully realized at the ethanol facility.

## **Research Progress**

The research has been divided into two main areas, namely those technologies and concerns associated with the wet mill and those associated with the dry mill. Previous progress reports have detailed the findings of the wet mill portion of the project. This progress report focuses on dry mill technology platforms, specifically: 1) Improved starch conversion 2) High extractable starch corn varieties 3) high amylase corn varieties

### *Improved Fermentation*

Intense research has been carried out to obtain more efficient fermentative organisms, low-cost fermentation substrates, and optimum environmental conditions for fermentation to occur. *Zymomonas mobilis*, a bacterium, is considered as a promising alternative to yeast in large-scale fuel ethanol production. Comparative laboratory- and pilot-scale studies on the kinetics of batch fermentation of *Z. mobilis* versus a variety of yeasts have indicated the suitability of *Z. mobilis* due to the following possible advantages:

- its higher sugar uptake and ethanol yield,
- its lower biomass production,
- its higher ethanol tolerance,
- it does not require controlled addition of oxygen during the fermentation, and
- its amenability to genetic manipulations.

### *High Extractable Starch/Fermentable Corn*

There is significant variation in starch yield potential across corn germplasm. In recent years, seed firms have screened their elite germplasm for elevated starch and fermentability. By focusing on elite, high-yielding germplasm, seed firms have managed to introduce high extractable starch (HES) and highly fermentable corn (HFC) hybrids that have comparable yields to conventional ones.

### *High Amylase Corn*

Corn naturally contains a small amount of amylase, which can assist in the breaking down of cornstarch into simple sugars for fermentation. However, because of the inadequate expression of  $\alpha$ -amylase in the corn seed, large amounts of  $\alpha$ -amylase are synthetically added to the corn slurry during the process of liquefaction. Since  $\alpha$ -amylase can represent a significant material input cost for ethanol production, economizing on its inclusion is attractive. To facilitate this, biotechnology companies are producing strains of high amylase corn that will decrease the  $\alpha$ -amylase that needs to be artificially added to the process.

## **Model Development**

The estimation of the value of the above technologies requires the evaluation not only of their unit operation but the entire system where they are utilized. The implementation of

these technologies often impacts that system sending changes throughout the process and the entire supply chains.

Understanding how a technology works as part of a system is complicated, requiring a method of analysis capable of considering the detailed operation of a large number of unit operations as well as the inherent uncertainty and stochasticity. In order to account for these factors, Process and Economic Simulation of IP (PRESIP), a hybrid economic-engineering simulation model was developed and used to estimate IP and traceability costs for a representative supply chain in starch and ethanol manufacturing.

PRESIP, as it is employed for this project, consists of separate modules. The first being the wet and dry mills themselves. In addition to the mills, many of the technologies that are being evaluated involve specialty corn varieties with unique production and handling requirements. For these crops a second module was constructed to evaluate the farm level production of the crops as well as the transportation and handling necessary to bring them to the mill. PRESIP, was calibrated through actual production, procurement, and processing data acquired from industry collaborators.

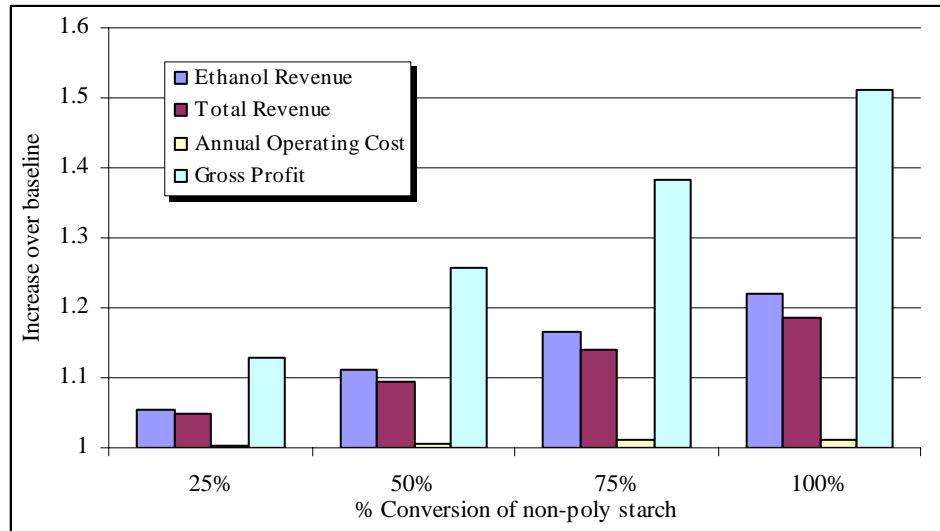
## **Preliminary Findings**

Initial results suggest that all the evaluated technologies have the potential to lower the cost of production at the dry mill facility, although the benefits vary significantly by technology.

### *Improved Fermentation Technologies*

A number of biotechnologies are currently being investigated that could enhance the efficiency of converting sugars to ethanol. One previously mentioned example is *Z. mobilis*, which is a bacterium that could replace yeast in the fermenter. Studies on the kinetics of *Z. mobilis* have indicated the potential for shorter fermentation time and higher ethanol yield compared to yeast. Perhaps even more importantly is the potential of genetically engineered varieties of *Z. mobilis* to ferment xylose and arabinose as well as other cellulosic biomass. While this garnishes the most excitement in producing ethanol from cellulosic sources such as switchgrass, it also has application to corn, which is also comprised of cellulose (non-starch polysaccharides). Non-starch polysaccharides comprise about 7% of the dry matter entering the fermenter and the following table shows how its conversion, at various levels, would impact the economics of the dry-mill.

## **Economics of Improved Fermentation Technologies**



Improved fermentation could thus equate to significant unit production cost reductions.

#### Unit Cost of Ethanol Compared to Baseline (\$/kg)

25% conversion	50% conversion	75% conversion	100% conversion
-0.02	-0.04	-0.05	-0.07

Improved fermentation agents could also impact the time that the mash must dwell in the fermenter. This is not likely to have a significant impact on currently operating facilities as their systems are generally optimized to work under the current constraints. Finding time efficiencies in one section may have little improvement in flow rate although these calculations are difficult and facility specific. However, new facilities that are constructed with the technology in mind would benefit from the shorter fermenter dwell times. An ethanol facility operating with a 50% shorter dwell could be constructed for 6.8% less than a comparable conventional facility. Improved conversion of fermentables is another benefit of agents like *Z. mobilis*, although the economic impact is not comparatively as large.

Such advances in fermentation technology bring efficiency to ethanol production regardless of the rest of the supply chain. The value of such technologies is entirely captured by the ethanol facility, with the exception of any added costs of the new fermenting agent. Conversely, the value of those technologies that are present in the corn itself (e.g. highly fermentable corn and high amylase corn) must be shared with the upstream actors -namely the farmer and the seed company.

#### Highly Fermentable Corn & High Amylase Corn

At the farm HFC hybrid varieties are comparably priced to conventional hybrids and do not present a yield drag. At the ethanol facility the added fermentability has the potential to increase ethanol output by a modest 4%, equating to an almost 2% increase in gross profit potential for a 40mmgy facility (or \$.04 per bushel of corn). This situation of limited cost to the farmer and moderate benefit to the ethanol manufacturer has resulted

in few ethanol facilities willing to pay premiums for HFC varieties. As such, not all farmers may choose to deliver HFC varieties, leaving the ethanol facilities unable to fully benefit or even adequately optimize their facility for any HFC that is received. This suggests a need for some coordination between farmers and the ethanol facility although it may not be robustly feasible do to the limited value creation.

While some portion of the benefit of HFC varieties can still be experienced in the absence of supply chain coordination, this is less likely to be the case for high amylose varieties. Coordinating efforts will be important since the ethanol facility will likely require a sufficient and consistent supply of high amylase corn to efficiently displace synthetically added amylase.

In instances where high amylase corn simply reduces the need for synthetic a-amylase, the savings are likely to be modest. For example, a 40 mmgy facility uses 250,000 kg of a-amylase per year totaling \$824,626 per year which represents a potential cost decrease of no more than 1.6%, or \$.03 per bushel. However, if high amylase corn can completely eliminate the incorporation of synthetically added amylase then more significant capital expenses can be eliminated, especially for future facilities. In such cases a 5% increase in gross profitability could be possible (\$.10 per bushel). This latter level of value creation may be adequate, in some situations, to warrant a value sharing program with farmers and the genetics provider.

## **Equipment Purchases**

None

## **Bibliography**

### *Journal Articles*

N. Kalaitzandonakes and J. Kaufman “The Economics of IP and Traceability in the US Wet Milling Industry” in review

### *Trade Publications*

N. Kalaitzandonakes and J. Kaufman (feb. 2006) “GM Crops Impact Starch Industry, Wet Milling Industry,” Grain World.