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# Corn Ethanol Industry Process Data

## September 27, 2007 – January 27, 2008

*BBI International, Project Development Division*
*Denver, Colorado*

***Subcontract Report***
**NREL/SR-6A1-45152**
**February 2009**

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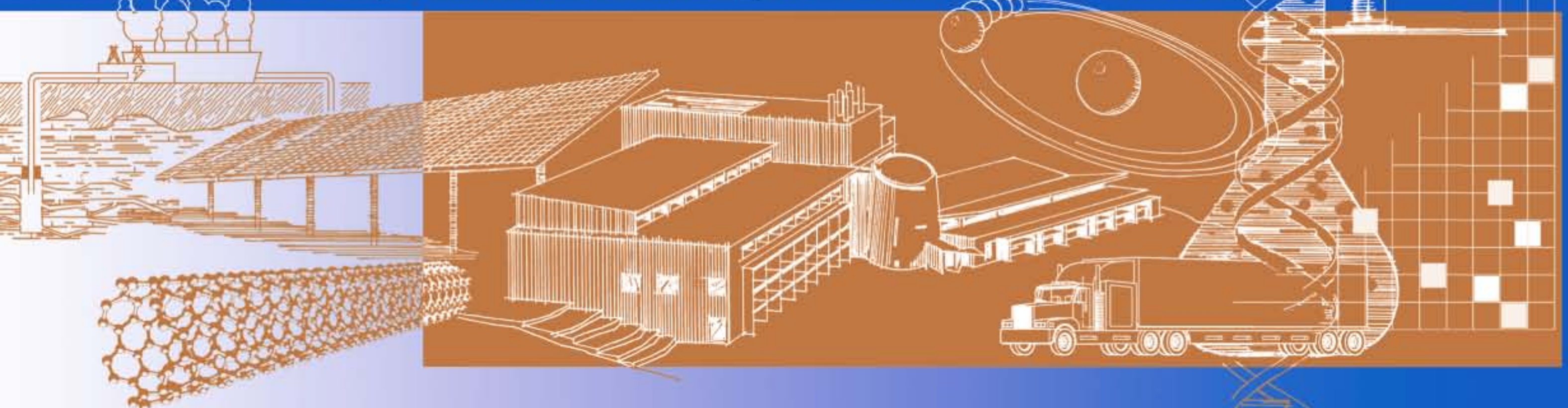

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NREL Technical Monitor: Debra Sandor

Prepared under Subcontract No. AEV-7-7638-01

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# I. EXECUTIVE SUMMARY

Capital costs for corn dry grinds have increased significantly with the recent building boom for new capacity, but are expected to fall in the coming years due to an anticipated drop in demand. Once the plants currently under construction are completed, ethanol production capacity from corn will approach 15 billion gallons, which is widely regarded as the maximum feasible.

Over two thirds of the existing capacity has been built since 2001. New state of the art plants have incremental advantages in ethanol yields and energy consumption. We expect future construction to be mostly driven by updates and expansions to existing plants, due to the difficulty of getting green field projects financed.

Technological advances for the future will most likely see the adoption of fractionation technology by more plants, which will allow the production of higher value co-products than DDGS. In addition, new corn strains with higher starch contents will become available. Another area of technological innovation will focus on reducing the use of fossil energy and the emission of greenhouse gases.

## II. PROJECT OVERVIEW

### Purpose of Study

The objective of this effort is to supply timely data on the historical make-up of the corn ethanol industry, and the current best estimate of what the industry is installing now. Any projections of where the industry might be able to go will also be useful as the model will carry out the expansion of corn ethanol for the next 10-20 years.

### Scope of Work

The Subcontractor has performed the following tasks:

### Task 1: Existing Corn Ethanol Dry Grind State-of-the-Industry

The Subcontractor has utilized experience, contacts and involvement in the current dry grind corn ethanol industry and has established our best industry average estimate of each of the following parameters for new state-of-the-art mills being installed today:

1) Capital Cost ($/gallon of annual capacity installed)
2) Fixed and Variable Operating Cost (less feedstock and by-products, e.g., DDGS)
3) Design, Construction and Start-up Time (Months)
4) Capital Recovery Factor (typical)
5) Plant Life (yr)
6) EtOH Yield (gal/bu)
7) DDGS Yield (lb/bu)

The Subcontractor has used the following information to characterize the existing installed base of corn ethanol production:

1) Fixed and Variable Operating Cost (less feedstock and by-products, e.g., DDGS)
2) EtOH Yield (gal/bu)
3) DDGS Yield (lb/bu)

### Task 2: Future of the Dry Grind Corn Ethanol Industry

The Subcontractor has utilized knowledge of historic trends, published ideas for new technology being developed and implemented, and theoretical limits as well as own impressions of where the costs will go, and forecasted how the following might potentially change over the next 10 to 20 years,

1) Capital Cost ($/gallon of annual capacity installed)
2) Fixed and Variable Operating Cost (less feedstock and by-products, e.g., DDGS)

3) EtOH Yield (gal/bu)
4) DDGS Yield (lb/bu)

## DELIVERABLES

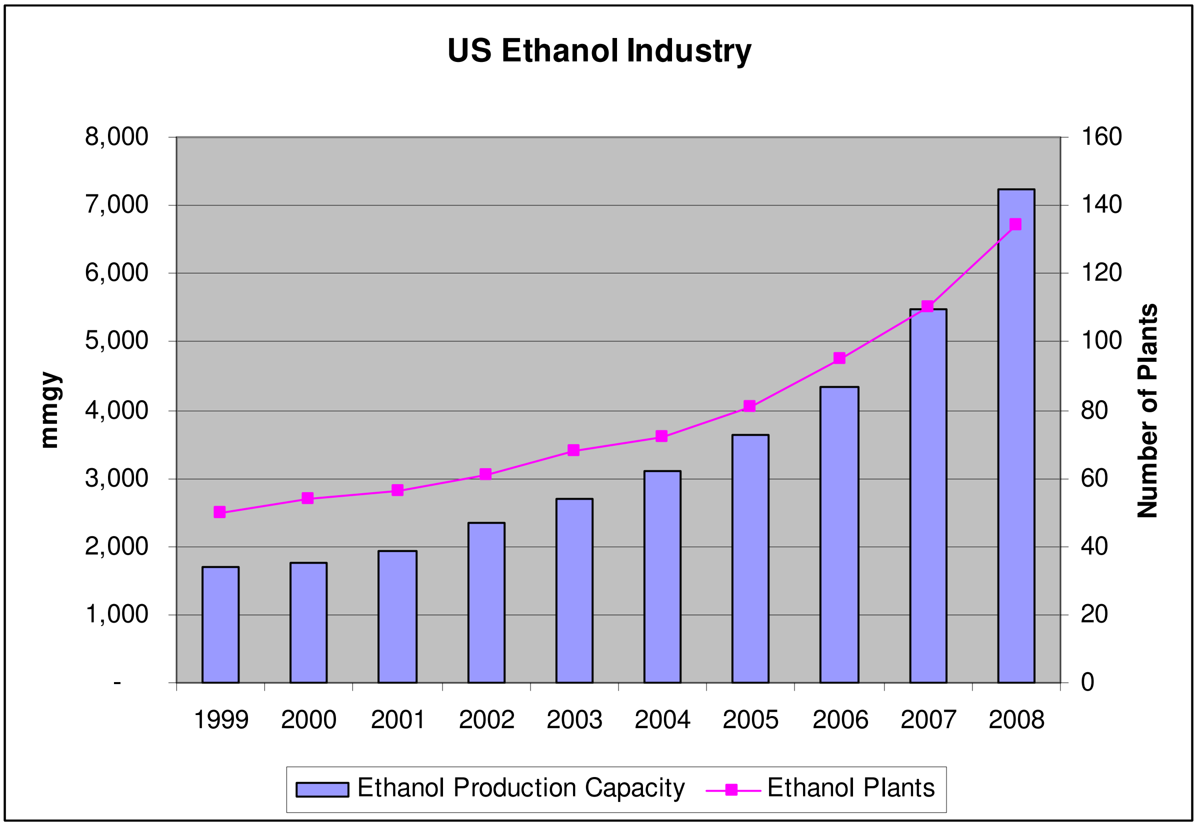
Deliverable 1: Summary Report on Current State-of-the-Industry.
Due three months after subcontract execution.

Deliverable 2: Final Report on expected future trends of the corn ethanol dry grind industry. Due upon subcontract completion.

## III. EXISTING CORN ETHANOL DRY GRIND STATE-OF-THE-INDUSTRY

The dry grind industry in the US has undergone rapid change over the last few years, both in terms of size and costs. This section provides information on the existing installed base for corn ethanol production as well as current new state of the art new installations. Figure 1 below displays the build-out of the US ethanol industry since 1999 in terms of overall capacity and number of plants. Over two thirds of today's capacity has been installed since 2001. To the best of our knowledge, the last financial close for a corn to ethanol dry grind plants was in October 2007.

**Figure 1 – US Ethanol Industry Capacity and Number of Plants**

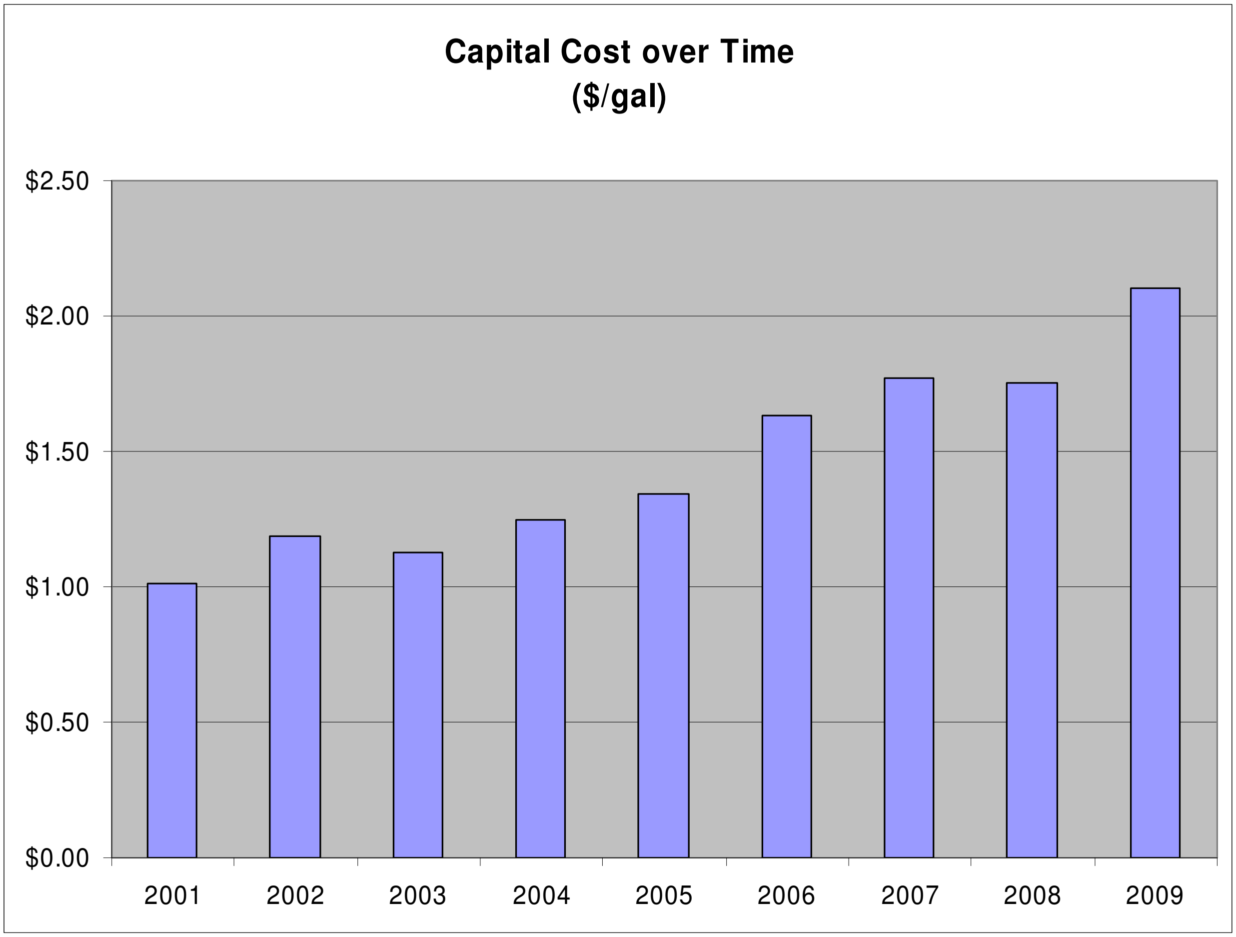



Source: BBI Analysis using RFA Data

**Capital Costs:**

Figure 2 below outlines the development of the capital costs for ethanol plants over time. The big increase in demand for new ethanol production capacity in 2006 triggered a jump in capital costs. The run-up in costs is caused, among others, by higher costs for stainless steel and labor, shortages of critical pieces of equipment and increased profits along the value chain. Costs for plants starting up in 2008 were lower on average than 2007 due to the prevalence of lower cost US Bio plants (Ord, Dyersville, Janesville, Hankinson) with pre-existing contracts that reduced the average cost. Capital costs are defined here as all-in costs, including items such as working capital, inventories, interest, and risk management funds.

**Figure 2 – Capital Cost Evolution**




Source: BBI Estimates

Table 1 below shows the typical breakdown for the capital costs for a 100 mmgy denatured ethanol dry grind that starts operation in 2009.

**Table 1 – Typical Capital Cost Breakdown**

| | |
|---|---|
| **Nameplate Ethanol Production (gal/year)** | **110,000,000** |
| Anhydrous Ethanol Production (gal/year) | **104,761,905** |
| **Project Engineering & Construction Costs** | |
| EPC Contract | $156,500,000 |
| Site Development including Water, NG, Electr | $10,295,000 |
| Rail | $4,518,000 |
| Grain Receiving and Storage | $10,072,000 |
| **Total Engineering and Construction Cost** | **$190,070,000** |
| | |
| **Owners Costs** | |
| Inventory - Feedstock | $4,479,000 |
| Inventory - Chemicals/Yeast/Denaturant | $1,000,000 |
| Inventory - Spare Parts | $100,000 |
| Startup Costs | $1,330,000 |
| Land | $792,000 |
| Other Owner's Costs | $0 |
| Administration Building & Office Equipment | $650,000 |
| Insurance & Performance Bond | $525,000 |
| Rolling Stock and Shop Equipment | $675,000 |
| Organizational Costs and Permits | $935,000 |
| Capitalized Interest & Financing Costs | $11,302,000 |
| Working Capital/Risk Management | $14,589,947 |
| **Total Owners Costs** | **$36,377,947** |
| | |
| **Total Project Capital Cost** | **$226,447,947** |

Source: BBI Estimates

**Yields:**

BBI estimates the ethanol yield of the installed plants to be 2.67 gallons of undenatured ethanol per bushel of corn. Assuming 5% denaturant, this equates to 2.80 gallons of denatured ethanol per bushel of corn. The DDGS yield is around 18 pounds per bushel at 10% moisture.

For state of the art new installations, the ethanol yield can go up to 2.7 gallons of undenatured ethanol per bushel of corn, with the DDGS yield decreasing to 17 pounds per bushel, depending on the starch content of the corn.

**Fixed Costs:**

BBI does not see significant differences in the fixed costs between the installed base and new installations. However, we assume that the majority of the installed plants that started up in or before 2003 are now debt-free. Table 2 below indicates the typical fixed costs for a 110 mmgy corn dry grind operating at 119 mmgy.

**Table 2 – Fixed Costs**

| **Administrative & Operating Expenses** | **$/gal** |
|---|---|
| Maintenance Materials & Services | $0.031 |
| Repairs & Maintenance, Wages & Benefits | $0.006 |
| Property Taxes & Insurance | $0.026 |
| Admin. Salaries, Wages & Benefits | $0.006 |
| Office/Lab Supplies & Miscellaneous | $0.004 |
| **Total Administrative & Operating Expenses** | **$0.072** |
| Interest - Senior Debt | $0.097 |
| Depreciation & Amortization | $0.114 |

Source: BBI Estimates

Table 3 below shows the depreciation schedules usually applied to ethanol plants.

**Table 3 – Typical Depreciation Schedule**

| | Depreciation Method (note1) | 2nd Year Operations |
|---|---|---|
| Major process equipment | 15 year SLN | 8,236,285 |
| Minor process equipment | 15 year SLN | 1,816,828 |
| Process buildings | 30 year DDB | 2,083,154 |
| Vehicles | 5 year DDB | 150,750 |
| Office building | 30 year DDB | 25,630 |
| Office equipment | 5 year DDB | 55,833 |
| Start-up cost | 20 year DDB | 125,242 |
| Annual capital expenditures | 10 year SLN | 0 |
| Total Depreciation | | 12,493,721 |

Note 1: Depreciation Method = DDB (Double Declining Balance) or SLN (Straight Line)

Source: BBI Estimates

**Operating Cost**

The existing plants will typically encounter operating costs as detailed in Table 4. New state of the art facilities will have slightly lower operating costs due to the more efficient use of natural gas – reducing the costs to 23.7¢ per gallon at an assumed natural gas cost of $8/mmBTU (29,000 BTU per gallon of ethanol). This number assumes that 100% of the DDGS will be dried.

**Table 4 – Operating Costs in $ per Gallon**

| | |
|---|---|
| Chemicals, Enzymes & Yeast | $0.067 |
| Natural Gas | $0.261 |
| Electricity | $0.029 |
| Denaturants | $0.102 |
| Makeup Water | $0.002 |
| Effluent Treatment & Disposal | $0.002 |
| Production Labor & Benefits | $0.012 |
| **Total Production Costs (excl. corn)** | **$0.475** |

Source: BBI Estimates

### Design, Construction and Start-up Time

The time from financial close to start-up of a new plant is between 14 and 20 months. Start-up usually takes 30-60 days, with the end of the start-up period being marked by the completion of the performance test, which indicates that the plant operates at least at nameplate capacity within the guaranteed performance parameters.

### Financing

Historically, most ethanol plants were able to limit the amount of equity required to around 40%. However, with capital costs increasing, lenders now require more equity. Most lenders cap the amount of debt at $0.90 per gallon of capacity, or $90 million for a 100 mmgy plant. At a $1.77 per gallon average all in cost for 2007, 50% would need to be raised as equity. The most recently financed ethanol plants raised around 50% of the total project costs in equity, and financed the remaining 50% at LIBOR (London Interbank Offered Rates, currently around 4.4%) plus 4% with a 10 year loan.

### Plant Life

The majority of the existing ethanol plants have been built since 2001, so there is only limited information available on the actual plant life of this latest generation of ethanol plants. Most major pieces of equipment are designed to last about 20 years, actual performance will depend on maintenance and other factors.

## IV. FUTURE OF THE DRY GRIND CORN ETHANOL INDUSTRY

BBI expects very few new ethanol plants to be built once the ones under construction are completed, due to the amount of ethanol produced (14 bn gallons) and the amount of corn used. Instead, we believe that the future of the ethanol dry grind industry will be driven by modifications to existing plants.

The most important trend that will continue in the future is the increased use of fractionation technology in dry grind facilities. Fractionation is the process of separating the components found in corn to produce different co-products, currently employed in five ethanol dry grinds. Traditionally, the starch is used to produce ethanol, and the remainder of the corn kernel ends up in the DDGS. Fractionation separates the corn fiber (bran) and germ (protein and oil) from the starch. Fractionation technology will reduce the amount of starch that is fermented by 3-5% due to separation losses. Fractionation can be done before fermentation, which increases the throughput of the fermenters, as a purer starch stream will be processed compared to a typical dry grind without fractionation. In addition, this front-end fractionation could easily yield higher value, food-grade products. The alternative is back-end fractionation, where the DDGS is further processed to remove components such as the oil that may have higher value applications than DDGS' typical use as animal feed, such as the production of biodiesel.

The separation of the fiber offers the opportunity to produce a limited amount of cellulosic ethanol from the corn fiber. Actual production will depend on the cost of and incentives for cellulosic ethanol production and the availability of alternative markets for the fiber such as dietary fiber. If cellulosic ethanol is produced, the yield per bushel of corn could increase by up to 10%.

In parallel, we expect advances in corn strain development to yield corn strains with higher starch contents. Currently, corn contains about 68% starch, and we expect that to reach 74% over the next 10 to 20 years. As a result, ethanol yields may reach over 3 gallons per bushel at 74% starch content (90% of theoretical limit) without the use of fractionation. Table 5 below compares the impact of fractionation and new corn strains on ethanol and co-product outputs.

We do not expect the use of biomass to increase significantly based on financial considerations. The capital investment required for the installation of a biomass burner and the logistics involved in collecting and transporting the biomass will rarely be more advantageous than the use of natural gas. However, future legislation providing incentives for reduction of greenhouse gas emissions and carbon footprints may make these investments more attractive.

Other technologies that reduce natural gas consumption are closer to commercialization and will continue to receive attention from the existing ethanol plants. For example, the cold cook process (raw starch hydrolysis) could reduce natural gas use by as much as 10-15%.

Yeast strains that are able to withstand higher solids concentrations are required for "high gravity fermentation", which can increase the concentration of ethanol to up to 25%, reducing energy use in the distillation process.

The biggest operating cost for dry grinds is the cost of corn (excluded from this analysis), followed by natural gas. Currently, natural gas futures trade on the NYMEX between $7.75 and $9.00 per mmBTU through 2010. We expect labor and electricity cost increase at the rate of inflationl, and enzyme costs to drop to 5¢ per gallon. We expect capital cost to return to around $1.50 per gallon in 2007 dollars, due to a drop in demand.

## Table 5 – Technology Overview

| Feedstock | Input - 56 lbs of Corn @ 13% Moisture | | | | Technology | Outputs (in Pounds) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Starch | Oil | Protein | Fiber | | EtOH | DDGS | CO2 | Bran | Protein | Oil |
| Current Corn Composition - In Percent | 68% | 5% | 7% | 7% | | | | | | | |
| Current Corn Composition - In Pounds | 38.1 | 2.8 | 3.9 | 3.9 | Current Standard | 18.47 | 19.06 | 18.47 | | | |
| | | | | | Fractionation | 17.71 | 9.95 | 17.71 | 3.92 | 3.92 | 2.8 |
| New Corn Composition - In Percent | 74% | 3% | 5% | 5% | | | | | | | |
| New Corn Composition - In Pounds | 41.4 | 1.7 | 2.8 | 2.8 | Current Standard with New Corn | 20.10 | 15.80 | 20.10 | | | |
| | | | | | Fractionation and New Corn Strains | 19.27 | 10.18 | 19.27 | 2.8 | 2.8 | 1.68 |

Source: BBI Estimates and Analysis

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**14. ABSTRACT** *(Maximum 200 Words)*
This subcontract report supplies timely data on the historical make-up of the corn ethanol industry and a current estimate of where the industry stands. The subcontractor used experience, contacts, and involvement in the dry grind corn ethanol industry and established an estimate of industry averages for new state-of-the-art mills. The subcontractor has also reported on the expected future trends of the corn ethanol dry grind industry. Capital costs for corn dry grinds have increased significantly with the recent building boom for new capacity but are expected to fall in the coming years due to an anticipated drop in demand. Once the plants currently under construction are completed, ethanol production capacity from corn will approach 15 billion gallons, which is widely regarded as the maximum feasible. Technological advances for the future will most likely see the adoption of fractionation technology by more plants, which will allow the production of higher value co-products than DDGS.

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