Industrial Crops and Products 56 (2014) 145–155

Contents lists available at ScienceDirect

Industrial Crops and Products

journal homepage: www.elsevier.com/locate/indcrop

# Techno-economic modeling of a corn based ethanol plant in 2011/2012

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ARTICLE INFO

*Article history:*
Received 29 July 2013
Received in revised form 24 February 2014
Accepted 2 March 2014
Available online 25 March 2014

*Keywords:*
Ethanol
Corn oil
DWG
DDGS
Economics

ABSTRACT

As studies continue to examine new value added uses for ethanol coproducts, it is important to easily determine the feasibility of the processing steps involved. This study observed the sensitivity of a corn-based ethanol plant model to changes in input prices and various coproduct processing. The simulations verified that corn price had the greatest impact on the overall annual operating costs for the ethanol plant, and that the market price of ethanol had the greatest impact on annual revenues. It was apparent that coproducts are an essential component to the sustainability of an ethanol plant in that: (1) they have continued marketability to the livestock industry, and (2) processing is not overly expensive. This study has provided a basis for further exploration of the feasibility of new coproduct processing options, and illustrates the use of the model for determination of processing costs and revenues, as well as mass and energy balances.



## 1. Introduction

In the past decade the United States ethanol industry increased production from 1.6 billion gallons in 2000 to 13 billion gallons in 2010 (RFA, 2011a). Between 2009 and 2010 alone, the US ethanol industry increased production by 743 million gallons, with an additional 840 million gallons expected from biorefineries under construction (Urbanchuk, 2011). During 2010 about 30% of the total American corn crop was transformed into ethanol (RFA, 2010a), which equated to 4.65 billion bushels of corn (RFA, 2011a).

The production of ethanol from corn begins with the breakdown of starch into useable sugars. In order for this to begin the corn must first be processed. A small portion of ethanol is produced by wet milling methods, which requires corn to be soaked for a time in order to assist with the separation of the germ from the fiber, gluten, and starch (which are then processed into ethanol). The predominant method of processing corn into ethanol is dry grind processing, where corn is ground and then the starch is transformed by enzymes into sugar, which is then fermented into ethanol by yeast (Singh et al., 2001). Dry grind is the preferred method as it requires less capital to build, a smaller staff to run, and has more flexibility (McAloon et al., 2000). More than 88% of the ethanol produced in the United States is produced using dry grind processing, while the remaining 12% is produced from wet milling process (RFA, 2010b). In both types of processing proteins, minerals, fat, and fiber are unprocessed as they are not fermentable. In the dry grind process, these non-fermentable co-products are generally in the form of distillers wet grains (DWG) or distillers dried grains with solubles (DDGS), while in the wet milling process they are in the form of corn gluten meal or corn gluten feed. RFA (2011b) reported that in 2010, around 32.5 million metric tons of these coproducts were produced, which is an increase of nearly 30 million metric tons over what was produced in 2000.

Somewhat variable, DDGS contains 86–93% dry matter, 25–35% protein, 3–14% fat, and 7–10% fiber (Bhadra et al., 2009; Ganesan et al., 2008; ISU, 2008; Kim et al., 2007; RFA, 2011b; Rosentrater and Muthukumarappan, 2006; Shurson and Alhamdi, 2008; Srinivasan et al., 2005, 2009; Weigel et al., 1997). This nutrient balance makes it valuable as an animal feed ingredient. Of the 32.5 million metric tons of DDGS produced in 2010, 80% was used for feeding cattle (beef and dairy), who can more easily utilize the nutrients within DDGS than non-ruminant poultry and swine whose industries utilized 9% and 10% respectively (RFA, 2010a). A small percentage of the DDGS market is comprised of other uses, including aquaculture feed, deicers, cat litter, lick barrels, and worm food (Bothast and Schlicher, 2005; Kannadhason et al., 2010; Rosentrater et al., 2009a,b; Schaeffer et al., 2009). Ongoing research is being done to find new, value-added uses and high-value applications for these coproducts (Rosentrater, 2007). For example, studies are being done on using DDGS as a human food ingredient (Rosentrater,

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http://dx.doi.org/10.1016/j.indcrop.2014.03.001
0926-6690/

2007; Rosentrater and Krishnan, 2006), and in the production of biodegradable plastics (Bothast and Schlicher, 2005; Tatara et al., 2006, 2007).

Most studies to find new uses for DDGS and other coproducts are done on a small scale (either bench top or in pilot plants). Many processes can be feasible at small scales, but determining their feasibility at a large scale can be tricky. At bench top or pilot scale, a few pennies may not make a big difference, but when scaled to a commercial scale, economic inputs can be increased by several orders of magnitude, and can have a huge impact on the feasibility of the process. For this reason, accurately predicting the cost of production prior to adding new technology to an existing large scale facility is important.

Computer based modeling and simulation allows for such economic predictions to be made, and permits planning for resources, for equipment capacities, and for the determination of required process parameters (Petrides et al., 2011). Modeling and simulating of processes is currently used in many domains, such as pharmaceutical production and waste water treatment (Akiyama et al., 2003; Prazeres and Ferreira, 2004; Petrides et al., 1998, 2002). During the 1960s, the petrochemical industry began to model and simulate industrial processes in order to optimize production capacities (Petrides et al., 2011). Simulation programs have recently began to be used in the biofuels industry as well; for example, ASPEN PLUS has been extensively used to simulate the transformation of corn into ethanol, and to perform cost analysis of the production biodiesel (McAloon et al., 2000; Rajagopalan et al., 2004). Similarly, a corn ethanol plant model was created with SuperPro Designer (Intelligen, Inc., Scotch Plains, NJ); which allows for the estimation of process and economic parameters of a typical 40 million gal/y dry grind facility (Kwiatkowski et al., 2006).

The Kwiatkowski et al., (2006) model was determined to have the ability to compare various process modifications to help researchers develop new technologies. In 2011 the model was updated by McAloon and Yee (2011) to reflect new processing technologies, but it was not used for simulation with actual market prices, nor were the sensitivities to pricing changes assessed. This study analyzes the behavior of this updated model to determine the model's sensitivity. Understanding how the updated model responds to changes in material and market prices, as well as changes in quantity of coproducts produced will set the foundation for future studies to utilize the model for determination of economic feasibility of new coproduct processing technologies.

## 2. Materials and methods

### 2.1. Computer model

SuperPro Designer (Intelligen, Inc., Scotch Plains, NJ) allows the processing characteristics (composition, retention time, temperature, pressure, power consumption, capacity), and equipment and economic parameters (size, power consumption, purchase price, operating cost, maintenance cost, and depreciation) to be defined along with volumes, composition, and physical characteristics for each stream. These characteristics are then used by the program to determine mass and economic balances for the individual unit operations and in turn the mass and economic balances for the entire process.

Kwiatkowski et al., (2006) created a 40 million gal/y ethanol plant model using SuperPro Designer (Intelligen, Inc., Scotch Plains, NJ) that allowed the user to estimate both process and economic parameters of a generic ethanol plant design. The model was not intended to replicate a specific plant design, but instead a generic plant design containing equipment and unit operations necessary to convert corn into ethanol. The model included grain handling procedures (conveyers, storage, cleaning, and milling), starch to sugar conversion (liquefaction and saccharification), fermentation, ethanol processing (distillation, ethanol recovery, ethanol denaturing), and coproduct processing ($CO_2$ scrubber, stillage centrifugation, conveyers, and DDGS dryer).

**Table 1**
Definition of simulations scenarios.[a]

| Treatment | Corn oil extraction (%) | Wet coproduct (%) | Material prices (year) |
|---|---|---|---|
| 1 | 1 | 1 | 2005 |
| 2 | 1 | 1 | 2011a |
| 3 | 1 | 33.33 | 2005 |
| 4 | 1 | 33.33 | 2011a |
| 5 | 80 | 1 | 2005 |
| 6 | 80 | 1 | 2011a |
| 7 | 80 | 33.33 | 2005 |
| 8 | 80 | 33.33 | 2011a |
| 9 | 1 | 1 | 2011b |
| 10 | 1 | 33.33 | 2011b |
| 11 | 80 | 1 | 2011b |
| 12 | 80 | 33.33 | 2011b |

[a] Year refers to the time period from which prices were used. 2011a refers to prices taken from the June 2011 model (McAloon A., and W. Yee, unpublished model, 2011. Wyndmoor, P.A.: USDA, ARS). DDGS and DWG market prices in the 2005 and 2011a scenarios were automatically determined by the software based on their protein concentration. In the scenarios identified as 2011b, DDGS and DWG prices were based on actual market prices at the time of simulation. Corn and ethanol prices were also adjusted in these scenarios so that all were taken from the same time period. Prices are defined in Table 2.

In June of 2011, McAloon and Yee updated the model by adjusting processing parameters and adding additional equipment (grain separator and corn oil extractor) to reflect new ethanol process technologies. They also updated the economic values of equipment and materials. The addition of a wet grain separator allowed the user to set how much grain was dried, which is more representative of the typical ethanol plants (39% of distiller's grains are marketed as wet); and the addition of an corn oil extractor provided opportunities to explore the economics of corn oil extraction from CDS (62% of plants extract corn oil (Reidy, 2012; RFA, 2011a)).

This paper utilizes these additional pieces of equipment to determine the sensitivity of the model to changes in coproduct processing (the change in quantity of oil extracted and the change in quantity of grains dried (Table 1)). Fig. 1 is a simplified flow diagram of the dry-grind ethanol process used within this paper (corn processing and handling has been excluded). The actual model developed by McAloon and Yee (2011) contains around 100 pieces of equipment and unit operations. Typical ethanol plants operate 24 h/day year round with scheduled down time for maintenance and repairs; for this reason the model is set up to operate on a basis of 330 days/y and all annual costs are associated with this operation. The processing characteristics (retention time, temperature, and flow rates); equipment parameters (power consumption and capacity), salaries, and costs (utility, material, and equipment) were updated from the original model and set by McAloon and Yee, based on published materials and typical salaries in rural America. In addition to updating this information, McAloon and Yee added a few coproduct processing pieces to the process: a corn oil extraction system and an option to extract DWG before being sent to the dryers. Although the model was updated, it was not utilized to assess any pricing or market scenarios, which was the objective of this study.

The information programmed into the model is used by SuperPro Designer to produce a variety of reports based on mass and economic balances. These reports were generated for each simulation scenario in this study and used to compare the economic feasibility and sensitivities of processing scenarios and material prices.