# *Advanced Biofuel Production in Louisiana Sugar Mills: an Application of Real Options Analysis*

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## Introduction

Risk and uncertainty are not new concepts to producers and processors operating in the agricultural sector. Over the years they have employed various risk management tools and strategies to help mitigate risk. Some of those tools are options and futures markets, marketing contracts, production contracts, crop insurance, and participation in governmental programs. These tools help them manage both input cost and output prices. A more difficult situation arises when producers and processors have to figure out how to manage uncertainty.

According to Knight (1921) and Chavas (2004) uncertainty occurs when *a priori* information about a probability distribution is unknown. Sources of uncertainty in agribusiness can be categorized into: Business/Operational, Financial, Market Conditions, Technology, Business Relationships, and Policy & Regulation (Detre et al., 2006). Tools and strategies for producers and processors to handle uncertainty are far less developed when compared to risk management tools and strategies. One method that has been gaining traction in many industries for evaluating uncertainty and which shows promise in the agricultural sector is Real Options Analysis (Dixit and Pindyck, 1994; Amran and Kulatilaka, 1999; Boehlje, 2003) . The objective of this study is to use Real Options Analysis to evaluate the uncertainty surrounding the development of the cellulosic ethanol industry in Louisiana, which has significant potential to produce biomass that can be converted to ethanol via the cellulosic production process.

For this industry to develop it is going to take a significant investment by cellulosic ethanol processors, in terms of both capital investments and long-term contracts with producers. Currently, the ethanol industry is receiving subsidies for the production of ethanol as well as protection, via tariffs from imports, and mandates. This makes ethanol production an attractive investment. These types of protectionary measures are typically used to help protect infant industries (Johnson and Runge, 2007). Historically, the infant industry argument has been made and accepted as an exception to the rationale for free trade (Sheldon, 2008). It is likely that, at some point in the future, typically when the industry has become economically viable, the subsidies, tariffs, and mandates will be removed. This introduces two additional sources of uncertainty for processor and producers interested in the Louisiana cellulosic ethanol market: 1.) When will the ethanol industry be deemed viable? and 2.) How will the removal of the subsidies and governmental protection occur?

Since cellulosic ethanol is currently not cost competitive when compared to conventional ethanol, potential processors are dependent upon these subsidies remaining in place, at least for the foreseeable future, until substantial gains in reducing input costs are achieved (Wyman, 2007). In recent years, subsidies were removed from biodiesel, even before it reached the maturity level of ethanol, which further compounds the uncertainty surrounding government support of the industry. Though the tax credit was later replaced, producing firms suffered from the effects of an uncertain future, and many shut down either temporarily or permanently (Gerpen, 2005).

The model developed in this paper can serve as a decision tool for processors who need to examine a variety of future scenarios to help them determine under what conditions they are willing to make an investment in the cellulosic ethanol industry. More importantly this model can likely serve as a framework for Real Options Analysis in other infant agricultural industries.

## Ethanol

Supplying the current and future market for renewable energy in the United States will require a large basket of energy sources from many different technologies. In the liquid fuels sector, ethanol has a large role to play and will have an increasingly important role in the next decade.

While the vast majority of this country's ethanol is currently produced from corn, this is by no means the only option. With the rise of cellulosic ethanol, many alternatives open up, including the production of fuel from sugarcane waste fiber. Additionally, ethanol can be obtained from sugar-bearing crops like sugarcane and sugar beets.

In February of 2010, the EPA finally concluded its years-long review of the original RFS and released its new standard, the RFS2. The long-term goals of producing domestic ethanol didn't change, and the short-term production targets were only changed modestly. However, there is one major change that is relevant to this study. Under the RFS, there is a category of biofuel called "advanced biofuel," a designation that includes ethanol from sugarcane juice. Since the RFS standards call for 21 billion gallons of advanced biofuels by 2022, and 16 billion gallons of that from cellulosic ethanol, that leaves a 5 billion gallon mandate for other advanced biofuels that could be filled by ethanol from sugarcane juice.

## Sugarcane

Of particular interest to Louisiana is the possibility of producing commercially-viable quantities of ethanol from sugarcane. There are several possible mechanisms by which this might be accomplished, but the two that have been most frequently explored are "juice" ethanol, obtained by fermenting high-sugar cane juice, and cellulose or biomass ethanol, which is obtained via an enzymatic process performed on the biomass portion of the crop.

While sugar-based ethanol is certainly an interesting possibility and a proven technology, cellulosic ethanol might be the most tempting prospect, due to the large quantities of bagasse (waste fiber) produced as a byproduct of the sugarcane milling process. This is one of the primary benefits of locating a cellulosic ethanol plant in Louisiana. This fiber is generally burned at the mill, producing enough steam power to make the plant energy self-sufficient, but there is usually 10-20% excess bagasse that must be disposed of. Since that bagasse currently has no value, using it to make ethanol represents a value-add to the mill.

It is not yet clear how cost-effective a cellulosic ethanol process would be using the full sugarcane stalk, but the biomass content of traditionally harvested varieties is not likely to be high enough for the ethanol produced to be an economically feasible product on its own. There are other varieties that are currently being developed that have much higher biomass yields however, and a full-plant cellulosic ethanol process may indeed end up being a viable option using some of these "energy cane" varieties.

These energy cane varieties represent a large risk for the farmer though, since they contain very low levels of sugar and could not therefore be efficiently ground for sugar production. In order for the farmer to actually be able to switch to energy cane, he would have to be able to generate as much revenue from the ethanol produced as he gives up in lost sugar revenue. Whether or not this could happen is dependent upon market prices for sugar and ethanol, as well as pricing strategies employed by biofuels producers, and the uncertainty in the market makes it unlikely that any farmers will switch to energy cane in the short term, at least until the production technology is proven. This presents a problem for a processor who is interested in building a cellulosic ethanol plant, as no viable feedstocks will be available for processing in the short term. The planting cycle for all cane varieties means that a processor would likely be stuck with the current low-biomass varieties for at least one or two years, and possibly longer.

To guarantee a ready feedstock supply from a risk-averse producer, a hypothetical cellulosic ethanol plant would have to guarantee revenue that is at least equal to that which the producer would have made had his energy crop acres stayed in sugarcane. Because of the long planting cycle of all sugarcane varieties (including energy cane), the processor will have to contract for the energy cane at least four years before he intends to produce any ethanol from the new crop, and seven years before he intends to be producing at full capacity. The planting cycle for cane can be seen in Figure 1.

Until then, sweet sorghum offers an additional route of feedstock diversification. As an annual crop, it represents less of a commitment to the producer and is something that can be contracted for on a yearly basis. Further, sorghum stocks could potentially be added to the plant's input stream starting in the first year, given its short lifecycle. Sweet sorghum growth in south Louisiana has not been studied quite as much as energy cane has, but there is enough to suppose that it could be a reliable energy crop. (Viator et al., 2009).

## The mill

If a small cellulosic ethanol plant were available at the sugar mill, ethanol could be produced from some or all of the on-site bagasse, which would not affect the raw sugar or molasses generated by the mill. Given a representative mill that grinds 12,000 tons of cane per day during the harvest season, about 15,000 gallons of ethanol could be produced per day from the mill's excess bagasse (Day, 2010). This would represent about a 6 million gallon annual capacity, if the bagasse were available year-round. If all of the onsite bagasse were used to make ethanol, this figure would be 85,000 gallons daily, or 30 million annually. In the latter scenario, power would have to be generated via some other boiler fuel, such as natural gas. If the ethanol generated from this process had a higher value than the deferred cost of boiler fuel that comes from burning the bagasse, then the ethanol plant would be able to generate added value from the same sugarcane harvest that it already sees. If only the excess were made into ethanol, the entire process would be a value-add, though external feedstocks are required in order for the plant to reach commercial levels of production.

For this research, the initial plant is modeled as a 10 million gallon plant capable of running on 100% bagasse if necessary, but with a preference to run on a combination of bagasse and harvested feedstocks. Based on existing corn ethanol plants and on NREL models for cellulosic ethanol, a full-size plant producing commercially-viable quantities of ethanol is also designed, with an annual capacity of 70 million gallons. This is modeled separately, as an expansion to the smaller plant. The risk portfolio for the mill changes significantly when switching between these two plants for two major reasons. Firstly, the smaller plant can run strictly on bagasse if necessary, while the larger plant must have a ready supply of energy crops or other non-bagasse feedstocks in order to run profitably. Secondly, the sugar mill with the smaller collocated plant still draws most of its revenue from sugar, limiting its exposure to the volatility of the ethanol market, while the larger capacity plant would mean that the facility's largest revenue stream will be from ethanol.

## Dealing with Ethanol Market Uncertainty

Producers in the agricultural sector deal with risk and uncertainty on a daily basis. They use futures and options markets to help truncate downside risks. These risks and uncertainties are then passed on to upstream firms that further process these commodities. A perfect example of the uncertainty faced by producers took place in 2008 as floods in Corn Belt destroyed significant corn acreages and corn prices increased from \$2.00 per bushel to over \$6.00 per bushel. As a result, of this many ethanol producers went from a financial position of paying off a new ethanol plant in six months to some of the ethanol plants entering bankruptcy. One method of examining the risk of capital investments is the usage of net present value (NPV). Previously, a net present value analysis was conducted to determine if a sugarmills would benefit from additional revenue streams from ethanol from sugar or converting the bagasse into ethanol. However, a downfall of NPV analysis is that it fails to accurately capture the economic value of investments in an environment of widespread uncertainty and rapid change.

This is exactly what sugarmills will be facing as they consider the production of ethanol to increase the number of revenue streams for the business. Therefore, we propose a real options approach to examine the incorporation of an ethanol facility into the primary sugar milling business. This approach allows the manager of the mill to determine the proper timing of the expansion given widespread uncertainty in this infant market.

## Why Real Options?

Walters and Giles (2000) state that, while real options analysis (ROA) has some features in common with classical NPV analysis, ROA is valuable, “when investment involves an irreversible cost in an uncertain environment. And the beneficial asymmetry between the right and the obligation to invest under these conditions is what generates the option's value.” In the case of the collocated ethanol plant, there is a clear place where this decision point can be examined. If a cellulosic ethanol plant is going to produce ethanol at a capacity that relies on energy cane, it must first contract for the crop and wait for a productive quantity to be available for harvest. Given the long production cycle of sugarcane (and thus energy cane), this effectively translates to a four year lag between contracting with the growers and having enough cane for the intended plant to run in a cost-effective manner. Given an assumed two year build time for the modeled ethanol plant, this gives us a two year window to observe the market and decide whether or not to build the plant.

Translated into real options analysis terminology, this means we've got a European Call option to build with an expiration date two years from contracting, a price equal to the amount needed to enter into the contract, and an exercise price equal to the cost of building the ethanol plant. For ease of demonstration, we have previously modeled the facility as a representative Louisiana sugarmill with a small-scale (10 million gallon/year) ethanol plant located onsite which is capable of running strictly on available bagasse if necessary. The operational decision will be whether or not to expand this pilot plant to a full-scale cellulosic ethanol facility with an annual capacity of approximately 70 million gallons, which could only be sustained if there is significant local production of energy cane.

## Objectives

The objective of this research is to develop an analytical framework that can be used to study the potential to collocate cellulosic ethanol processing capabilities within a Louisiana sugarmill in an environment of both risk and uncertainty, and to present an alternative valuation method that may help decision makers understand the value and risks contained within different economic opportunities.

The framework should have general value for various types of production and processing facilities, but for this research the crops studied are sugarcane, energy cane, and sweet sorghum. Sugar is the most reliable source of profit for the sugarmill, and as such it will not be examined for processing into ethanol. Previous research has shown that, given the relative sugar and ethanol prices, it is unlikely that sugar juice from sugarcane could be profitably turned into ethanol, nor could the primary sugarcane co-product, molasses.

## Initial Plant

The fibrous sugarcane byproduct, bagasse, can be processed into ethanol using a cellulosic process, a process which could also be applied independently or jointly with other available or potential sources of biomass. It is this step in the processing cycle that we are primarily interested in. Specifically, this research examines the possibility of collocating a cellulosic ethanol processing plant at the same site as a sugar mill, to run initially on the excess bagasse from the sugar mill. The mill could also potentially run additional fibrous feedstocks through the grinders and make ethanol from the biomass, and even run sugar juice and/or molasses through the latter part of the ethanol facility to make conventional ethanol. Depending on the particular situation, this research might also be applicable to other regions that grow and process high-biomass crops, such as grain or forage sorghum, miscanthus, switchgrass, and possibly fast-growing tree species.

To begin with though, no specially-harvested energy crops will be included in the model, only bagasse. The potential benefits of collocating a cellulosic ethanol plant include reduced transportation costs when using on-site bagasse, fully-established transportation and unloading systems, and the ability to reuse some capital like grinders and storage.

After the first year, it is assumed that the plant will be able to attract a small number of producers, so some production of sweet sorghum and energy cane begins to take place. To fill out the 10 million gallon capacity of the small initial plant, under 10,000 acres of energy crops are required, given average expected yields.

## The Expansion Decision

In the research that immediately preceded this work, it was shown that this 10 million gallon plant is, given expected output parameters, a project worth considering. The downside risks are relatively low, even given various shocks to the output parameters, and the existence of a backup feedstock like bagasse means that the plant is also fairly insulated from shocks to the input parameters.

However if the plant wished to expand to a more commercially-standard capacity like 70 million gallons, some of the advantages disappear, and the plant becomes a more vulnerable venture. With ethanol revenue approaching or exceeding that from sugar, the entire mill is more exposed to the market and production conditions. The decision to expand carries with it unique risks and uncertainty, in addition to very large potential benefits.

It is this decision that the current research is focused on. A commercial cellulosic ethanol plant is subject to significant levels of uncertainty from many different areas, and of many different types. This research cannot study all possible sources of uncertainty, but will instead cover a small number of the most significant sources.

Given this uncertainty, the firm has incentive to delay the final decision as long as possible. However, in order to ensure that the plant, after the two year construction time, has enough ready feedstock to be able to begin recouping its construction costs, the mill must make one other decision prior to the final decision to build the plant. Specifically, the mill must decide to contract with energy cane producers to plant significantly larger amounts of energy cane two years prior to the beginning of construction, which results in planting beginning one year prior, and capacity being a roughly the break-even amount during the expansion's first year of operation.

In ROA terms, contracting with the growers for this new higher quantity is the equivalent of buying the option to expand capacity. If, during the intervening two years between writing the contract and needing to start construction, market conditions or production parameters change significantly enough that the expected value of the expansion project turns negative, the mill can "let the option expire" by simply not beginning construction. The mill's losses are equal to whatever it cost to contract with the growers for the expanded quantity. If the mill instead decides to exercise the option by building the plant, the potential losses could be much higher. The value of the option (to build or not build) is essentially represented by the value saved by letting the option expire in a down market instead of building and taking larger losses. If expected conditions are positive, then the mill will exercise the option, and the value of the project follows the same value path as traditional NPV analysis. For this reason, only negative shocks will be studied in this research.

In order for the real option to have value, there must be a significant chance that unexpected negative market or production conditions could arise in the years between buying and exercising the option. Since uncertainty is, by its nature, unpredictable, a large range of potential negative shock chances will have to be considered.

The risks and uncertainty facing potential cellulosic ethanol producers are an area of research that needs to be explored further. The goal of this research is to model some of the uncertainty facing a collocated plant using simulation techniques, and then explore some sources of uncertainty to learn more about how they might affect the business decisions facing the plant. The following are the objectives of this paper:

1) The primary objective of this paper is to develop a simulation model of a sugarmill collocated with a cellulosic ethanol plant capable of running on bagasse, energy cane, sweet sorghum, and other cellulosic feedstocks.
2) Additionally, an expansion to this mill is modeled, bringing the capacity up to commercial scale.
3) Using this simulated mill, test the response to uncertainty in production parameters and market conditions. Using Real Options Analysis, explore the decisions faced by the operators when negative market shocks are randomly incorporated.

Louisiana sugar mills are one set of stakeholders that would be interested in this research, for several reasons. If building an add-on ethanol processing facility would be a profitable endeavor that would pay for itself and provide additional revenue streams, this would interest any mill owner or cooperative seeking to increase profits. Not only could revenues be increased during the traditional sugarcane harvest season, but if other feedstocks were brought in during different periods of the year, the mill would be able to increase the period over which it has cash inflows. Additionally, the added revenue stream could diversify risk across multiple commodities and spread fixed costs out.

But the uncertainties inherent in the decision to expand to commercial capacity are daunting, especially to a sugar mill faced with the potential reality of having ethanol become its primary revenue source. Real options analysis can help make the strategic decision a simpler one to understand.

Sugarcane farmers are another group likely to be interested in this line of research. Sugarcane acres in Louisiana peaked in 2000 at 465,000, but since then have been decreasing by an average of two percent annually, as shown in Figure 2 (USDA, 2010). Additionally, revenues from sugar have been decreasing, as have earnings-per-acre (Salassi and Deliberto, 2006; 2007; 2008; 2009). The price of sugar did spike in 2009, but there is no guarantee that it will stay elevated for long. Expanding into the ethanol feedstock market would leave sugarcane farmers less exposed to changes in the market price of sugar.

## Literature Review

There are several areas of the literature that are important to understand in order to proceed with developing a methodology for this study.

### Net Present Value

One of the measures by which the tested scenarios will be analyzed is their Net Present Value (NPV). NPV analysis is a technique that is used to determine the total value of a project in present cash value, which is arrived at by subtracting initial cash outlays from a discounted set for cash flows from the project. The model looks like this:

$$NPV = \sum_{n=0}^{N} \frac{F_n}{(1+d)^n} = F_0 + \frac{F_1}{(1+d)^1} + \frac{F_2}{(1+d)^2} + \cdots + \frac{F_N}{(1+d)^N}$$

Where

$F_n$ is the net cash flows that can be realized each year

$F_o$ is the initial cash outlay

N is the planning time span

*d* is the discount rate

The cash flow from each year is discounted to its present value, and all of these values are added, along with the negative cashflow from the initial setup costs. If this value is positive, the investment is acceptable. If negative, it's not acceptable, and if zero it is indifferent. The size of a project's NPV can also be used to ranking it against rival projects (Barry, et. al., 2000). By using this tool we can, for instance, determine whether a collocated ethanol facility would be a better investment than a similarly-structured stand-alone facility. This will be used for several such comparisons throughout this study.

However, NPV and the Discounted Cash Flow (DCF) methodology underlying it suffer from two basic problems that prevent them from being the primary method by which we analyze this facility. Firstly, DCF is deterministic with respect to its input values. As such, NPV analysis alone cannot incorporate the risks inherent in the real-world probabilistic inputs. To address this, a researcher can vary some key inputs by fixed amounts, which amounts to a sensitivity analysis. Or, taking this a step further, the input values can be allowed to vary randomly over some distribution, and the problem can be analyzed over thousands of such random drawings. Monte Carlo simulation is an effective tool to accomplish this.

DCF and NPV analysis also assume a fixed path for decision makers. Because the technique does not allow for management flexibility, it necessarily simplifies what could be extremely complex multi-stage decisions into a simple progression of actions. This inability to react to changing conditions by reanalyzing decisions or even breaking them into multiple stages is a weakness than can be addressed by the use of Real Options Analysis (Kodukula and Papudesu, 2006).

## Simulation

The immaturity of the cellulosic ethanol industry presents a data-availability problem that puts some quantitative methods out of reach. However, this problem is ideally suited to the application of simulation techniques. Additionally, simulation methods can help account for random variation in input variables. Basic NPV analysis assumes that input values are deterministic and free of random variations. Given the nature of most real-world business decisions however, actual inputs are generally probabilistic and can randomly take on large ranges or distributions of values. Monte Carlo simulation is a technique via which an analyst can examine the behavior of a system over a very large number of such values (Boyle, 1977). And as Rose (1998) says, "Monte Carlo simulation can be used to value complex real options whose payoffs are dependent on a project's cash flows," which is exactly how such simulation techniques are used in this model.

Richardson, Klose, and Gray (2000) provide a framework for how to handle some of the challenges of agricultural simulation models. A major issue with agricultural data is the availability of data collected while the same operational conditions apply. Such conditions include policy regimes, management practices, and farm or processor practices. Richardson (2002) indicates that 20 or more comparable observations are needed to show a distribution is normal, something not likely to be possible for most of the agricultural data for this study. Additionally, to account for the likely correlation of two or more random variables, a multivariate empirical (MVE) distribution will be needed (Richardson and Condra, 1978). While Richardson, Klose, and Gray (2000) suggest that the MVE distribution would be a good approach for those variables for which there is at least a moderate amount of data, a triangular or GRKS distribution is ideal when presented with sparse data, as in Louisiana molasses prices.

## Real Options Analysis

A real option can be defined as "a right – not an obligation – to take an action … on an underlying non-financial asset at a predetermined cost on or before a predetermined date" (Kodukula and Papudesu, 2006). Purchasing a real option (by making some investment) essentially guarantees the purchaser the exclusive right to a particular price for some asset or project. In the absence of the initial investment, the project would either be impossible, or available at a significantly different price.

If conditions do not change between the purchase and exercise of an option, then the outcome is the same as if the situation were a predetermined path as is assumed in NPV analysis. However, "Between now and the time of decision, market conditions will change unpredictably, making one or the other of the available decisions better for us, and we will have the right to take whatever decision will suit us best at the time" (Howell et. al., 2001).

According to Courtney (2001), a growth option is one which grants the firm the right to capture future upside potential via expansion, and a learning option is one with grants the firm the right to postpone a future investment until more information is available. The expansion option studied in this research is a combination of these two option types. In using a real options approach, this model provides a better idea of how a flexible plant manager would actually react to new information gained between the purchase of the option to expand and the exercise (or expiration) of that option. DCF and NPV analysis "mechanistically discount back expected cash flows, while ROV [Real Options Valuation] starts at the end of the decision tree and works back one decision at a time, always asking, 'What would an intelligent manager choose to do at this point given the flexibility to reoptimize?'" (Courtney, 2001).

## Sensitivity Analysis

When developing a linear programming model or a simulation model, assumptions are made about some of the parameters in order to solve the model within the specified constraints. In reality, these assumed-known parameters are simply predictions about future states. To account for the fact that these predictions cannot actually be relied upon, some tests should be conducted to see how the model might be affected if some of these parameters took on other values. According to Hillier and Lieberman (2005) sensitivity analysis serves exactly this function. Conducting such an analysis on the various models built in this research will demonstrate which variables cannot be changed without changing the solution. It will also show over what ranges other variables can vary without affecting our model solutions. This is valuable not only to show which variables must be watched most closely, but also to show how robust the model is to changes in certain market conditions, or how vulnerable. In addition, sensitivity analysis can provide a more complete picture of the value of a real option and its robustness to various parameter shocks.

# Data and Methodology

The hypothesis that we want to test is whether or not a sugarcane mill with a built-in cellulosic ethanol plant could profitably use real options analysis to help make strategic decisions about future production capacity in an environment of uncertainty.

Since no such mill exists, the first goal is to build a simulation model to approximate the operations of a sugar mill with a collocated cellulosic ethanol plant of small scale. Additionally, a simulation of a commercial-scale expanded cellulosic ethanol facility will be added on to the initial model. This facility will have the capability to process cellulosic feedstocks into ethanol.

The time period studied will cover 25 years, the limit of EIA's forecasts for some important inputs like natural gas and crude oil. Some factors affecting the mill's performance are given in Appendix A.

The entire mill and ethanol models are built in Microsoft Excel, and Simetar is used for all simulation operations. The MVE model is made up of prices and yields for sugarcane, as well as ethanol and oil prices and yields for energy crops. Molasses data is sparse, so a GRKS distribution is employed. Commercial-recoverable sugar (CRS) is simulated using an empirical distribution built from 20 years of historical data. Following Salassi (2008), the actual formulas driving the mill simulation are:

$$\text{GROSS PROFIT} = \text{SALES} - \text{COST OF SALES} \tag{1a}$$

$$\text{NET INCOME} = \text{GROSS PROFIT} - \text{FACTORY EXPENSES} \tag{1b}$$

The supporting equations are given in Appendix B.

The outputs of the mill are raw sugar, molasses, ethanol, and bagasse. The operations of the mill itself are based on existing mills, with data gathered from personal interviews (Schudmak, 2009) and production studies (Salassi and Deliberto, 2010). On the output side, sugar and molasses prices come from ERS, bagasse prices are taken from NREL, and EIA supplies ethanol prices. Natural gas prices come from EIA and prices for energy crops are based on prior studies about crop pricing strategies for energy cane.

The forecasted yields for sugarcane, energy cane, and sweet sorghum follow the basic formula relating yields to the price of fertilizer. Natural gas is used as a proxy for nitrogen fertilizers since sufficient projections are available from EIA. Additionally, the yields were found to have an AR(1) autoregressive process, so a single lag was used, in addition to a time trend. Thus the equation takes the following form:

$$Yield_t = f(Yield_{t-1}, t, Natgas_t) \quad (5)$$

Ethanol prices are forecasted using an AR(1) process as well. In keeping with historical trends, ethanol price was found to be closely correlated to that of oil. Since EIA maintains projections of the price of oil, it was possible to incorporate that into the forecast equation. The formula takes the following form:

$$EthanolPrice_t = f(EthanolPrice_{t-1}, t, CrudeOilPrice_t) \quad (6)$$

With the full simulation model, several different issues can be examined. A sensitivity analysis is used to examine how the mill is affected by changes in transportation costs as well as the expected prices of sugar and expected production costs for the different energy crops.

The second objective is to simulate an expanded commercial-capacity cellulosic ethanol plant and incorporate this into the initial plant simulation. This cellulosic ethanol plant, like the smaller initial plant, will be modeled on existing plant data from Aden (2002) and Holcomb (2009) and some of the process parameters come from personal interviews (Day, 2010).

Due to the varied nature of the feedstocks involved in the cellulosic ethanol plants, some assumptions must be made about acquisition strategy. For the initial plant, it is assumed that, after the first full year of production, it will be possible to begin contracting with growers to produce energy crops. Production of sweet sorghum, an annual crop, begins in the second year. Planting of energy cane also begins in the second year, but no cane is delivered until the fourth year. To fill out the initial 10 million gallon capacity plant, the operator can run entirely on stored bagasse for the year, but if it is assumed that bagasse is readily available for one quarter of the year, then 3,500 acres of sweet sorghum and 5,000 acres of energy cane are enough to supply the rest of the year's feedstock demand, given average expected yields for both crops. The model reacts dynamically to stochastic energy crop yields by adjusting the quantity of bagasse purchased or fiber stored. Low yields stimulate the plant to buy additional bagasse from other sugar mills, and higher yields result in excess fiber being stored for up to 6 months.

For the expanded 70 million gallon plant, the feedstock assumptions change slightly. At that capacity, there would not be enough excess bagasse in the entire state to fill out an entire year's worth of production, so the plant will be much more dependent on the harvested feedstocks. Given expected yields, 20,000 acres of sweet sorghum and about 35,000 acres of energy cane should provide enough fiber for the plant to run at between 70% and 85% capacity, and the remaining capacity is assumed to be filled with onsite and purchased bagasse, of which there should be sufficient quantity to produce at or near full capacity during a normal year.

The option to expand the plant to the 70 million gallon capacity is a European call option to expand. The purchase price will be discussed below. At time of exercise, the value of the basic option can be given by:

$$V = \max\{0, S - X\} \tag{7}$$

Where $S$ is the value of the underlying asset, which is the revenue stream generated by the expanded plant, and $X$ is the exercise or strike price, which is the cost of building and operating the expansion. This term, $S$ - $X$ is effectively the net present value of the expansion at the time of the expiration of the option. Given that a smaller version of the plant already exists at the time of exercise, the actual value of the expansion option for a given simulation iteration *i* is given by:

$$ROV_i = NPV_x - NPV_o \quad (8)$$

Where $NPV_x$ is the value of the expanded plant and $NPV_o$ is the value of the original plant, both calculated at the time of expiration. The option is considered in the money if the value is positive. Since the value of the ROV is driven by the underlying NPV model, this value can be simulated over thousands of iterations and the mean and standard deviation analyzed over different scenarios and parameter assumptions.

The option price or premium is the irreversible investment made to purchase the right to buy the underlying asset. In this case, in order to be able to profitably build and operate the expanded ethanol plant, the operator must contract with growers of energy cane two years prior to the start of construction, which is the expiration date of the option. The cost of this contract is the option price. Given the high level of risk inherent in planting a perennial crop with no alternative market, the risk premium to convince growers to commit large amounts of land to energy cane should be very high. Based on existing contracting habits, it is assumed that the growers will have to be guaranteed at least the same level of expected revenue that would have been realized had they planted their acreage with sugarcane instead of energy cane. For this reason, the contract takes the form of a guaranteed payment over the contracted period equal to the greater of the present value of the energy cane revenue or the present value of the sacrificed sugarcane revenue. If the option is not exercised, the grower will cease production of the energy cane and return all contracted acres to sugarcane, which the mill will buy, realizing a small revenue stream from the resulting sugar. So the option price takes the following form:

(9)

$$O = \begin{cases} PV\left\{\sum_{t=1}^{n} PriceEC_t * QuantityEC_t\right\}, & if\ exercised \\ PV\left\{\sum_{t=1}^{n} PriceSC_t * QuantityTSC_t - \sum_{t=3}^{n} RevenueMSC_t\right\}, & if\ not\ exercised \end{cases}$$

Where

*n* is the length of contract (seven years in this example)

$PriceEC_t$ is the price of energy cane in period t

$QuantityEC_t$ is the quantity of energy cane harvested in period t

$PriceSC_t$ is the price of sugarcane in period t

$QuantityTSC_t$ is the total quantity of sugarcane that would have been harvested in period t if the total acreage had been in sugarcane from period 0

$RevenueMSC_t$ is the sugar revenue realized on the marginal sugarcane grown at the end of the contract from the acres that were contracted for energy cane

## The Shocks

In previous research it has been shown that a collocated mill of this sort facing the assumed production parameters and market conditions will always show a positive NPV in the absence of some exogenous shocks to the system. Given that situation, studying positive shocks to the system is of little value as the expansion option will always be exercised and the ROV will be zero. Instead, three different types of negative shocks have been designed to study this real options problem:

1. The price of oil significantly underperforms relative to market forecasts
2. The direct federal ethanol subsidy is eliminated
3. The price of sugar significantly exceeds expectations

If any of these shocks happens between the time at which the expansion option is purchased and the expiration date of the option, it could significantly change the value of the project and could change the decision from a "yes" to a "no." Cheap oil would significantly depress the price of ethanol, thus decreasing revenues and profits of the plant. The elimination of the subsidy, which takes the form of a direct payment to blenders of ethanol, would result in a lower price of ethanol paid to producers. Finally, if the price of sugar skyrockets, the price that the plant would have to pay for energy cane would also climb steeply, increasing production costs and decreasing profits.

Because there is no information that could dictate the probability of any of these shocks occurring, they are each modeled over a range of possible probabilities. The binary values that trigger the shocks are then simulated using a Bernoulli distribution, following Richardson (2002).

## Results

In the base case, the probabilities of each of the three shocks are set to zero, and so the scenario only analyzes the basic risks inherent in agricultural production and commodity distribution, but no uncertainty in market conditions. In this base case, the Monte Carlo simulated model produces a baseline NPV of $149.4 million, with a range of $115 million to $183 million. The full results for the base case are in Table 1.

Because each of the three tested market shocks are truly uncertain, the shocks were examined at five different levels of likelihood: 5%, 25%, 50%, 75%, and 95%. Because the pattern was found to be consistent across all five levels, only one is presented in full detail in Table 2. For this, the 25% likelihood case, there are three relevant numbers for each shock. One, the No-Option value, represents the value of the project when it is considered from the non-flexible vantage-point offered by traditional NPV analysis, and can be found on Table 2(a). The second value is found on Table 2(b), and is the value of the project when management is able to be flexible and allow the option to expand the plant to expire if market conditions change between the option purchase and expiration date. Finally, Table 2(c) has the summary statistics for the differences, which describe the value of the real option to expand or not.

From these tables, a simple picture can be seen. Firstly, each of the shocks greatly reduces the overall value of the project from the base case, which is to be expected. Each shock is designed to negatively impact the simulated plant either by decreasing the value of its revenue streams or increasing the costs of producing them. In the case of the oil price shock, the No-Option case has a value of $114.6 million, while the ROA case has a value of $121.1 million. As Table 2(c) shows, this means the real option itself has a value of $6.5 million, or stated another way, the plant would be willing to pay up to $6.5 million dollars to gain and preserve the flexibility to NOT build the plant if market conditions change. In addition, the coefficient of variation of the simulated values decreases from 54.6 to 41.8 by using the ROA strategy. So not only is the project more valuable when flexibility is incorporated, it also has a lower variability in value.

For the sugar price shock, a similar picture is seen. The No-Option value is $121.8 million, the ROA strategy value is $132 million, and the value of the real option is $10.2. Also like the oil shock case, the variability of the value drops, from a CV of 40.3 to a CV of 24. The somewhat surprising result comes from the case of dropping the federal ethanol subsidy. As mentioned earlier in the paper, it was assumed that 100% of the cost of the lost subsidy would be passed on to the ethanol producers, so this plant is assumed to be feeling the full brunt of that policy change. However, the results show that this shock causes the project to lose the least value from the base case. And more importantly, the value in the No-Option case is higher than that of the ROA strategy case, at $133.8 million versus $124.4 million, giving a real option value of -$9.4 million. This negative value implies that the correct value strategy will always be to build the expansion plant, regardless of whether or not the ethanol subsidy is dropped between the purchase of the option and its expiration. In addition, the variability in value is lower for the No-Option case, so based on this criterion, it is again always optimal to build the plant, regardless of the shock state. Put another way, if the only expected source of uncertainty were the state of the ethanol subsidy, the plant would not be willing to pay anything to gain and retain the flexibility to not build the expansion.

Tables 3(a) through 3(c) have the data for the 25% shock probability case arranged by each shock. Values from the cumulative probability distribution (CDF) for the NPV are also summarized, and an interesting picture appears for the oil price shock. As expected, the values above 25% are the same for the Option and Build (no option) cases, and below 25%, the Option case values are much higher. The unexpected thing is what happens right at 25%, where the value of the Build case is actually higher. What this essentially says is that the Build case has a much more severe downside than the Option case, and the overall mean expected value is lower, but it does bounce back very quickly as you move from worst-case to best-case scenarios, and in fact does so more quickly than the Option case. This suggests that the model is extremely sensitive to oil prices, and that care should be taken with respect to forecasting those prices and analyzing the uncertainty around them.

Finally, Table 4 has the real option values for each shock across each level of likelihood. The pattern is consistent across all levels. The value is positive and increasing with probability for the oil and sugar price shocks, and negative and decreasing for the ethanol subsidy shock.

## Summary and Conclusions

The essential goal of this research was to determine whether or not real options analysis could be useful to the study of advanced biofuel production under conditions of uncertainty. The base plant used was a cellulosic ethanol plant collocated with a sugar mill in south Louisiana. The real option tested was an option to expand capacity by contracting for additional guaranteed feedstock and then deciding whether to build two years later.

The other goal of the research was to put the real options strategy to the test by introducing some sources of uncertainty into the model. In order to test the plant's response to uncertainty in market conditions, we tested three different shocks that seem like plausible candidates for market disruption. Shocks to oil prices and sugar prices both worked as expected, sharply reducing the value of the project while also showing a strong positive value for the use of the real options strategy. However, the tested scenario in which the federal ethanol subsidy was completely taken away showed a quite different picture. This shock reduced the value of the project far less than the other two, and the option to not build proved to always be the wrong strategic move. On the one hand, this scenario proved that using a real options analysis approach is not necessarily a better method of strategic decision making, or at least that an analyst must be very careful about examining trigger values before developing decision strategies. On the other hand, this scenario also lends itself to a very interesting interpretation with regard to renewable energy policy. It has been strongly argued by interested parties that the ethanol industry needs subsidies and other government support due to its status as an infant industry, and this argument seems to apply even more to the far-newer sub-industry of cellulosic ethanol production. However, given the assumptions in this model, it appears that at least one federal ethanol policy, the blender's per-gallon credit, is not actually needed for an ethanol producer to be able to operate profitably. There are other direct and indirect supports for the industry that were not tested, but the blender's credit is the one that is easiest to understand and dismantle, as it is a simple per-gallon credit. This finding does not mean that the credit is necessarily unneeded, of course. It may well be that the loss of this credit would negatively impact the industry somewhere further down the supply chain, or would have some sort of transformative effect on the supply and/or demand functions of the industry. But in the limited scope of this study, the findings do indicate that the blender's credit is not likely to be a decision point upon which cellulosic ethanol producers' strategic choices should turn.

Further study needs to be done on other sources of uncertainty, especially where policy decisions are concerned. If the blender's credit really doesn't have a large impact on the production of ethanol, other energy and fuel policies might bear closer examination as well. In addition, other types of options need to be explored. In the current model, the plant operator has a single decision window of about two years, in between signing the contract and starting construction. In reality, the operator would thereafter have a continuous series of decisions about whether to stay in operation, temporarily shut down, or close the plant and sell off assets. These decisions can also be represented by real options, and hence could change the value of the project under certain scenarios. Other possible options might arise if the use of energy cane were less restrictive. As it stands now, energy cane could profitably used only for the production of cellulosic ethanol, and so all contracting decisions hinge on ethanol production. If however, there were alternative uses for the crop, each decision would grow more complicated, and the value of contracting would likely change depending on the relative value of alternative uses.

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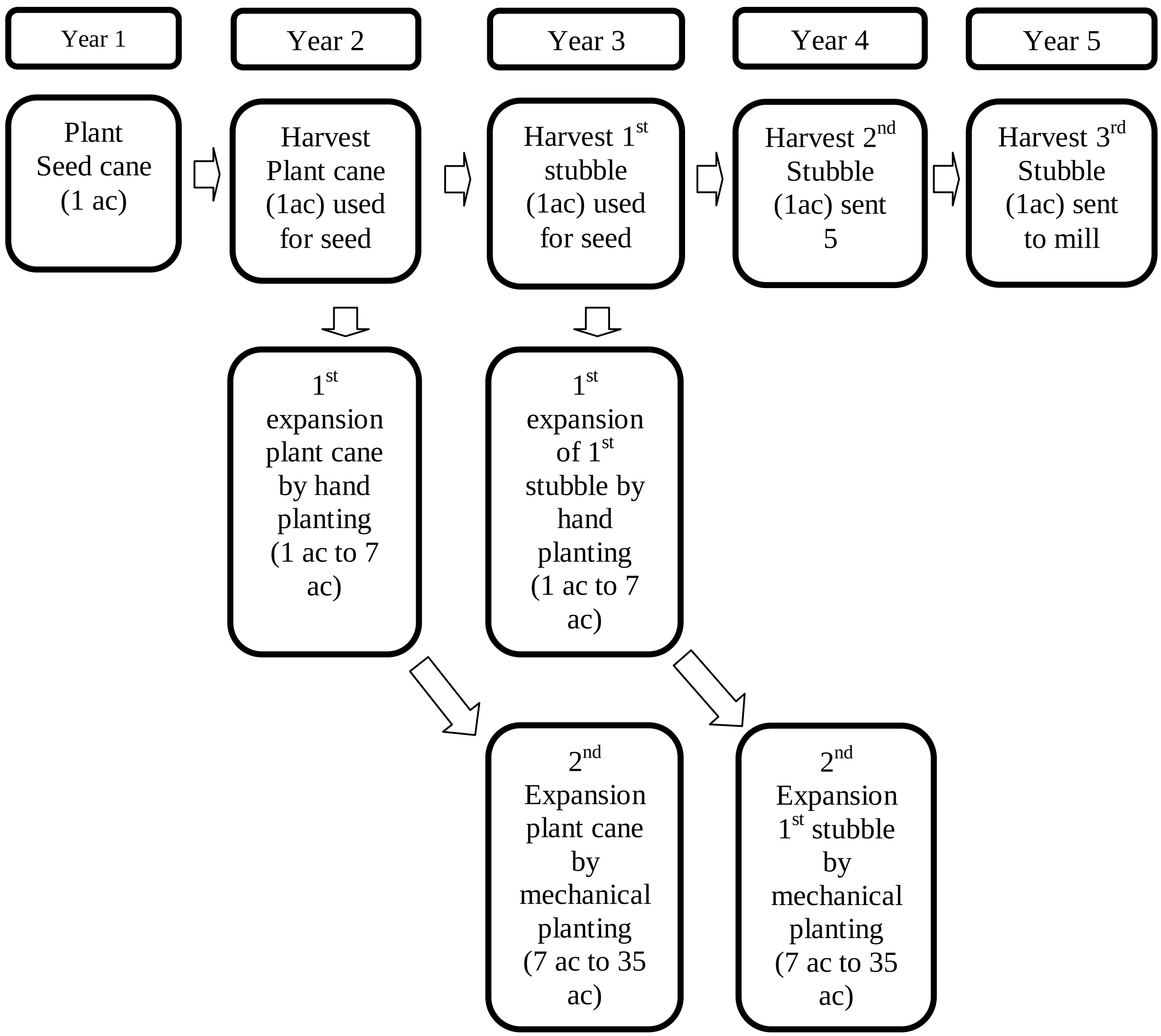
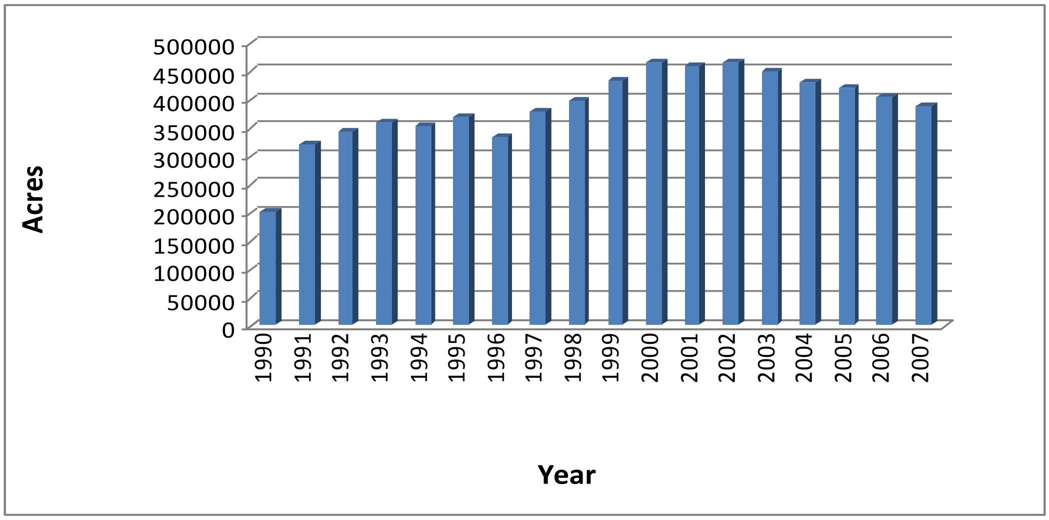
Figure 1




Mark, 2010

Figure 2




*NASS, 2008.*

Table 1: The Base Case With No Shocks

| No Shocks - Base Case | |
|---|---|
| **Mean** | $149,439,106.36 |
| **StDev** | $11,146,345.48 |
| **CV** | 7.46 |
| **Min** | $115,045,190.36 |
| **Max** | $183,285,156.49 |

Table 2: Summary of the 25% Shock Case

Table 2(a): Summary of the No-Option (NPV) case

| No-Option case at 25% chance of shocks | | | |
|---|---|---|---|
| | Oil Price | Eth Subsidy | Sugar Price |
| **Mean** | $114,664,191.95 | $133,888,426.14 | $121,870,892.78 |
| **StDev** | $62,573,188.42 | $29,199,068.74 | $49,121,521.98 |
| **CV** | 54.5708188 | 21.80850846 | 40.30619688 |
| **Min** | ($50,666,344.00) | $61,554,449.20 | $8,833,130.69 |
| **Max** | $183,285,156.49 | $183,285,156.49 | $183,285,156.49 |

Table 2(b): Summary of the Real Options case

| Real Option Strategy at 25% chance of shocks | | | |
|---|---|---|---|
| | Oil Price | Eth Subsidy | Sugar Price |
| **Mean** | $121,164,548.42 | $124,404,546.56 | $132,081,189.57 |
| **StDev** | $ 50,679,214.14 | $ 44,606,818.48 | $ 31,750,323.47 |
| **CV** | 41.82676765 | 35.85626066 | 24.03848994 |
| **Min** | $8,288,121.95 | $35,582,828.26 | $65,197,764.13 |
| **Max** | $183,285,156.49 | $183,285,156.49 | $183,285,156.49 |

Table 2(c): Summary of the values of the Real Options under each shock at 25%

| Summary Stats of Differences at 25% shock | | | |
|---|---|---|---|
| | Oil Price | Eth Subsidy | Sugar Price |
| **Mean** | $6,500,356.47 | ($9,483,879.57) | $10,210,296.79 |
| **StDev** | $14,005,972.16 | $16,898,841.40 | $18,227,060.51 |
| **CV** | 215.4646781 | 178.1849006 | 178.5164612 |
| **Min** | ($26,023,711.57) | ($58,374,558.60) | $0.00 |
| **Max** | $69,180,789.53 | $0.00 | $58,967,806.28 |

Table 3: The 25% Case, By Each Shock

Table 3(a): The Oil Price Shock at 25%

| Oil Price Shock | | | |
|---|---|---|---|
| | **Build** | **Option** | **difference** |
| min | ($50,666,344.00) | $8,288,121.95 | $58,954,465.95 |
| 5% | ($7,242,975.26) | $28,817,628.62 | $36,060,603.88 |
| 25% | $80,402,098.92 | $54,378,387.35 | ($26,023,711.57) |
| 50% | $144,735,603.09 | $144,735,603.09 | $0.00 |
| 75% | $154,606,222.34 | $154,606,222.34 | $0.00 |
| 95% | $167,547,365.34 | $167,547,365.34 | $0.00 |
| **mean** | **$114,664,191.95** | **$121,164,548.42** | **$6,500,356.47** |
| SD | $62,573,188.42 | $50,679,214.14 | ($11,893,974.28) |
| CV | 54.57 | 41.83 | (12.74) |

Table 3(b): The Ethanol Subsidy Shock at 25%

| Ethanol Subsidy | | | |
|---|---|---|---|
| | **Build** | **Option** | **difference** |
| min | $61,554,449.20 | $35,582,828.26 | ($25,971,620.94) |
| 5% | $78,933,371.76 | $44,648,930.25 | ($34,284,441.51) |
| 25% | $115,505,737.72 | $60,533,875.96 | ($54,971,861.76) |
| 50% | $144,309,122.71 | $144,309,122.71 | $0.00 |
| 75% | $154,298,488.36 | $154,298,488.36 | $0.00 |
| 95% | $166,591,338.32 | $166,591,338.32 | $0.00 |
| **mean** | **$133,888,426.14** | **$124,404,546.56** | **($9,483,879.57)** |
| SD | $29,199,068.74 | $44,606,818.48 | $15,407,749.75 |
| CV | 21.81 | 35.86 | 14.05 |

Table 3(c): The Sugar Price Shock at 25%

| Sugar Price Shock | | | |
|---|---|---|---|
| | **Build** | **Option** | **difference** |
| min | $8,833,130.69 | $65,197,764.13 | $56,364,633.44 |
| 5% | $29,504,819.68 | $75,507,193.44 | $46,002,373.76 |
| 25% | $67,824,297.93 | $92,050,860.18 | $24,226,562.25 |
| 50% | $144,551,679.84 | $144,551,679.84 | $0.00 |
| 75% | $154,410,940.87 | $154,410,940.87 | $0.00 |
| 95% | $166,591,338.32 | $166,591,338.32 | $0.00 |
| **mean** | **$121,870,892.78** | **$132,081,189.57** | **$10,210,296.79** |
| SD | $49,121,521.98 | $31,750,323.47 | ($17,371,198.52) |
| CV | 40.31 | 24.04 | (16.27) |

Table 4: Summary Matrix of Shock Probabilities

| Probability | OIL | Eth Subsidy | Sugar |
|---|---|---|---|
| 0.05 | $1,485,605.66 | ($1,972,842.23) | $2,055,793.79 |
| 0.25 | $6,500,356.47 | ($9,483,879.57) | $10,210,296.79 |
| 0.5 | $13,002,485.74 | ($18,730,333.16) | $20,244,192.69 |
| 0.75 | $19,634,862.90 | ($28,131,168.76) | $30,636,452.85 |
| 0.95 | $24,365,466.58 | ($35,508,001.55) | $38,813,195.62 |

Appendix A

1. Tons of sugarcane processed per day
   - A function of sugarcane yield/acre. Acres are held constant.
2. Sugar recovery (CRS)
   - Simulated with an empirical distribution based on 20 years of historical data
3. Growers' share of raw sugar and molasses
   - Held constant at 2009 level
4. Market prices of raw sugar and molasses
   - Sugar price is part of the MVE model, molasses is simulated with a GRKS distribution
5. Market price of ethanol
   - Part of the MVE
6. Factory grinding rate (tons per hour/day)
   - Starts at current representative 12000 tons/day, increases at 1% per year
7. Grinding cost per day (*variable cost*)
   - Inflated at 1% per year
8. Cane freight expenses (*variable cost*)
   - Inflated at 1% per year
9. Sugar freight expenses (*variable cost*)
   - Inflated at 1% per year
10. Offseason expenses (*fixed cost*)
    - Inflated at 1% per year
11. Employee expenses (*fixed cost*)
    - Inflated at 1% per year
12. Administrative expenses (*fixed cost*)
    - Inflated at 1% per year
13. Depreciation expenses (*fixed cost*)
    - Inflated at 1% per year

Appendix B

SALES = (TONS x TRS x LQF x SP) (2)
+ (TONS x MOL/TON x MP)
+ (TONS x TRS x LQF x 3STRSUG x CONVFAC x EP)
*+ (TONS x BAGEX x ETH/BAG x EP)*

where
TONS = tons of sugarcane processed (tons)
TRS = theoretical recoverable sugar (lbs/ton)
LQF = liquidation factor (%)
SP = raw sugar market price ($/lb)
MOL/TON = molasses production rate (gal/ton)
MP = molasses market price ($/gal)
3STRSUG = third strike sugar percentage (%)
CONVFAC = ethanol conversion factor (gal/lb)
EP = ethanol price
*BAGEX = Excess Bagasse Percentage (dry ton rate)*
*ETH/BAG = gallons of ethanol per dry ton of bagasse (gal/ton)*

COSTOFSALES =
[(TONS x TRS x LQF x SP x GSHRS) (3)
+ (TONS x MOL/TON x MP x GSHRM)]
+ [TONS x CANEFREIGHT]
+ [TONS x SUGFREIGHT]
+ DENATURANT

where
TONS = tons of sugarcane processed (tons)
TRS = theoretical recoverable sugar (lbs/ton)
LQF = liquidation factor (%)
SP = raw sugar market price ($/lb)
GSHRS = grower's share of sugar
MOL/TON = molasses production rate (gal/ton)
MP = molasses market price ($/gal)
GSHRM = grower's share of molasses
CANEFREIGHT = hauling rate for sugarcane ($/ton)
SUGFREIGHT = raw sugar freight rate ($/ton)
DENATURANT = blended at 4.76% of eth. volume (gal)

FACTORYEXPENSES = (4)
GRINDING COSTS + OFFSEASON COSTS
+ EMPLOY COSTS + ADMIN COSTS
+ DEPREC COSTS + COETHCOSTS + *CELLETHCOSTS*

GRINDING COSTS = [(TONS/GRDRATE) x GRDCOST] (4.1)
COETH COSTS = COETH EMPLOY + COETH ADMIN + COETH DEPREC (4.2)
*CELLETH COSTS = ETH EMPLOY + ETH ADMIN + ETH DEPREC* (4.3)

where
TONS = tons of sugarcane processed (tons)

GRDRATE = grinding rate per day (tons/day)
GRDCOST = grinding cost per day ($/day)
OFFSEASON = off season expenses ($/season)
EMPLOY = employee expenses ($/season)
ADMIN = administrative expenses ($/season)
DEPREC = depreciation expenses ($/season)
COETH EMPLOY = employee expenses for conv. ethanol ($/season)
COETH ADMIN = admin. expenses for conv. ethanol ($/season)
COETH DEPREC = depreciation for conv. ethanol ($/season)

*Note: all equations in italics only apply for the case where a cellulosic ethanol facility is built*