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The economics of processing ethanol at Louisiana sugar mills: a three part economic analysis of feedstocks, risk, business strategies, and uncertainty

Paul Michael Darby
Louisiana State University and Agricultural and Mechanical College, pdarby1@lsu.edu

THE ECONOMICS OF PROCESSING ETHANOL AT LOUISIANA SUGAR MILLS: A THREE PART ECONOMIC ANALYSIS OF FEEDSTOCKS, RISK, BUSINESS STRATEGIES, AND UNCERTAINTY

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ABSTRACT

The development of an efficient processing infrastructure is critical for the budding cellulosic ethanol industry. Developing a diverse feedstock portfolio is one crucial part of this process which can lead towards economically feasible cellulosic ethanol production. Cellulosic ethanol production requires the production and transportation of large quantities of biomass. Sugarcane and other dense grasses offer a compelling path towards a successful biomass supply chain. This is particularly applicable for Louisiana, which produces more than a third of the sugarcane in the US. The Louisiana sugar belt already has an infrastructure adapted to this task, and taking advantage of this is one key way that a cellulosic ethanol plant can benefit from the region's endowment. Additionally, the area has very large and sophisticated biomass processing facilities in the form of sugar mills. Finally, production of renewable energy from biomass is an area that is filled with economic uncertainty, both from the market and from economic policy. Dealing with this uncertainty will be crucial to any firm that attempts to operate in the cellulosic ethanol industry in the foreseeable future.

This study focuses on several possibilities for aiding the development of the cellulosic ethanol industry, including feedstock development and building upon and within existing agricultural infrastructure. The Louisiana sugarcane belt is the target area of the study, which concentrates on sugarcane bagasse, energy cane, and sweet sorghum as cellulosic feedstocks.

This study examines several possible scenarios and feedstock combinations, finding that a combination of sugarcane bagasse, energy cane, and sweet sorghum could supply a profitable cellulosic ethanol plant situated in the Louisiana sugar belt. By collocating with a sugar mill, a cellulosic ethanol plant can gain further advantage in the form of reusing capital and other fixed costs. This collocation is found to offer substantial benefits to both the cellulosic ethanol

processor and the sugar mill, offering a diversified revenue stream, which enhances both operations.

Finally, by employing real options analysis to the question of uncertainty in the market, it is found that a cellulosic ethanol plant can separate feedstock decisions from production and capacity decisions in a manner that mitigates downside potential from at least some types of market and policy shocks. This is found to greatly enhance the value of the firm in cases where unpredictable negative shocks occur.

CHAPTER 1: INTRODUCTION

The global demand for energy is massive and growing. Liquid fuels in particular are a major component of the energy market in every economy in the world. In the US energy market, these liquid fuels primarily consist of fossil fuels from sources outside our own country. On average, 19,480,000 barrels of petroleum were consumed each day in the United States in 2008, and 11,114,000 barrels of that (or 57%) was imported (EIA, 2008). Any viable energy strategy must then recognize the inherent limitations in relying primarily on foreign, non-renewable fossil sources for our liquid fuel needs. Aside from the need to manage the supply of these depleting fossil energy sources, the need for energy security is a large motivator for displacing some traditional fuels with renewable, sustainable alternatives. A crucial part of our energy policy going forward will be to find, develop, and maintain renewable domestic sources to satisfy some of our growing energy demands while reducing our dependence on foreign fuels. Domestically-obtainable types of renewable liquid fuels include corn ethanol, non-corn ethanol, and biodiesel.

Ethanol

Traditionally obtained via the fermentation of sugar-containing starch crops, ethanol has been periodically examined for fuel use in the United States for over a century. Throughout most of this period, the largest barrier to ethanol adoption has been economic feasibility. Compared to petroleum, ethanol was simply cost-prohibitive, at least until 1973. Since the Oil Embargo in 1973, US energy policy has moved steadily towards a petroleum shortage-management regime, which has naturally led to an increased interest in “alternative fuels.” Given the easily-manageable nature of the fermentation of agricultural goods into alcohols, agriculturally-derived ethanol was a natural choice for a home-grown alternative fuel (Meekhof et al., 1980).

After the price of oil came back down, the emergency drive towards alternative fuels was significantly reduced, but research continued in both the private and public sectors. Evidence started to mount quickly that suggested that bio-ethanol, though still economically infeasible, had significant potential as an alternative fuel. Oil price drops and governmental controls helped ensure that ethanol researchers had the time and funding to examine critically traditional ethanol production from the fermentation of starchy crops like corn (Lee et al., 1991).

While the vast majority of this country's ethanol is produced from corn, this is by no means the only option. In Brazil for instance, 80% of the vehicles in the country run on ethanol produced from sugarcane. The ethanol yield from an acre of sugarcane is almost twice that of corn, and some other crops are even more efficient on a per-acre basis.

Historical Ethanol Policies

Though the history of ethanol's use as a combustible fuel goes back to at least the early nineteenth century, the U.S. government did not start addressing ethanol until the American Civil War. Early in the conflict, the federal government established a heavy excise tax of $2.08 per gallon on liquor to help pay for the war effort. The demand for ethanol, commonly used at that time as a fuel for lamps, fell under this policy, and was effectively taxed out of the market. In keeping with political tradition, this tax was not repealed after the war, and was actually in effect until 1906 (EIA, 2005).

After the ethanol tax was repealed, some demand returned for combustible ethanol. As electric lighting had begun spreading across the country in the 1880's, there was little demand for ethanol as a lamp fuel anymore, but Henry Ford's automobiles represented an entirely new market, and many of the early cars ran on some combination of ethanol and gasoline. Due to this early use as a motor fuel, the market for ethanol was soon affected by another war, as World War I saw the demand for ethanol fuel rise sharply (NESEA, 2008).

The next great impact that ethanol would see from the federal government was the enactment of Prohibition on January 29, 1920. As a fermented grain product, ethanol was banned along with all other liquors. However, since it could still be sold when blended with petroleum, ethanol began finding a market as a fuel additive, used to boost octane. After the end of Prohibition in 1933, this use expanded somewhat. When World War II came shortly afterward, ethanol experienced another wartime boost, but this time it was primarily for non-fuel purposes. Since the relatively cheap gasoline had gradually become the standard in motor fuels, ethanol fuel more or less disappeared after the war (EIA, 2005).

The next big event in federal ethanol policies would not come until 1974. The Solar Energy Research, Development, and Demonstration Act contained within it some incentives for the research and development of fuels from organic materials, though it was primarily concerned with various forms of solar energy (PL. 93-473).

Ethanol's use as an octane booster started in the early twentieth century, but it was far from the only such substance used in gasoline. The most common of these substances for decades was lead. When the Environmental Protection Agency (EPA) began investigating, regulating, and eventually banning the use of lead in gasoline in the 1970s and 80s, ethanol was once again thought of as a possible octane booster (EPA, 1973).

Ultimately though, the most common fuel additive became Methyl tert-butyl ether (MTBE) after lead's phase-out. MTBE offered the same anti-knocking and octane-boosting benefits as lead, and in the higher concentrations used starting in the early 1990s, offered significant air quality benefits as well. However, the natural-gas-derived MTBE showed a tendency to leak from storage tanks and runoff into waterways or seep into groundwater. Though it has yet to be officially addressed by the federal government, various state and local governments began restricting the use of MTBE in the late 1990s. In its place, both ethanol and the ethanol-derived Ethyl tert-butyl ether (ETBE) have become the standard additives for reformulated gasoline (EPA, 2008).

In 1978, the Energy Tax Act created a legal definition of "gasohol," a gasoline and ethanol blend with at least ten percent ethanol content by volume. In addition, this law specifically exempted the fuel ethanol from the four-cent-per-gallon excise tax on gasoline, effectively creating the first federal subsidy for ethanol's use as a motor fuel. This amounted to a forty-cent-per-gallon ethanol subsidy, which was later raised to 50 cents with 1982's Highway Revenue Act and 60 cents with 1984's Deficit Reduction Act. This rising trend was first reversed in 1990's Omnibus Budget Reconciliation Act, and the subsidy has been gradually reduced to its current 51 cents per gallon (Solomon, 1980).

In addition to direct payments in the form of subsidies, starting in 1980 the federal government began assisting the fuel ethanol industry via other protections and non-monetary incentives. The Energy Security Act and Gasohol Competition Act were both efforts to make the motor-fuel marketplace more competitive for the ethanol industry and especially the smaller producers. In addition, Congress established a new tariff on imported ethanol with the Omnibus Budget Reconciliation Act of 1980, protecting domestic ethanol producers from competition coming from Brazil and other ethanol-producing nations.

Additionally, 1988's Alternative Motor Fuels Act (AMFA) essentially provided automobile manufacturers and fuel-distributors with a guaranteed market for alternative fuels and alternative fuel-powered vehicles by mandating the inclusion of alternative-fuel-powered vehicles into the federal government's transportation fleet, requiring the availability of alcohol fuels where federal vehicles are fueled, and making it easier for these vehicles to be fit into federal budgets. It also created new guidelines for fleet fuel-economy labeling for alternative-fuel vehicles, which effectively allowed manufacturers of such vehicles to claim higher gas mileage on their labels than the vehicles actually achieved by multiplying the actual mileage by an adjustment factor. When taken together, the impacts of AMFA were intended to help the still-new industry by eliminating some of the risk involved in entering the market (EIA, 2003).

Providing additional guaranteed market for ethanol, the Clean Air Act Amendments of 1990 mandated significantly expanded use of reformulated gas in many metropolitan areas. Since MTBE was beginning to fall out of favor, this eventually amounted to a boost in demand for ethanol and ethanol-derived ETBE. Additionally, the various tax benefits for ethanol blenders were extended to producers of ETBE in 1995, setting it up to become the fuel additive of choice (EPA, 1991).

Current Ethanol Policy

The Energy Policy Act of 1992 can be seen as starting the modern era of alternative fuel policy. Aside from expanding on earlier regulations concerning vehicle fleets, the law established new incentives for private citizens who wished to purchase alternatively-fueled vehicles or to convert their own vehicles to alternative fuel use. These tax deductions and low-interest loans were also extended to fuel-providers for the installation of equipment specific to the dispensing of alternative fuels.

The 2004 Jobs Creation Act redefined some of the processes and specifics of the ethanol subsidy, and extended the policy into 2010, but there was no net change in the subsidy itself. The Energy Policy Act of 2005 also had no direct effect on ethanol, but in requiring all alternative-fuel-capable federal fleet vehicles to actually use alternative fuels all the time, the law created a temporary shortage of fuel-ethanol. Additionally, the law greatly expanded the mandated quantity of ethanol that would be required in domestic fuels, incrementally increasing this amount over the next eight years (Tyner, 2007).

Up to 2007, this federal Renewable Fuel Standard (RFS) called simply for the production of billions of gallons of ethanol. Without any further specification, the mandate was largely filled by conventional corn ethanol. The passage of the 2007 Energy Independence and Security Act (EISA) changed that. Of the 36 billion gallons mandated for production in by 2022, 21 billion gallons are to come from non-cornstarch derived biofuels, and 16 billion gallons are to come from cellulosic ethanol (OPS, 2007). Figure 1 outlines the timeline of pertinent ethanol policies through 2007.

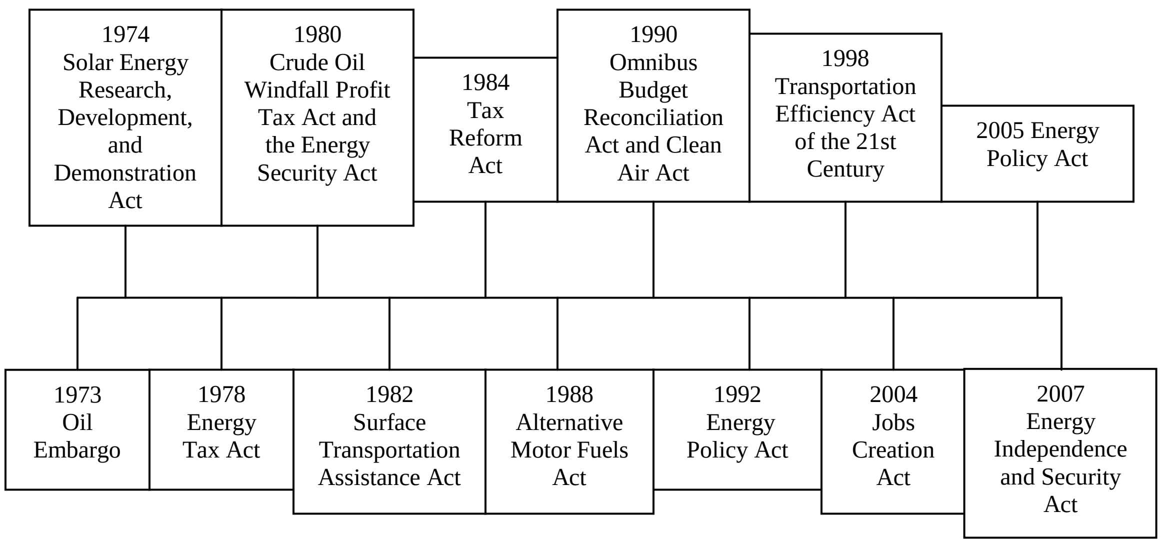

Figure 1 - Timeline of Ethanol Policies
Source: Mark et al., 2010

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 did not change, and the short-term production targets were only modestly changed. However, there is one major change that is relevant to this study. Under the RFS, there is a category of biofuel called “advanced biofuel.”

In order for a fuel to qualify for this designation, it must be shown to reduce greenhouse gas (GHG) emissions by at least 50% over gasoline. Under the original RFS, there was no specific mention of ethanol derived directly from sugarcane, but under the RFS2, sugarcane ethanol is now considered an advanced biofuel. In fact, their official study found that sugarcane ethanol produced via Brazilian-style methods achieve a 61% reduction on a lifecycle basis. 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 (EPA, 2010).

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Renewable Biofuel	9.0	10.5	12.0	12.6	13.2	13.8	14.4	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Advanced Biofuel		0.6	1.0	1.4	2.0	2.8	3.8	5.5	7.3	9.0	11.0	13.0	15.0	18.0	21.0
Cellulosic Biofuel			0.1	0.3	0.5	1.0	1.8	3.0	4.3	5.5	7.0	8.5	10.5	13.5	16.0
Biomass-based Diesel		0.5	0.7	0.8	1.0										
Undifferentiated Advanced Biofuel		0.1	0.2	0.3	0.5	1.8	2.0	2.5	3.0	3.5	4.0	4.5	4.5	4.5	5.0
Total RFS	9.0	11.1	13.0	14.0	15.2	16.6	18.2	20.5	22.3	24.0	26.0	28.0	30.0	33.0	36.0

Figure 2 - Biofuel Mandate Schedule

Sugarcane

Louisiana’s climate makes it a good location for the production of multiple biofuel crops. 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 entire biomass portion of the crop. Salassi (2006) found that juice-based sugarcane ethanol is not likely to be economically feasible, given currently projected gas and ethanol prices. However, the Brazilian method of taking the first two strikes of juice for sugar production and using the remaining juice for ethanol production has never been studied in Louisiana, and may show potential for profitable production. 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, assuming identical costs. Whether or not this could happen is dependent upon market prices for sugar and ethanol, as well as pricing strategies employed by biofuels producers. The uncertainty in the market, however, makes it unlikely that any farmers will switch to energy cane in the short term. 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 at least in the short term. The planting cycle for all cane varieties means that a processor would likely be limited to the current low-biomass varieties for at least one or two years, and possibly longer.

However, there may be a third way. In a current sugarcane mill, the cane is ground and three products are produced: raw sugar, molasses, and bagasse. The raw sugar is sent to a refinery where it is processed into refined white sugar. The molasses is sold and generally ends up being used as a livestock feed additive. Most of the bagasse is burned and used to provide electrical power for the mill, offsetting the need to buy natural-gas-generated electricity from the grid or other fuel for the boilers. However, most mills actually produce much more bagasse than would be needed to produce the power they need. Since local utilities rarely allow this power to be sold back to the grid, the boilers are instead run as inefficiently as possible so as to burn as much of the bagasse as they can. Even so, most mills still produce excess bagasse, which must then be trucked out and disposed of.

If a 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 might have to be acquired in order for the plant to reach commercial levels of production.

Why Louisiana?

One of the advantages of building an ethanol system around Louisiana sugarcane is that much of the infrastructure is already in place. The area has long had sugarcane fields and mills in desirable spatial relationships, as shown respectively by the shaded parishes and the ovals in Figure 3, and the transportation capacity is already very high. From a logistical standpoint, overlapping a sugarcane ethanol system on top of the existing sugar infrastructure makes sense. If existing sugar mills could also process cane fiber into ethanol and if sugarcane farmers grew some mix of both traditional sugarcane and the higher biomass-content energy cane, they would be able to send all of their harvest to the same place, and the output would be a mix of ethanol and sugar.

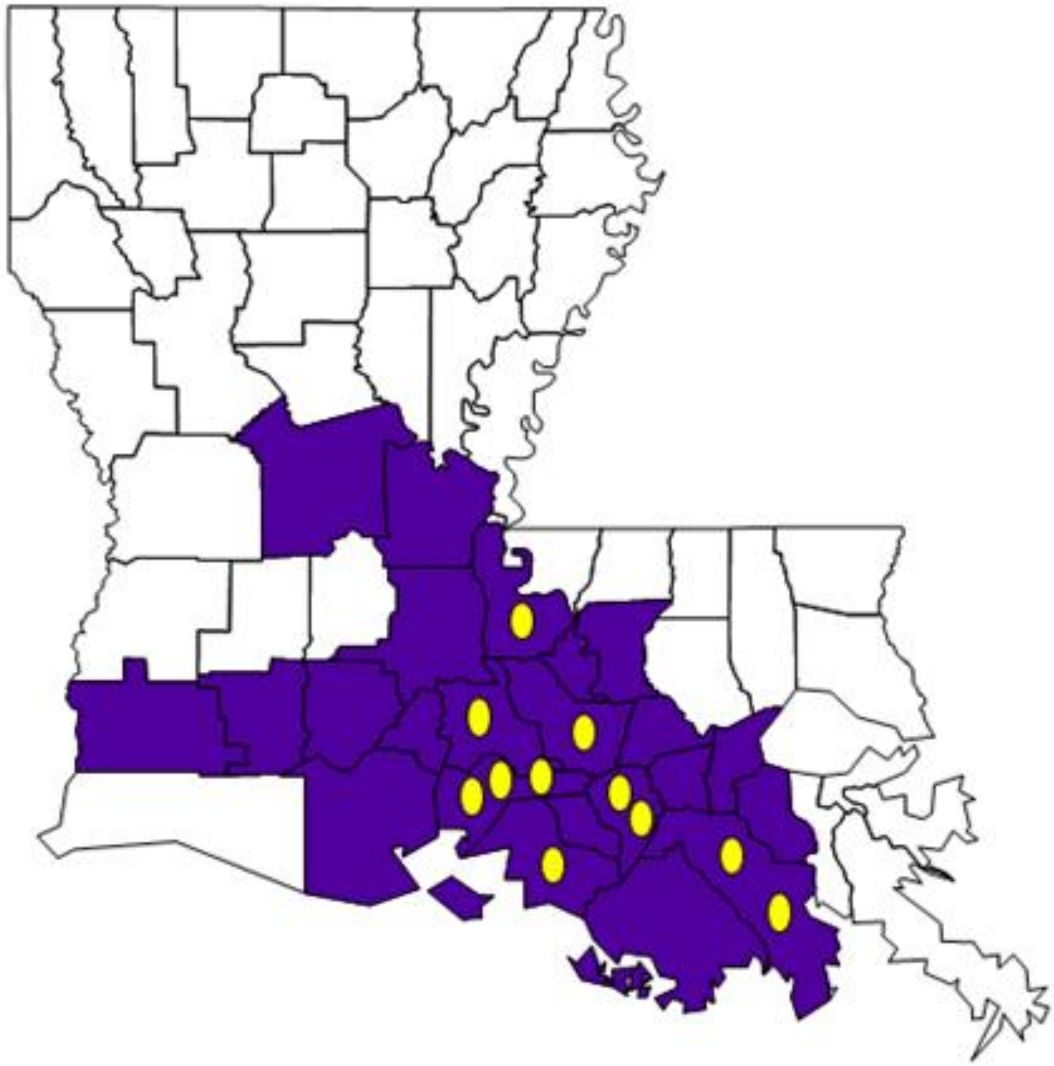

Figure 3 - Location of Louisiana Sugar Belt and Sugar Mills
Source: Mark et al., 2010

In 2008, Louisiana produced 12 million tons of sugarcane, producing 1.2 million dry tons of bagasse, enough to make a theoretical 100 million gallons of cellulosic ethanol (USDA, 2009). Furthermore, the Louisiana sugar belt presents several other opportunities for energy crops. Several high-fiber breeds of energy cane have been extensively studied and found to have high potential as a cellulosic ethanol feedstock (Alexander, 1985; Turhollow, 1994). However, energy cane does have some disadvantages. The primary source of difficulty is the lifecycle of the crop. Due to the perennial nature of the crop and the fact that it does not produce harvestable yields until its second year, energy cane represents a large commitment of time and land for a producer, and is thus likely to meet with some initial resistance in the absence of long-term contracts. As the ethanol plant begins showing profits, contracting for energy cane should become less of a problem (ASCL, 2009).

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).

Purpose

The purpose of this research is to investigate the feasibility of creating an advanced biofuel industry in Louisiana that could coexist with and derive synergistic benefits from existing agricultural activities. Specifically, this research examines the biofuel industry from the perspective of a potential producer of ethanol derived from sugarcane and/or cellulosic feedstocks. It approaches questions of feedstock strategy, collocation with existing processing facilities, and the management of risk and uncertainty. Results and conclusions derived from this research will provide processors and producers with strategic tools to analyze project feasibility. In addition, policy-makers and stakeholders can utilize the results for this research to understand the industry and the potential for its future in this region.

Objectives

The objectives of this research can be divided into three parts:

1) The first objective of this paper is to develop a simulation model of a cellulosic ethanol plant running on some combination of locally sourced bagasse, energy cane, and sweet sorghum and test the economics of various feedstock strategies.
2) The second objective of this paper is to develop a simulation model of a sugar mill collocated with a cellulosic ethanol plant capable of running on bagasse, energy cane, sweet sorghum, and other cellulosic feedstocks. The collocated plant is examined for its potential to profitably produce ethanol either from sugar or from bagasse.
3) An expansion to this mill is modeled, bringing the capacity up to commercial scale. The mill is then tested for its response to uncertainty in production parameters and market conditions. Using Real Options Analysis, the decisions faced by the operators are examined when negative market shocks are randomly incorporated.

Objective 1 – Stand Alone Cellulosic Ethanol Plant

In order to break into the ethanol market, a plant will have to make use of the feedstocks available. The inbuilt sugarcane infrastructure in south Louisiana makes for a tempting candidate, but sugar is generally too profitable for producers to be interested in diverting substantial quantities of sugarcane to produce conventional ethanol (Salassi, 2006). The large quantities of bagasse produced as a byproduct of the sugarcane milling process might present a different situation. The sugarcane industry is one that has large amounts of cellulosic material that is discarded as a by-product that could potentially be used for cellulosic ethanol. Further, using this by-product from this industry helps to solve the first mover problem of feedstock development versus capacity building. Locating a cellulosic ethanol facility next to one or more sugar mills allows the plant to be constructed and begin operation without first contracting with growers to produce another feedstock. The primary advantage of this is that it gives producers confidence that if they do contract with the plant that a market exists for their energy crop, whereas, other strategies for the development of this industry do not offer this (Day, 2010).

Of particular interest to Louisiana is the possibility of producing commercially-viable quantities of cellulosic ethanol from sugarcane, either via bagasse, which is the fibrous cellulose-based byproduct of milling sugarcane, or high-fiber energy cane varieties. The processing flow of sugarcane can be seen in Figure 4, illustrating the source of bagasse.

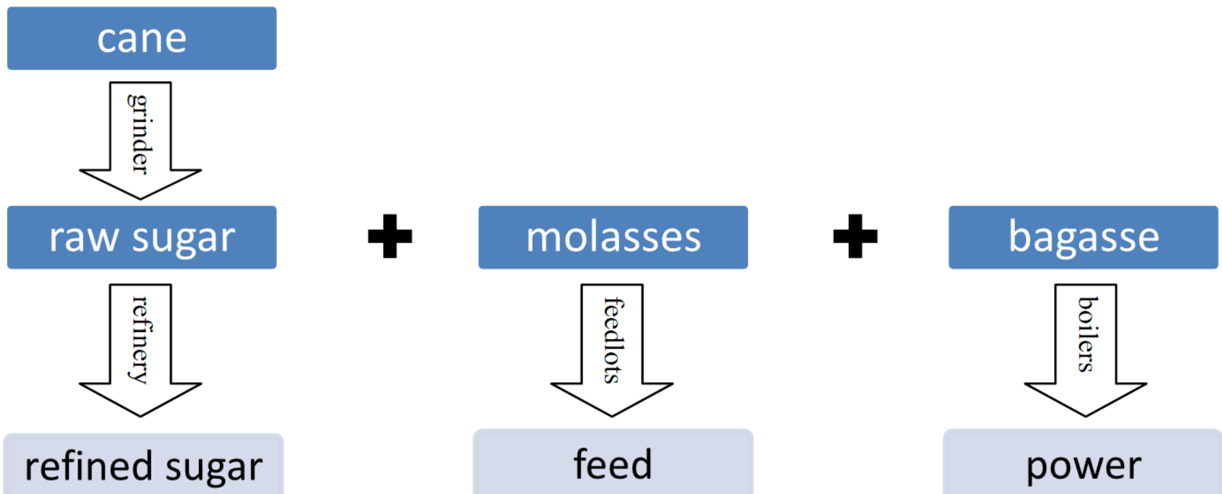

Figure 4 - Sugarcane Processing Flow

For cellulosic ethanol to become a viable option, two profitability conditions must be met. First, the grower of the feedstock must be profitable, and secondly the biofuel producer must be profitable. The feedstock producer's profit has been examined in previous research, but production profitability has not been examined from the perspective of the biofuel processor. The first objective of this research is to explore the possibility of locating a cellulosic ethanol facility in the south Louisiana sugar belt. Three different feedstock scenarios are examined using Net Present Value (NPV) analysis to gauge their feasibility. Additionally, a sensitivity analysis is conducted to determine how sensitive the model is to transportation costs, feedstock costs, and ethanol price.

Objective 2 – Cellulosic Ethanol Plant Collocated With Sugar Mill

Another key to the development of an advanced biofuel industry in south Louisiana is developing the capability to synergistically coexist with the existing agricultural infrastructure, including the ever-prevalent sugar mills. The second objective of this research is to develop an analytical framework that can be used to study the possibility of collocating ethanol processing capabilities within sugar mills as well as the resulting structural change of inputs.

Sugar is the main source of profit for the mill, and as such, the bulk of the profitable sugar will not be sacrificed. The first two cycles of sugar production, called first strike and second strike, remove about 80-85% of the raw sugar from the cane juice. It might be possible to process the remaining juice into ethanol using conventional methods, following the Brazilian model. The first coproduct, molasses, could also potentially be processed into ethanol using conventional methods. For collocation to become a reality though, the structural changes that must take place at the mill need to be examined.

The fibrous byproduct, bagasse, can be processed into ethanol using a cellulosic 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 this research is primarily concerned with. 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 sweet 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. The added flexibility to switch conventional feedstocks between ethanol and sugar/molasses production depending on the market prices for each also allows the facility to maximize profits whenever prices of the two commodities change.

The potential to collocate an ethanol-processing plant alongside a sugar mill is an area of research that needs to be explored further. The second goal of this research is to model such a mill using simulation techniques, and then explore some questions about the input and output conditions created by the mill, given the addition of sugar ethanol and/or cellulosic ethanol processing capabilities.

Objective 3 – Expanding The Collocated Plant Under Uncertainty

The third objective of this research is to develop an analytical framework that can be used to study the potential to collocate large-scale cellulosic ethanol processing capabilities within a Louisiana sugar mill 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 sugar mill, and as such it will be examined as one potential source of uncertainty in market conditions, alongside oil prices and the continued existence of federal ethanol subsidies. The resulting framework will provide processors and decision-makers with a set of tools with which they can take greatest advantage of any specialized knowledge they have about market conditions, production parameters, and policy developments.

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), which can be seen in Figure 5, 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 the processor 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 there is 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, it is assumed that the small-scale (10 million gallon/year) collocated cellulosic ethanol plant already exists onsite which is capable of running strictly on available bagasse if necessary. The operational decision will be whether 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.

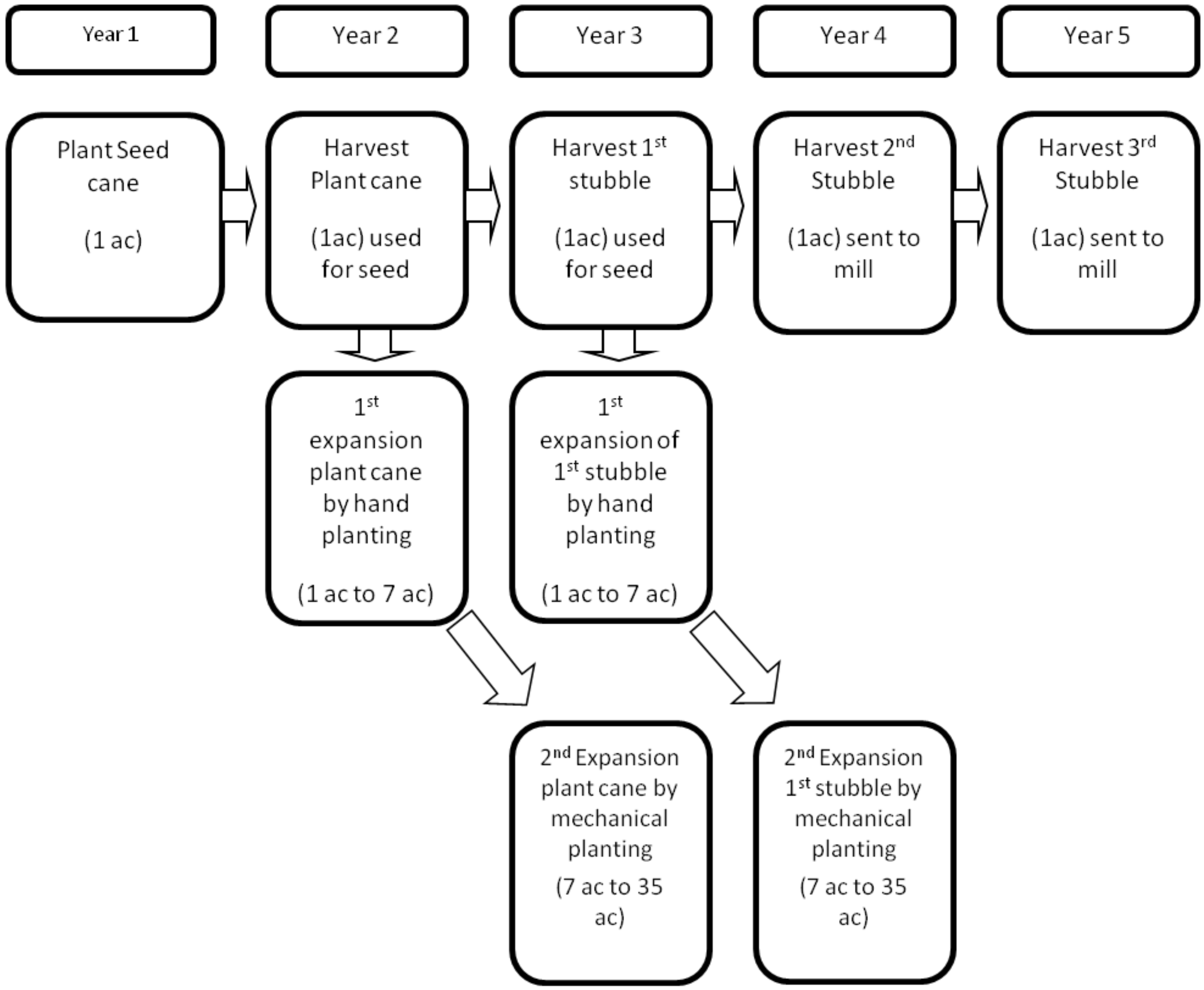

Figure 5 - Energy Cane Planting Cycle – Expanding from 1 acre to 35 acres
Source: Mark et al.,2010

Initial Plant

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 models from the National

Renewable Energy Laboratory (NREL) for cellulosic ethanol, a full-size plant producing commercial-scale 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.

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, about 10,000 acres of energy crops are required, given average expected yields.

The Expansion Decision

In the rest of this study, it is 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.

Interested Parties

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, with a minor uptick for 2009 and 2010, as shown in Figure 6 (USDA, 2010).

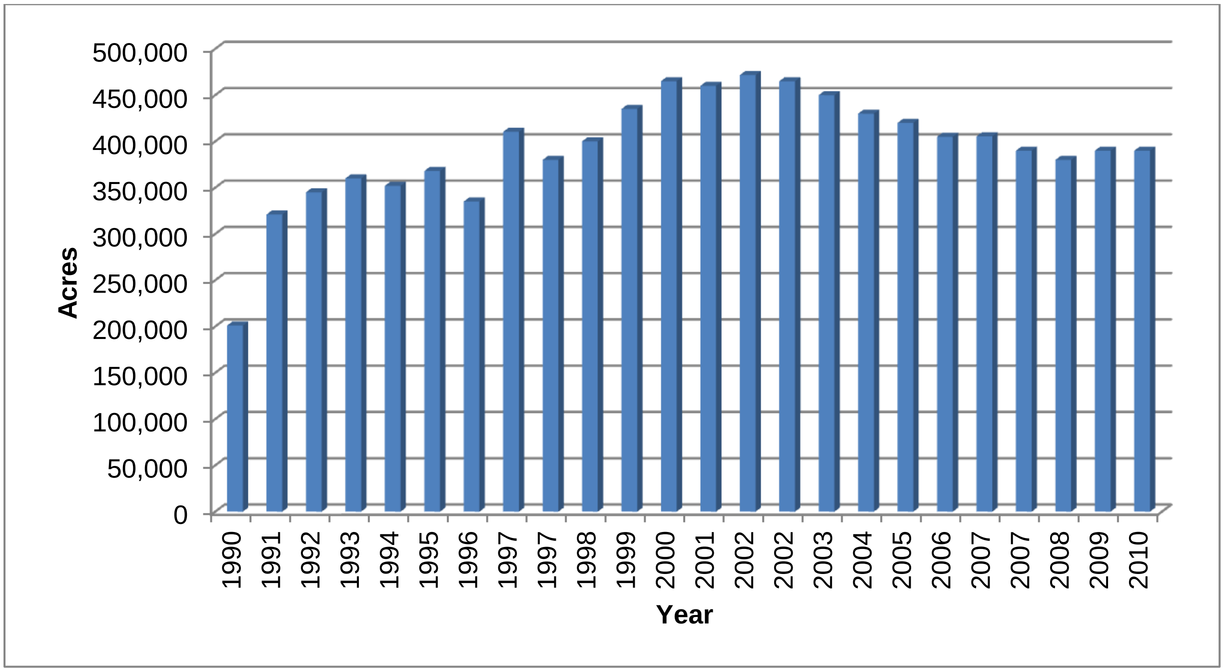

Figure 6 - Sugarcane acres in Louisiana
Source: NASS 2011

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.

Study Area

This research is focused on south Louisiana, where the production of sugarcane is concentrated. With rising input costs and uncertain sugar prices, producers are looking for new sources of revenue, and processors are looking for feedstock diversity and new revenue streams. Long-term contracts for cellulosic feedstocks would provide producers with greatly-desired certainty, and expansion into ethanol production would provide processors with much-needed new revenue streams. The existing infrastructure is already highly developed and well-suited to the efficient harvest and transportation of large quantities of fibrous crops.

CHAPTER 2: LITERATURE REVIEW

As cellulosic ethanol is a relatively new area of research, the body of literature directly associated with it is somewhat limited. However, there have been some very good economic analyses performed in the area that bear discussion.

Cellulosic Ethanol Production

Wooley et al. (1999) produced an extremely thorough cost analysis framework for a cellulosic ethanol plant, which later formed the basis of many further studies on production economics in this area. The specific dollar figures used in the study are no longer strictly relevant, but the basic conclusion was that given some reasonable assumptions about technological development, the production process of lignocellulosic ethanol should scale up to a commercial-scale plant that would be economically profitable.

Aden et al. (2002) wrote an updated look at the production economics outlined in Wooley et al.,(1999), and revised cost and technological development assumptions based on research in the intervening years. They found that, in general, the situation had improved, and that the potential to profitably produce cellulosic ethanol at a commercial scale had increased. Again, the precise dollar figures are out-of-date, but the results essentially indicate that the expected break-even ethanol price was about 30% lower than previously projected in the 1999 study.

In addition, Aden et al (2007) found that cellulosic ethanol from woody or non-specific biomass was likely to be cost-competitive with corn ethanol by 2012. The process on which that study was based included a thermochemical conversion process rather than the biochemical lignocellulosic pretreatment process used in this research, but the conclusions are applicable due to the similar nature of the respective cost breakdowns. The portion of production costs determined by the pretreatment processes are similar for the two plant types that Aden studied in the two NREL publications produced by that team. Both of these also used discounted cash flow and net present value for their economic analyses.

Shapouri and Salassi (2006) found that the other advanced biofuel in this study, sugar ethanol, could not be profitably produced in the United States, given expected prices for sugar and for ethanol. The central insight for this research is that, while both can be produced from Louisiana sugarcane, cellulosic ethanol and sugar ethanol face very different economic realities and the domestic production of the two fuels is likely to face two very different futures in this country.

Collocation of Ethanol Processing

Economic theory would suggest that collocation of two related industrial processes can achieve cost savings from multiple areas. For cellulosic ethanol production from corn stover, research has been done on collocation of the cellulosic ethanol plant with a traditional ethanol plant running on a conventional corn-to-ethanol conversion process. This can lead to cost savings from five main areas: utilities costs, ethanol purification/distillation, primary and by-product processing, fermentation, and transportation costs (Wallace et al, 2005). With a cellulosic ethanol plant using sugarcane bagasse, energy cane, and sweet sorghum, some of the potential savings could come from similar areas, with the exception of the fermentation and purification steps, since no ethanol is produced at a sugar mill. In addition, savings could be realized from the preprocessing area, as the grinders used for sugarcane could also be used for energy cane and sweet sorghum.

A few studies have been done in the corn ethanol area that provide some idea of how the economics of processing collocation might actually turn out. McAloon et al (2000) examined lignocellulosic ethanol from corn stover collocated with a corn ethanol plant and concluded that most corn ethanol plants would not have excess capacity in certain processing areas like fermentation and distillation, meaning no cost savings could come from those areas. They also concluded that, without a previously existing large-scale cellulosic ethanol plant, it is difficult to estimate the additional labor needed to handle a cellulosic feedstock like corn stover, which has very different characteristics from the primary feedstock for the plant, corn. These concerns do not really apply to the scenario studied in this research, as the two processes being combined do not have to share ethanol processing capacity, and the cellulosic feedstocks being handled are extremely similar in nature to the previously existing feedstock for the combined mill.

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).

The risk and uncertainty profile faced by a sugar mill is well understood, both by the literature and by the processors themselves. However, if a sugar mill were to add cellulosic ethanol processing capacity to its previously existing operations, it would be faced with sources of risk and uncertainty unlike anything the operation had previously dealt with. In particular, if the ethanol output accounted for a significant portion of the facility's expected revenue streams, the combined plant would essential transform from a traditional agricultural processing facility, complete with government price supports, to an energy company competing in the tempestuous world of liquid fuels.

The uncertainty faced by a cellulosic ethanol plant collocating with another agricultural processing facility has not been studied directly, but similar strategic investment decisions have been examined in the literature, often using the same real options methodology employed in this research. In general, the literature has supported the two basic ideas present in this part of the current research: (1) irreversibility of investments and uncertainty in market or production parameters are very important factors in these kinds of strategic decisions, and (2) under these conditions, real options analysis can be a valuable tool to model optimal investment behavior.

For example, Purvis et al (1995) found that “uncertainty about costs […] is an important determinant of dairy producers’ investment behavior,” and used real options to explain and study this behavior. Carey and Zilberman (2002) applied real options analysis to the issue of irrigation technology adoption. They found that “the uncertainty of future water supplies and prices and the quasi-irreversible nature of an investment in modern technology,” shaped the decision-making process and meant that analysis with real options was useful. They also found that there would be good reason to later extend their model to incorporate the ability to reduce or eliminate the technology investment after the initial adoption, but found that an assumption of total irreversibility simplified the model without significantly changing their results. Similarly, this research assumes near-total irreversibility of investment, with only a small salvage value attached to the capital involved in the cellulosic ethanol plant. A further extension might incorporate some form of investment reduction such as partial utilization or even capacity reduction via disinvestment.

Price and Wetzstein (1999), in examining commercial peach production in Georgia, found that uncertainty and irreversible investments can drastically impact production decisions, causing optimal strategies to differ significantly from those found with net present value analysis. Relatedly, Richards and Green (2003) found that uncertainty and irreversible investments delay adoption of new wine grape varieties. Their application of real options analysis shows that growers are following a decision-making pattern consistent with option valuation when they delay investment in new varieties.

Engel and Hyde (2003) used real options to examine the decision to adopt new milking technology in dairy operations. Under the assumed conditions of uncertainty and irreversibility of investments, they found that the optimal decisions computed differed significantly from those found with traditional capital budgeting techniques such as net present value analysis. This finding was robust to changes in many parameters studied. Odening et al (2005) similarly found that, in an uncertain environment, an option value strategy would generate significantly different recommended choices than net present value analysis, and that hog producers in Germany seemed to be making investment decisions consistent with those suggested by options valuation.

Tzouramani and Mattas (2004) used real options analysis in a case study examining greenhouse construction. They found that, "the real options approach can be proved useful with assessing projects with uncertainty and irreversibility and it can provide a new way of examining agricultural investment decisions." In a paper that was somewhat more related to the current research, Stokes et al (2008) also found that real options analysis could be applicable to the investment by dairy farmers into methane digesters for the purposes of on-site power generation. They found that producers in Pennsylvania were rational to resist investment in the absence of grant funding, despite what traditional net present value analysis might suggest. Such grant funding acted as financial compensation for the uncertainty inherent in the project.

Overall, there are many examples in the literature of other researchers examining ethanol production, collocation of various production facilities, and real options analysis under uncertainty. However, no study or body of research has yet combined these into a study of the specific economic conditions that would be faced by a cellulosic ethanol plant that collocated with a traditional agricultural processing facility such as a sugar mill. This research is intended to contribution exactly that combination of factors, in an effort to advance the literature in this area. While the current research specifically examines Louisiana sugar mills as the agricultural processing facility in question, the findings could be applicable to many other such facilities in this and other countries.

CHAPTER 3: DATA AND METHODS

There are several basics of analysis that are important to understand in order to proceed with developing a methodology for this study. This chapter first examines some of the methodological techniques before delving deeper into the methodology used for each individual objective.

Net Present Value

One of the measures by which the tested scenarios were analyzed was 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 calculated by subtracting initial cash outlays from a discounted set of cash flows from the project. The NPV model is specified as:

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

Where

F_n is the net cash flows that can be realized in year *n*

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 is 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). This tool can, for instance, be used to 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 the facility is analyzed. 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. Alternatively, 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).

The discount rate used for the NPV analyses in this research is 12%. There is support in the literature for using either 10% (Aden et al., 2002; Short et al., 1995) or 12% (Wyman et al. 1993; Goldemberg et al., 1993) for renewable energy projects in general and cellulosic ethanol production specifically. The higher figure was chosen as the more conservative estimate, and a sensitivity analysis was performed on this rate to determine what ranges might be feasible.

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). In addition, 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.

Uncertainty

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.

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 a more attractive investment, but one that is still clouded by uncertainty. 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.) In what manner and at what speed 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 the third objective section 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.

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.

The models used to study the objectives in this research all built upon one another and as such, rely on the same sources for all the data that they share in their overlapping portions. The methodologies used to study each objective are also related, but the full details are herein broken down by objective.

Objective 1 Methods – The Stand Alone Plant

One method to approach the study of a standalone cellulosic ethanol plant would be to start with the waste feedstock (bagasse) and add feedstocks as producers see that the plant represents a viable partner. This requires a model that dynamically switches feedstocks from year to year, in addition to the within-year switching modeled here. However, while the model is capable of year-to-year feedstock switching, for the sake of simplicity, the standalone plant is limited to three potential feedstock scenarios which are examined separately: 1) a plant running entirely on bagasse sourced from multiple sugar mills, 2) a plant that sources bagasse from multiple mills and also has supplier(s) of a fairly low-commitment feedstock (sweet sorghum), and 3) a plant that has sweet sorghum supplier(s), at least two bagasse suppliers, and long-term-contracted supplier(s) for energy cane. For each scenario, the net present value (NPV) is simulated based on the model detailed in the next objective's section. A sensitivity analysis is performed to determine how the different scenarios respond to changes in different operational parameters.

Determination of Plant Size

A conservative estimate is that the representative Louisiana sugar mill grinds 10,000 wet tons of sugarcane a day. This produces about 1,000 dry tons of bagasse each day, about 80-85% of which is burned to supply all the steam power that is needed to run the mill. The remaining bagasse (estimated to be about 150-200 dry tons) is excess, and must be disposed of. Because this excess bagasse represents a waste product, most mills run their boilers very inefficiently and/or let off excess steam, so as to burn off as much total bagasse as possible (Day, 2010).

Based on the above, a relatively small plant size of 10 million gallons per year with an estimated yield of 85 gallons of ethanol per dry ton of bagasse, about 300 dry tons of bagasse per day could supply the plant's input needs. If bagasse is used as it comes in throughout the 90-day Louisiana sugarcane harvest season, the plant could stay supplied if it could source bagasse from two or three sugar mills.

Scenario 1 – Ethanol From Bagasse

Sourcing bagasse from seven or eight sugar mills would provide enough bagasse to operate the 10 million gallon facility at full capacity for a year. This would be a feasible solution in the short run, but competition for the bagasse is assumed to eventually drive prices upwards to the point that a 100% bagasse plant is not considered sustainable in the long run.

Scenario 2 – Ethanol From Bagasse and Sweet Sorghum

The second scenario represents one wherein the low-commitment feedstock (i.e. sweet sorghum) is contracted. With 6,000 acres planted, 1,000 tons of sweet sorghum is brought in per day during its July-September harvest window, and the remaining three quarters of the year the plant is still run on bagasse.

Scenario 3 – Ethanol From Bagasse, Sweet Sorghum, and Energy Cane

The third scenario adds 6,000 acres of energy cane. These acres will supply about 2,200 tons of cane per day for the planned 90-day harvest. The fiber is stored and conventional ethanol is produced from the juice during this period. In the following quarter, the stored fiber is used to make cellulosic ethanol. Sweet sorghum is harvested during its summer quarter and bagasse is purchased and processed during the sugarcane harvest quarter. This is currently considered to be the most stable long-run case, involving the least amount of storage costs and losses, as well as the most diversified feedstock portfolio. The three scenarios are presented in Table 1.

Table 1- Diagram of Scenarios and Quarters For Ethanol Plant Feedstocks

	January-March	**April-June**	**July-September**	**October-December**
Scenario 1	Bagasse	Bagasse	Bagasse	Bagasse
Scenario 2	Bagasse	Bagasse	Sweet Sorghum	Bagasse
Scenario 3	Energy Cane	Energy Cane	Sweet Sorghum	Bagasse

Data

The cellulosic ethanol plant cost data is adapted from that in an NREL study, an Oklahoma State model, and from personal interviews (Aden 2002; Holcomb, 2009; Day, 2010). The plant uses a lime-based pretreatment process, and grows its own enzymes using a quantity of reserved biomass. Fermentation is done in batches, and distillation is continuous. The waste stream from distillation, or vinasse, is processed in an anaerobic digester. This produces three additional streams, biogas, landfillable solids, and a liquid stream. The liquids are further processed in an aerobic digester, producing additional biogas and a final solid waste.

The final waste, landfillable solids and biogas are all burned in a boiler/turbogenerator using a Circulating Fluidized Bed Combustor (CFBC), which is optimal for its capability to burn a wide range of materials indiscriminately. There are two additional waste streams that have potential value, the lignin released during pretreatment and the primarily-yeast solid residue from the fermentation stage. Both are potentially marketable, but as no proven market value can really be relied on, both are instead considered to be burned in the boiler as well. This CFBC boiler generates more than enough steam power to run the entire plant. The excess power could hypothetically be sold back to the local grid, but it is currently assumed that that will not happen.

Sugarcane bagasse is (on a dry matter basis) composed of about 60% carbohydrates (cellulose and hemicellulose) and the remainder is lignin and other solids. Those carbohydrates can, via pretreatment and enzymatic hydrolysis, be converted to fermentable sugars. Once these sugars are obtained, fermentation and distillation of ethanol follow the familiar pattern common to other ethanol processes. One mole of these sugars produces one half mole of ethanol and one half mole of carbon dioxide, so the stoichiometric yield is theoretically 91.1 gallons per dry ton. However, due to losses and inefficiencies, the real-world yield is about 85 gallons per ton and this is the figure used (Day, 2010).

Based on the sucrose content of energy cane and the yield for sucrose syrup, the juice from energy cane is expected to produce 12.7 gallons per ton of cane (Salassi, 2006). Based on a fiber percentage of 15%, the energy cane fiber is estimated to yield 11.9 gallons of cellulosic ethanol per ton. By a similar process, sorghum is estimated to yield 14 gallons of juice ethanol and 10.3 gallons of cellulosic ethanol per ton. The expected yields are summarized in Table 2.

Table 2 - Expected Crop and Ethanol Yields

	Bagasse	Energy Cane	Sweet Sorghum
Yield	n/a	35 tons/acre	15 tons/acre
Gallons/Ton **Juice Ethanol**	n/a	12.69 gal/wet ton	14 gal/wet ton
Gallons/Ton **Cellulosic Ethanol**	85 gal/dry ton	11.89 gal/wet ton	10.3 gal/wet ton

These yields are presented for illustrative purposes and were used as a benchmark to check the forecasted yields that were produced by the stochastic model detailed in the next section. When running the simulations for all three objectives, yields were stochastic and forecasted using the regression models. Ethanol prices for this model were also taken from the stochastic model detailed in the next section. Gasoline denaturant prices are taken from EIA projections. Denaturant is blended at 4.76% of total volume, as per RFA (RFA, 2003).

Stand Alone Cellulosic Ethanol Plant Model

For the first objective, the model needed to incorporate all operations for a cellulosic ethanol plant running on any combination of three possible feedstocks: bagasse, energy cane, and sweet sorghum. The model is specified as follows.

GROSS PROFIT = SALES – COST OF SALES (2a)

NET INCOME = GROSS PROFIT – FACTORY EXPENSES (2b)

where SALES = revenues from ethanol

COST OF SALES = inventory and shipping costs

FACTORY EXPENSES = costs of operation and factors of production

The supporting equations are

SALES = (BAGTONS x ETH/BAG x EP) (3)

+ (ECTONS x ETH/EC x EP)

+ (SSTONS x ETH/SS x EP)

where EP = ethanol price

BAGTONS = Bagasse processed (dry tons)

ETH/BAG = gallons of ethanol per dry ton of bagasse (gal/ton)

ECTONS = tons of energy cane processed (wet tons)

ETH/EC = gallons of ethanol per wet ton of energy cane (gal/ton)

SSTONS = tons of sweet sorghum processed (wet tons)

ETH/SS = gallons of ethanol per wet ton of sweet sorghum (gal/ton)

COSTOFSALES = (4)

(ECTONS x ETH/EC x EP x GSHRETH)

+ (SSTONS x ETH/SS x EP x GSHRETH)

+ (ECTONS x CANEFREIGHT)

+ (SSTONS x CANEFREIGHT)

+ DENATURANTCOST

where CANEFREIGHT = hauling rate for crops ($/ton)

ECTONS = tons of energy cane processed (wet tons)

ETH/EC = gallons of ethanol per wet ton of energy cane (gal/ton)

SSTONS = tons of sweet sorghum processed (wet tons)

GSHRETH = grower's share of ethanol

ETH/SS = gallons of ethanol per wet ton of sweet sorghum (gal/ton)

DENATURANTCOST = blended at 4.76% of eth. volume (gal)

FACTORYEXPENSES = (5)

GRINDING COSTS + OFFSEASON COSTS

+ CELLETHCOSTS

GRINDING COSTS = [(ECTONS/GRDRATE) + (SSTONS/GRDRATE)]

x GRDCOST (6a)

CELLETH COSTS = ETH EMPLOY + ETH ADMIN + ETH DEPREC (6b)

where ECTONS = tons of energy cane processed (wet tons)

SSTONS = tons of sweet sorghum processed (wet tons)

GRDRATE = grinding rate per day (tons/day)

GRDCOST = grinding cost per day ($/day)

OFFSEASON = off season expenses ($/season)

ETH EMPLOY = employee expenses for cellulosic ethanol ($/season)

ETH ADMIN = admin. expenses for cellulosic ethanol ($/season)

ETH DEPREC = depreciation for cellulosic ethanol ($/season)

Objective 2 Methods – The Collocated Plant

Having studied a simulated stand-alone cellulosic ethanol plant operating in south Louisiana, the next step was to examine how that facility might benefit from being collocated with a sugar mill. The second hypothesis tested is whether a sugarcane mill with a built-in ethanol plant would generate any added value from producing either third-strike or “Brazilian-style” sugar ethanol or cellulosic ethanol from bagasse. The problem is that no such mill exists.

The first step then is to build a simulation model to approximate the operations of a sugar mill. Additionally, a simulation of a conventional ethanol facility is added on to the sugar mill model. This facility has the capability to process simple sugars into ethanol. The first two strikes of raw sugar remain untouched, and the cane juice after the second strike can be used as an ethanol feedstock. The time period studied covers 25 years, the limit of EIA's forecasts for some important inputs like natural gas and crude oil.

Collocated Ethanol and Sugar Mill Model

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 Gray, Richardson, Klose, and Schuman (GRKS) distribution is employed (Richardson, 2006). 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:

$$\text{GROSS PROFIT} = \text{SALES} - \text{COST OF SALES} \tag{7a}$$

$$\text{NET INCOME} = \text{GROSS PROFIT} - \text{FACTORY EXPENSES} \tag{7b}$$

where SALES = revenues from sugar, molasses, and ethanol

COST OF SALES = inventory and shipping costs

FACTORY EXPENSES = costs of operation and factors of production

The supporting equations are

$$\begin{aligned} \text{SALES} = \; & (\text{TONS} \times \text{CRS} \times \text{SP}) \\ & + (\text{TONS} \times \text{MOL/TON} \times \text{MP}) \end{aligned} \tag{8}$$

+ (TONS x CRS x 3STRSUG x CONVFAC x EP)

+ (TONS x BAGEX x ETH/BAG x EP)

+ (ECTONS x ETH/EC x EP)

+ (SSTONS x ETH/SS x EP)

where TONS = tons of sugarcane processed (tons)

CRS = commercial recoverable sugar (lbs/ton)

SP = raw sugar market price ($/lb)

MOL/TON = molasses production rate (gal/ton)

MP = molasses market price ($/gal)

3STRSUG = estimated sugar in the third strike (%)

CONVFAC = gallons of ethanol obtained from a pound of sugar (gal/lb)

EP = ethanol price

BAGEX = Excess Bagasse Percentage (dry ton rate)

ETH/BAG = gallons of ethanol per dry ton of bagasse (gal/ton)

ECTONS = tons of energy cane processed (wet tons)

ETH/EC = gallons of ethanol per wet ton of energy cane (gal/ton)

SSTONS = tons of sweet sorghum processed (wet tons)

ETH/SS = gallons of ethanol per wet ton of sweet sorghum (gal/ton)

COSTOFSALES = (9)

[(TONS x TRS x LQF x SP x GSHRS)

+ (TONS x MOL/TON x MP x GSHRM)]

+ (TONS x CANEFREIGHT)

+ (TONS x SUGFREIGHT)

+ [(ECTONS x ETH/EC x EP x GSHRETH)

+ (SSTONS x ETH/SS x EP x GSHRETH)]

+ (ECTONS x CANEFREIGHT)

+ (SSTONS x CANEFREIGHT)

+ 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 crops ($/ton)

SUGFREIGHT = raw sugar freight rate ($/ton)

ECTONS = tons of energy cane processed (wet tons)

ETH/EC = gallons of ethanol per wet ton of energy cane (gal/ton)

SSTONS = tons of sweet sorghum processed (wet tons)

GSHRETH = grower's share of ethanol

ETH/SS = gallons of ethanol per wet ton of sweet sorghum (gal/ton)

DENATURANTCOST = blended at 4.76% of eth. volume (gal)

FACTORYEXPENSES = (10)

GRINDING COSTS + OFFSEASON COSTS

+ EMPLOY COSTS + ADMIN COSTS

+ DEPREC COSTS + COETHCOSTS + CELLETHCOSTS

GRINDING COSTS = [(TONS/GRDRATE) + (ECTONS/GRDRATE)

+ (SSTONS/GRDRATE)] x GRDCOST (11a)

COETH COSTS = COETH EMPLOY + COETH ADMIN + COETH DEPREC (11b)

CELLETH COSTS = ETH EMPLOY + ETH ADMIN + ETH DEPREC (11c)

where

TONS = tons of sugarcane processed (tons)

GRDRATE = grinding rate per day (tons/day)

ECTONS = tons of energy cane processed (wet tons)

SSTONS = tons of sweet sorghum processed (wet tons)

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)

ETH EMPLOY = employee expenses for cellulosic ethanol ($/season)

ETH ADMIN = admin. expenses for cellulosic ethanol ($/season)

ETH DEPREC = depreciation for cellulosic ethanol ($/season)

Some factors affecting the performance of the simulated mill are summarized in Table 3. Note that, since commercial recoverable sugar (CRS) is equal to theoretical recoverable sugar (TRS) times liquidation factor (LQF), only CRS needs to actually be simulated. This CRS term is broken down into TRS times LQF under Cost of Sales simply because this is how producers are traditionally paid out, first based on an estimated TRS, then on a corrected basis based on LQF at the end of the season. The net amount is the same as the CRS used to calculate sales. The general sugar mill parameters were inflated at 1% per year for the reported results, but were tested for levels from 1-5%. Each additional percentage point increase resulted in a roughly 1% decline in mean NPV value.

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. Summary statistics and sources for data are listed in Table 4.

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. These natural gas prices were also tested with lags up to three years for the perennial crops, but the differences were minimal and the lower quality of older data meant that choosing non-lagged natural gas prices made for a higher quality forecast.

Table 3 - Simulation Factors

Factor	Initial Value	Changes
Tons of sugarcane processed (TONS)	N/A	A function of forecasted sugarcane yield/acre. Acres are held constant.
Sugar recovery (CRS)	N/A	Simulated with an empirical distribution based on 20 years of historical data
Growers' share of raw sugar and molasses (GSHRS and GSHRM)	61% and 61%	Held constant at 2009 level
Molasses per ton of sugarcane (MOL/TON)	6 gallons per ton	Held constant
Third strike sugar percentage (3STRSUG)	10%	Held constant
Gallons of ethanol obtained from a pound of sugar (CONVFAC)	0.0705	Held constant
Excess Bagasse (BAGEX)	15%	Held constant
Gallons of ethanol from dry ton of bagasse (ETH/BAG)	85 gallons per dry ton	Held constant
Hauling rate for sugarcane, energy cane, sweet sorghum (CANEFREIGHT)	\$1.00 per ton and \$0.10 per mile	Increases 1-5% per year
Raw sugar freight rate (SUGFREIGHT)	\$2.00 per ton	Increases 1-5% per year
Denaturant, blended at 4.7% of ethanol volume	Wholesale price of unleaded gasoline from EIA	Forecasted gasoline prices from EIA
Grinding rate per day (GRDRATE)	12,000 tons per day	Increases 1-5% per year
Grinding cost per day (GRDCOST)	\$38,000 per day	Increases 1-5% per year
Offseason Expenses (OFFSEASON)	\$4,000,000 per year	Increases 1-5% per year
Employee Expenses (EMPLOY, COETH EMPLOY, and ETH EMPLOY)	\$1,000,000 per year for sugar mill plus varying amounts for each ethanol component, up to \$4,000,000 per year	Increases 1-5% per year
Administrative Expenses (ADMIN, COETH ADMIN, ETH ADMIN)	\$500,000 per year, plus \$0.22 per gallon of ethanol produced	Increases 1-5% per year
Depreciation Expenses (DEPREC, COETH DEPREC, ETH DEPREC)	\$1,000,000 per year for sugar mill, plus varying amounts for each ethanol component, up to \$7,000,000 per year	Sugar mill costs increase 1-5% per year, the rest are calculated using 39 year straight line, 10-year straight line, and 7 year MACRS

Table 4 - Data Sources and Stats

Variable	Units	Mean	Stdev	Max	Min	Source
Historical Sugar Price (Raw)	cents/lb	21.36	1.48	24.93	19.09	USDA, 2010
Historical Sugarcane Yield	t/ac	28	2.69	31	23	USDA, 2009
Forecasted Sugar Price	cents/lb	31.04	1.84	39.22	24.4	model
Historical Commercially Recoverable Sugar	lb/ac	209.1	13.78	229	179	ASCL, 2010
Historical Sugarcane Production Costs less harvest	\$/ac	487	37.63	529	425	Salassi and Deliberto, 2010
Historical Sugarcane Harvest costs	\$/t	3.05	0.24	3.31	2.59	Salassi and Deliberto, 2010
Historical Crude Oil Price	\$/barrel	46.35	23.05	92.33	21.99	EIA, 2010
Historical wholesale Ethanol price	\$/gal	1.79	0.50	2.58	1.12	NEB, 2010
Forecasted Ethanol Price	\$/gal	3.41	0.26	4.72	2.24	EIA, 2010; model
Historical Natural Gas Prices	\$/1000ft^3	6.52	1.87	9.67	4.02	EIA, 2010
Forecasted Natural Gas Prices	\$/1000ft^3	6.54	0.35	6.88	6.05	EIA, 2010

Additionally, the crop yields were found to have an AR(1) autoregressive process, so a single lag was used, in addition to a time trend. The random deviate generated by the MVE model was used to generate noise for the forecasts. The yield equations take the following form:

$$SCaneYield_t = f(SCaneYield_{t-1}, t, Natgas_t) \tag{12}$$

$$ECaneYield_t = f(ECaneYield_{t-1}, t, Natgas_t) \tag{13}$$

$$SweetSGYield_t = f(SweetSGYield_{t-1}, t, Natgas_t) \tag{14}$$

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:

$$EthanolPrice_t = f(EthanolPrice_{t-1}, t, CrudeOilPrice_t) \tag{15}$$

Results for the forecast models are summarized in the following tables, and some detailed results are in Appendix A.

Table 5 - OLS Regression Results for Ethanol Price

Variable	Coefficient	Standard Errors
Intercept	0.917*	0.153
$EthanolPrice_{t-1}$	-0.039	0.150
t	-0.010	0.006
$oilprice_t$	0.020*	0.003
N	27	
R^2	0.831	

*Significant at the 10% level

Table 6 - OLS Regression Results for Sugar Cane Yields

Variable	Coefficient	Standard Errors
Intercept	21.857*	9.908
$SCaneYield_{t-1}$	0.409	0.276
$natgas_t$	-.649	0.603
t	0.096	0.322
N	13	
R^2	0.429	

*Significant at the 10% level

Table 7 - OLS Regression Results for Energy Cane Yields

Variable	Coefficient	Standard Errors
Intercept	19.875*	9.154
$ECaneYield_{t-1}$	0.455	0.265
$natgas_t$	-1.067*	0.547
t	0.441	0.288
N	13	
R^2	0.535	

*Significant at the 10% level

Table 8 - OLS Regression Results for Sweet Sorghum Yields

Variable	Coefficient	Standard Errors
Intercept	20.137*	7.503
$SSGyield_{t-1}$	0.173	0.313
$natgas_t$	0.478	0.416
t	-1.016	0.753
N	13	
R^2	0.359	

*Significant at the 10% level

With the full simulation model, several different issues are 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. This analysis also examines whether or not producing conventional ethanol following the Brazilian model can be profitable in the U.S. An extreme case where all sugar is diverted to ethanol production is also examined.

The second part of this objective is to simulate an add-on cellulosic ethanol plant and incorporate this into the sugar mill simulation. The cellulosic ethanol 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). The additional processing cycle means that additional input and output prices will be needed. Natural gas prices come from EIA, and bagasse prices are taken from NREL. The same basic methodology is followed to study the base case, where the mill is able to obtain enough bagasse to run its cellulosic ethanol facility all year. Additionally, two other cases are studied, wherein the mill either has to rely solely on its onsite bagasse or is able to contract for enough additional bagasse to run for half the year.

Due to the varied nature of the feedstocks involved in the cellulosic ethanol plants, some assumptions must be made about acquisition strategy. 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. A comparison with the previously examined standalone mill is made to discover whether there are in fact synergies to be captured by collocation.

Objective 3 Methods – Expanding the Plant Under Uncertainty

Having tested both conventional and cellulosic ethanol plants collocated with a sugar mill, for the third objective the research question moves on to studying the risk and uncertainty that are involved in the business decisions that such a facility would face. The third hypothesis to be tested is whether 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.

The first step is to build upon the previously developed model of a sugar mill collocated with a small-scale cellulosic ethanol plant. A simulation of a commercial-scale expanded cellulosic ethanol facility is added on to the initial model, and the entire model is rebuilt to be able to respond dynamically to introduced risk and uncertainty. This facility has the capability to process cellulosic feedstocks into ethanol. 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).

Assumptions about feedstock acquisition for the smaller capacity plant were given for Objective 2. 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. This means that the holder of the option has purchased the right, but not the obligation, to expand the plant on a single pre-defined point in time, or expiration date. The purchase price will be discussed below. At time of exercise, the value of the basic option can be given by:

$$V = \max\{0, S - X\} \tag{16}$$

where V is the value of the expansion option, 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:

$$ROV_i = NPV_x - NPV_o \tag{17}$$

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 real option value (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. Therefore, the option price (OP) takes the following form:

$$OP = \begin{cases} \max \begin{bmatrix} PV\left\{\sum_{t=1}^{n} PriceEC_t * QuantityEEC_t\right\}, \\ PV\left\{\sum_{t=1}^{n} PriceSC_t * QuantityESC_t\right\} \end{bmatrix}, & if\ exercised \\ PV\left\{\sum_{t=1}^{n} PriceSC_t * QuantityESC_t - \sum_{t=3}^{n} RevenueMSC_t\right\}, & if\ not\ exercised \end{cases}$$

where (18)

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

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

$QuantityEEC_t$ is the quantity of energy cane harvested in period t from the expanded acres

$PriceSC_t$ is the price of sugarcane in period t

$QuantityESC_t$ is the quantity of sugarcane that would have been harvested from the expansion-contracted acres in period t if the total acreage had been in sugarcane from t=0. This represents the sacrificed sugar revenue that the grower would have realized if the expanded acres had stayed in sugarcane instead of moving to energy cane.

$RevenueMSC_t$ 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 prices and quantity figures are given by:

$$PriceSC_t = CRS_t * SP_t * GSHRS \tag{19}$$

$$PriceEC_t = Eth/EC_t * EP_t * GSHRETH \tag{20}$$

$$QuantityEEC_t = ECaneYield_t * ExpansionAcresEC_t \tag{21}$$

$$QuantityESC_t = SCaneYield_t * ExpansionAcresEC_t \tag{22}$$

In addition, the mill equations are somewhat changed. The changes are highlighted below in bold print.

GROSS PROFIT = SALES – COST OF SALES (23a)

NET INCOME = GROSS PROFIT – FACTORY EXPENSES – **CAPITAL COSTS**(23b)

where SALES = revenues from sugar, molasses, and ethanol

COST OF SALES = inventory and shipping costs

FACTORY EXPENSES = costs of operation and factors of production

CAPITAL COSTS = purchase and depreciation costs from building the plant expansion

The supporting equation "COSTOFSALES" is now:

COSTOFSALES = (24)

[(TONS x TRS x LQF x SP x GSHRS)

+ (TONS x MOL/TON x MP x GSHRM)]

+ (TONS x CANEFREIGHT)

+ (TONS x SUGFREIGHT)

+ [(ECTONS x ETH/EC x EP x GSHRETH)

+ (SSTONS x ETH/SS x EP x GSHRETH)]

+ (ECTONS x CANEFREIGHT)

+ (SSTONS x CANEFREIGHT)

+ DENATURANTCOSTS

+ SACRIFICE COSTS

where

SACRIFICE COSTS = costs incurred if expanded feedstock acres are contracted for but the expansion is not built

Economic Shocks to the Collocated Ethanol Plant

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 significantly outperforms expectations, the price that the plant would have to pay for energy cane would also climb steeply, increasing production costs and decreasing profits. The timeline of the shock and option relationship is shown in Figure 7.

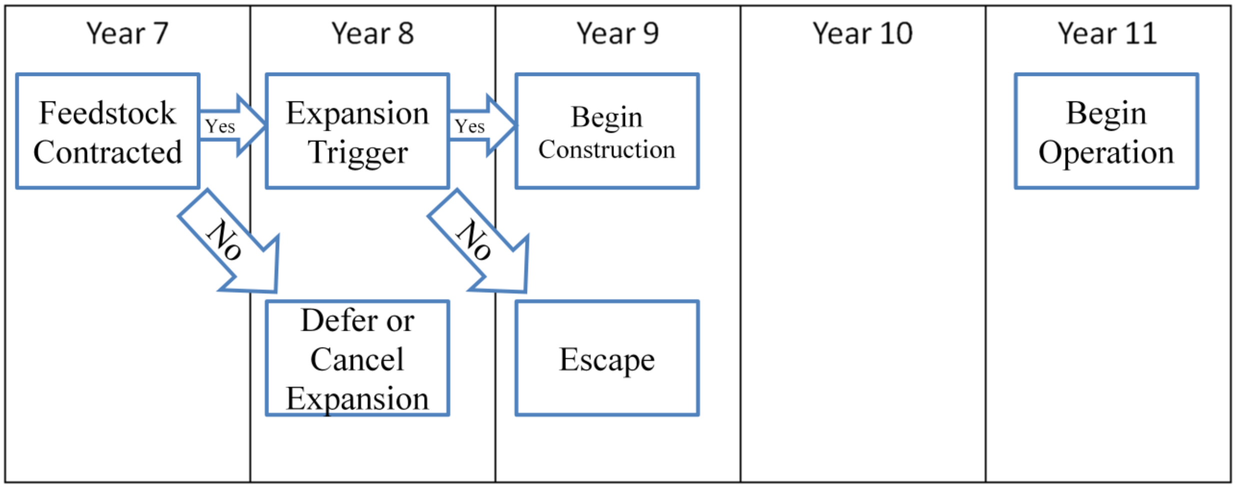

Figure 7 - A Timeline of the Expansion Option

In the modeled timeline, the expanded feedstock decision happens in the seventh year. This is when the option to expand is purchased via the feedstock contract. Between that point and the ninth year, if any market or parameter changes indicate that expanding the plant would become a losing proposition, the option is allowed to expire, the expansion is not built, and the sacrifice costs are incurred. If the ninth year is reached without any expansion trigger turning negative, then the option is exercised, the strike (construction) price is paid, and construction begins. Roughly two years later, the expanded plant is up and running. Detail of the expansion trigger structure is given in Figure 8.

In this case, each of the triggers is structured such that a “Yes” result from the binary question means that the expansion should not be built. If all three triggers remain in the “No” state until the expiration/exercise date of the option, then the option is exercised. If even one turns to “Yes,” the option is allowed to expire, the expansion is not built, and the sacrifice costs are incurred.

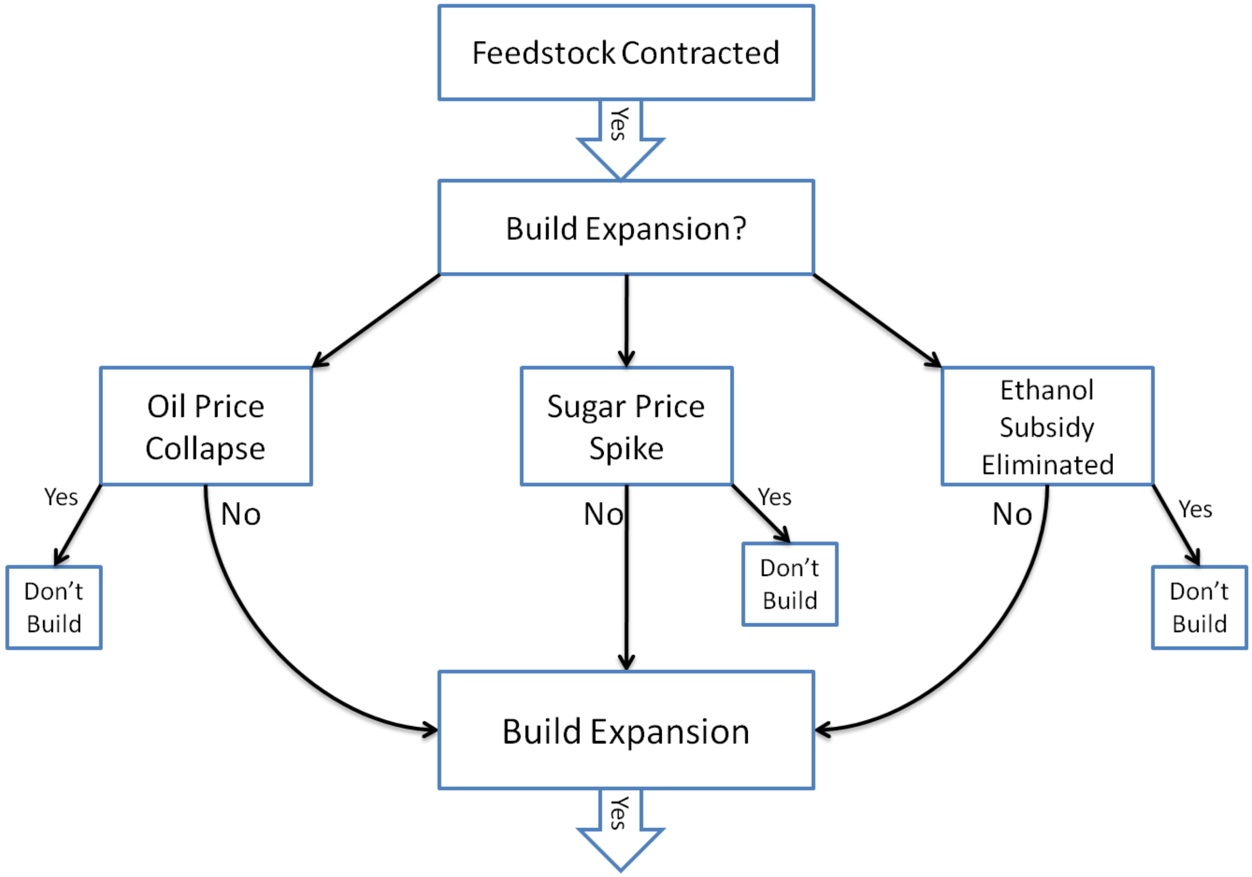

Figure 8 - Flowchart for the Plant Expansion Trigger

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).

CHAPTER 4: RESULTS AND DISCUSSION

The models developed over the course of this research were used to study three different types of questions so, while the results are interrelated in content, they are herein broken down by objective. The models for each of the objectives were simulated in Simetar over 10,000 iterations using the random seed value of 31517, Simetar's default value. Results for each will be summarized and briefly discussed in this chapter, and conclusions will be offered in Chapter 5.

Objective 1 – Standalone Ethanol Plant

For the first objective, a standalone cellulosic ethanol facility was modeled and three feedstock supply scenarios were examined. Using stochastic input and output parameters, the model was simulated over ten thousand iterations. In all of these results tables, the "mean" represents the mean value obtained for the NPV of the tested scenario when the simulation is run for thousands of iterations. The other summary statistics also relate to those iterated results in the same manner.

In general, all scenarios had positive NPVs for the twenty-five year time horizon examined at a 12% discount rate. Of the three scenarios, the first, using just bagasse sourced from local mills, has the highest mean NPV at $29.6 million. As the processor diversifies their feedstocks, NPV for the plant decreases, so the second scenario, with the addition of sweet sorghum, is the next highest, and the third, which adds energy cane, is the lowest. One explanation for this is that as the plant diversifies into other feedstocks, the overall gallons per ton of feedstock diminished, since bagasse is the most theoretically-efficient of the feedstocks. In addition, scenario one has the least variability in expected NPV, as measured by the coefficient of variation (CV). The third scenario has a very high CV, meaning that a risk-averse processor might not take on the project, regardless of its positive NPV. The value of the CV is over 100, indicating that the standard deviation of the NPV is larger than the mean, making this a very risky project overall.

Table 9 – Standalone Ethanol Plant Feedstock Scenario Net Present Values (NPV)

	Just Bagasse Scenario	**Bagasse and SSorg Scenario**	**Bagasse, SSorg, and ECane Scenario**
Mean	$29,600,000	$15,400,000	$4,170,000
StDev	5,720,000	5,790,000	5,800,000
CV	19.2	37.6	139
Min	$11,400,000	($2,810,000)	($14,100,000)
Max	$46,500,000	$32,500,000	$21,200,000

The large positive expected NPV for the first scenario provides evidence that, under these assumptions, the construction of a 10 million gallon per year bagasse ethanol facility would be profitable. Furthermore, it would provide an answer for the first mover problem and let the processor have additional time to allow feedstock producers to be contracted with for the production of alternative feedstocks. The large positive NPV for scenario one also could allow for the possibility of transportation costs to rise significantly. This is important because this plant is a standalone plant and all feedstocks have to be trucked to the plant from one of the eleven sugar mills in the state.

From this analysis it seems that sweet sorghum may be a good option as a second feedstock as shown in scenario two. This is due to several reasons. First, sweet sorghum allows the feedstock producers to respond quicker to market signals coming from the ethanol industry relative to energy cane. Second, sweet sorghum is capable of producing the same amount of ethanol per ton as energy cane, so it is no more vulnerable to pressures like high transportation costs per ton. Third, the cost to purchase sweet sorghum is significantly lower if sweet sorghum is being produced on fallow sugarcane lands. If the acres used are not fallow lands, additional planting costs would make the cost of this feedstock almost double, decreasing the NPV.

The third scenario provides the lowest NPV of the scenarios examined. Partially, this is because current energy cane varieties are expensive to source because their yields are nearly the same as sugarcane. As the genetics for this crop improve and yields are driven up, the cost to source this feedstock will fall. According to Mark et al. (2009) energy cane yields could reach 50 plus tons per acre, reducing their calculated feedstock cost from $27.00 per ton to less than $20. The pricing model used in this model bases energy cane prices largely on sugar prices, but the principle is similar: higher yields lead to lower costs per ton. Furthermore, one other issue with contracting for energy cane is it will reduce the flexibility of the processor and the producer's ability to respond to changing market conditions. This inflexibility and uncertainty is addressed in objective three.

The main reason the standalone plant seems to suffer from the addition of harvested feedstocks is that additional capital expenditure is required to move from pre-ground feedstocks like bagasse. Specifically, the plant must invest in grinders and rollers to process either sweet sorghum or energy cane, whereas bagasse requires neither. This is part of the rationale that lead to the development of a collocation strategy, as detailed in the rest of this research.

Sensitivity Analysis

Two key drivers to this model are ethanol prices, which determine the expected value of the revenue stream, and transportation costs, which are a relatively large cost of production that is subject to large-term uncertainty. In general, scenarios one and two are both less responsive to either ethanol prices or transportation costs, with scenario one being the most robust to these changes overall.

Given that its primary revenue stream will be the sale of ethanol, it makes sense that ethanol price is a key driver of plant profitability. In scenario one, a 15% decrease in average projected ethanol prices leads to an 85% decrease in expected NPV, while a 15% increase in price leads to an 82.7% increase in expected NPV.

Table 10 –Effect of Ethanol Price Changes on the Bagasse Scenario NPV

	Base EP	**15% decrease in EP**	**15% increase in EP**
Mean	$29,600,000	$4,350,000	$54,200,000
% diff		-85%	83%
StDev	5,720,000	4,960,000	6,190,000
CV	19.3	114	11.4
Min	$11,400,000	($11,200,000)	$34,100,000
Max	$46,500,000	$18,900,000	$71,500,000

For scenario two, the decrease in ethanol price leads to a decrease in NPV of 165.6%, and the increase in prices leads to an NPV increase of 161.46%. For scenario three, the numbers are even more drastic. A 15% decrease in the price of ethanol leads to a 619.5% decrease in mean expected NPV, while a 15% increase leads to a 599% increase in NPV.

Table 11 - Effect of Ethanol Price Changes on the Bag. + SSorg. Scenario NPV

	Base EP	**15% decrease in EP**	**15% increase in EP**
Mean	$15,400,000	($10,100,000)	$40,300,000
% diff		-165%	161%
StDev	5,790,000	4,990,000	6,370,000
CV	37.6	-49.4	15.8
Min	($2,820,000)	($25,600,000)	$19,800,000
Max	$32,500,000	$4,540,000	$58,700,000

Table 12 - Effect of Ethanol Price Changes on the Bag. + SSorg. + ECane Scenario NPV

	Base EP	**15% decrease in EP**	**15% increase in EP**
Mean	$4,170,000	($21,600,000)	$29,100,000

% diff		-619%	599%
StDev	5,790,000	5,070,000	6,360,000
CV	139	-23.4	21.8
Min	($14,100,000)	($37,800,000)	$8,590,000
Max	$21,200,000	($6,860,000)	$47,500,000

These numbers show that, as expected, the cellulosic ethanol facility is highly sensitive to ethanol prices, regardless of feedstock strategy. However, they also show that, while the diversified feedstock strategy represented by scenario three is not likely to be attractive under the default assumptions, a 15% increase in ethanol prices makes the strategy significantly more attractive. In fact, not only is the NPV much higher, but the CV drops to 21.8, indicating that it is a much less risky strategy with these elevated prices that it is under the default assumptions. In fact, just a 5% increase in average expected ethanol prices offers significant improvements, resulting in a $12.5 million mean NPV and a CV of 47.7. This is encouraging, as there is not enough excess bagasse available in the state to be able to obtain commercially-significant quantities of cellulosic ethanol without the use of significant levels of energy crops, and energy cane is perhaps best situated to fill the gap in the longer term, so scenario three is the one that is likely closest to what a commercial plant in Louisiana would look like. Additionally, if cost reductions could be realized via strategies like collocation with a sugar mill, this feedstock portfolio might be considerably more viable.

Lastly, transportation costs are very important for cellulosic ethanol facilities. Given that many potential biomass crops are high in moisture content, transportation costs have the potential to be a very large driver of production costs and hence profitability. Increasing transportation costs for a cellulosic ethanol feedstock can come from two directions. One is an increase in the moisture-to-fiber ratio, leading to more weight being transported for the same amount of fiber. The crops studied in this research are very high in moisture content, but it comes in the form of juices high in fermentable sugars, so the moisture-to-fiber ratio is considerably less important than it would be for some other energy crops like miscanthus or switchgrass. More important to this research is the second source of transportation cost variability: the cost per truckload. The transportation model for this research is based on the actual practices used in the sugarcane industry, in which costs are essentially static on a per-truck-mile basis. However, the trip cost can increase either by increasing the number of miles that each trip averages, or by increasing the per-mile cost. To capture both potential effects at once, the value that was varied was the actual per-truckload cost.

In scenario one, a 15% increase in transportation cost resulted in a 5% decrease in mean expected NPV, and vice versa for a decrease in transportation costs.

Table 13 – Effect of Transportation Costs on Bagasse Scenario NPV

	Base TCosts	**15% decrease in TC**	**15% increase in TC**
Mean	$29,600,000	$31,100,000	$28,200,000
% diff		5.01%	-5.02%
StDev	5,720,000	5,700,000	5,730,000
CV	19.2	18.3	20.4
Min	$11,400,000	$12,900,000	$9,930,000
Max	$46,500,000	$47,900,000	$45,100,000

For scenario two, a 15% change in transportation costs resulted in an NPV change of 13% in the opposite direction. For scenario three, wherein energy cane is the primary feedstock, a 15% change in transportation costs resulted in an NPV change of 55% in the opposite direction. In addition, while scenario one and two only saw a small increase in variability as measured by CV, scenario three saw a very large jump in variability when transportation costs increase. This variability is so high that, while NPV is still positive, a risk averse processor would be quite unlikely to adopt the project under those circumstances. A 15% decrease in transportation costs, however, brings the CV down below 100, making the project considerably more attractive to a risk-averse processor. Again, this shows that the preferred scenario, with diverse feedstocks, is not far from being a viable prospect, and if the assumptions in the model are only slightly pessimistic in some parameters, this sort of plant might actually be feasible.

Each model and scenario in this study was run using a 12% discount rate. This rate was sensitivity tested and it was found that each increase of two percentage points resulted in a decrease in mean NPV value by 26% from the previous value.

Table 14 - Effect of Transportation Costs on Bag + SSorg Scenario NPV

	Base TCosts	**15% decrease in TC**	**15% increase in TC**
Mean	$15,400,000	$17,400,00	$13,400,000
% diff		12.9%	-12.9%
StDev	5,790,000	5,780,000	5,790,000
CV	37.6	33.2	43.2
Min	($2,820,000)	($841,000)	($4,790,000)
Max	$32,400,000	$34,500,000	$30,500,000

Table 15 - Effect of Transportation Costs on Bag + SSorg + ECane Scenario NPV

	Base TCosts	**15% decrease in TC**	**15% increase in TC**
Mean	$4,170,000	$6,460,000	$1,870,000
% diff		54.9%	-55.1%
StDev	5,790,000	5,780,000	5,800,000
CV	139	89.5	**310**
Min	($14,000,000)	($11,700,000)	($16,300,000)
Max	$21,200,000	$23,500,000	$18,900,000

Objective 2 – Collocated Ethanol and Sugar Mill

For the second objective, a representative Louisiana sugar mill was modeled, and then simulations of both a conventional sugar ethanol plant and a cellulosic ethanol plant were added to model a collocated bioprocessing facility.

In the case of the base sugar mill, the simulation model produces results in line with prior expectations. The baseline case for the sugar mill produces an NPV of $28.7 million. As Table 16 shows, this proves highly sensitive to sugar prices, especially on the upside.

Table 16 – Effect of Sugar Price Changes on Standalone Sugar Mill NPV

	Baseline	10% Decrease	10% Increase	15% Decrease	15% Increase
Mean	$ 28,700,000	$ 22,700,000	$ 38,600,000	$ 22,400,000	$ 43,600,000
StDev	$ 2,050,000	$ 1,740,000	$ 2,300,000	$ 1,740,000	$ 2,420,000
CV	7.16	7.69	5.96	7.76	5.56
Min	$ 21,600,000	$ 15,300,000	$ 30,900,000	$ 15,200,000	$ 35,500,000
Max	$ 35,200,000	$ 28,300,000	$ 45,800,000	$ 28,200,000	$ 51,100,000

A 10% increase in the mean price of sugar produces a 35% increase in NPV, while a 15% increase results in an increase of 52%. On the downside, the effects are somewhat different. Both a 10% decrease and a 15% decrease in the mean price of sugar result in a roughly 20% decrease in NPV. The reason for this mitigation of the downside is the US sugar policy which currently has a forfeiture price of 19.81 cents per pound of sugar. When the sugar price trend is allowed to drop by large amounts, that forfeiture price is triggered more and more often, so the sugar price effectively becomes fixed at 19.81 cents per pound.

The mill is much less sensitive to the price of molasses, which is again as expected since molasses makes up a much smaller share of a mill's revenue. In each scenario tested, the largest effect was still less than a 4% change in NPV, as can be seen in Table 17.

Table 17 – Effect of Molasses Price Changes on Standalone Sugar Mill NPV

	Baseline	5% Decrease	5% Increase	15% Decrease	15% Increase
Mean	$ 28,700,000	$ 28,400,000	$ 29,000,000	$ 27,700,000	$ 29,700,000
StDev	$ 2,050,000	$ 2,050,000	$ 2,060,000	$ 2,040,000	$ 2,070,000
CV	7.16	7.22	7.10	7.35	6.99
Min	$ 21,600,000	$ 21,300,000	$ 21,900,000	$ 20,700,000	$ 22,500,000
Max	$ 35,200,000	$ 34,800,000	$ 35,600,000	$ 34,100,000	$ 36,300,000

In the previous section, results showed that a standalone cellulosic ethanol plant could be highly sensitive to changes transportation costs. The sugar mill also has to transport a feedstock with high moisture content, and is expected to show some sensitivity to transportation costs. However, as Table 18 shows, the effect is relatively minor.

Table 18 – Effect of Transportation Cost Changes on Standalone Sugar Mill NPV

	Baseline	**5% Decrease**	**5% increase**	**10% increase**	**15% increase**
Mean	$ 28,700,000	$ 30,300,000	$ 27,100,000	$ 25,500,000	$ 23,800,000
StDev	2,080,000	2,090,000	2,060,000	2,050,000	2,030,000
CV	7.26	6.92	7.63	8.06	8.56
Min	$ 22,200,000	$ 23,800,000	$ 20,600,000	$ 18,900,000	$ 17,300,000
Max	$ 34,700,000	$ 36,300,000	$ 33,000,000	$ 31,300,000	$ 29,700,000

Table 19 summarizes the results for the two attempts to make Brazilian-style sugar ethanol. As can be clearly seen, the value of the project drops precipitously when the third-strike ethanol plant is added.

Table 19 – Summary of Sugar Ethanol Scenario NPVs

	Sugar Mill	**Third Strike Ethanol**	**100% Sugar to Ethanol**
Mean	$ 28,700,000	$ (21,700,000)	$ (22,700,000)
StDev	2,060,000	2,830,000	11,800,000
CV	7.18	-13.1	-52.0
Min	$ 21,800,000	$ (30,600,000)	$ (57,500,000)
Max	$ 35,200,000	$ (12,500,000)	$ 15,800,000

When all of the sugar production is redirected to ethanol, things get even worse. The central insight here is that there is so little actual ethanol that can be produced in this manner that the add-on ethanol plant cannot generate enough revenue to pay for itself. In Louisiana the sugar production season is about 3 months, which is the only period during which the plant would have feedstock available. In Brazil, this period lasts at least 6 months in most years. Running at about 25% capacity, Louisiana’s mills simply cannot produce enough product to make it worthwhile.

The next phase is to examine the collocated cellulosic ethanol plant to see if it performs any differently. Tables 14 through 16 summarize the results for three basic scenarios. In Table 20, the assumption is that the sugar mill is unable to obtain any outside bagasse and so it is limited strictly to the excess bagasse produced onsite and not burned for power. This should be considered a worst-case scenario. In the case where the ethanol plant is collocated (Sugar & Bagasse), the project has a negative NPV. For a standalone plant running the same amount of bagasse (Just Bagasse) the situation is even worse. This project would never go forward unless significantly more bagasse were available and contracted for ahead of time.

Table 20 – Summary for Cellulosic Ethanol Plant NPV at 25% Capacity

	Just Sugar	Sugar & Bagasse	Just Bagasse
Mean	$ 28,700,000	$ (12,700,000)	$ (47,500,000)
StDev	2,060,000	2,910,000	1,200,000
CV	7.19	-22.9	-2.53
Min	$ 21,800,000	$ (22,200,000)	$ (50,800,000)
Max	$ 35,100,000	$ (2,900,000)	$ (43,700,000)

Table 21 summarizes a more realistic scenario. The assumption underlying this case is that the mill has managed to contract for excess bagasse from one or two other mills, securing enough feedstock to run the plant at about half capacity. Unlike with sugar juice, bagasse is a feedstock that can be stored for significant amount of time without catastrophic losses from degradation. There are some losses during storage, but they are manageable, at less than 1% per month. With this additional stored feedstock, the collocated case is much improved over the previous scenario. The project actually does have a positive NPV, but the option to take on the project would still have a negative value to a previously-existing sugar mill, as the do-nothing

(Just Sugar) case has about $21 million greater value. And again, the standalone case is even worse.

Table 21 - Summary for Cellulosic Ethanol Plant NPV at 50% Capacity

	Just Sugar	Sugar & Bagasse	Just Bagasse
Mean	$ 28,700,000	$ 7,860,000	$ (25,300,000)
StDev	2,060,000	3,310,000	2,210,000
CV	7.18	42.1	-8.71
Min	$ 21,700,000	$ (2,990,000)	$ (31,500,000)
Max	$ 35,100,000	$ 19,100,000	$ (18,200,000)

Finally, Table 22 summarizes the ideal case, and the one that would be most likely to occur if this plant were ever built. It is unlikely that funding could be secured for the project unless guaranteed feedstocks were contracted for such that the plant could run efficiently. This third case assumes just such a situation, where the ethanol plant can run at or near full capacity. The situation here is dramatically different from the previous two cases. For the collocated plant, the NPV is positive and greater than the do-nothing case, meaning the project has positive value for a previously-existing sugar mill. The standalone plant from objective one also has a positive value, roughly equal to the sugar mill's value, coincidentally.

Table 22 - Summary for Cellulosic Ethanol Plant NPV at Full Capacity

	Just Sugar	Sugar & Bagasse	Just Bagasse
Mean	$ 28,600,000	$ 60,700,000	$ 28,900,000
StDev	2,060,000	5,570,000	5,510,000
CV	7.18	9.18	19.0
Min	$ 21,700,000	$ 44,700,000	$ 12,600,000
Max	$ 35,100,000	$ 78,600,000	$ 46,400,000

What is especially interesting about this case is that it vividly illustrates the actual value of collocation, even for a plant running just on bagasse with no harvested feedstocks. If you take the sum of the two standalone plants, and subtract this from the collocated plant, the difference comes out to $3 million. This represents the additional value of producing sugar and bagasse-ethanol together at the same facility rather than at separate locations. This value comes from two primary sources: savings on transportation costs, and the freely available nature of the onsite bagasse. It is assumed that all bagasse that comes from an external mill will be purchased, whereas the bagasse used from the onsite excess is free. In fact, there is a negative cost associated with it due to the avoided cost of landfilling the excess, but for the purposes of this model, it was left at zero. There is still a handling cost associated with the local material, but the savings from transportation and purchasing is great enough to make a strong case for collocation. If the collocated plant were running on harvested feedstocks like energy cane, the value of collocation would be even higher, due to the fact that the grinders and rollers needed to preprocess the cane are already part of the sugar mill.

Finally, Table 23 shows the sensitivity of this collocated plant to the price of ethanol. The projected ethanol prices were varied by the percentages shown, and the effects were dramatic. For each 5% change in the price of ethanol, the NPV changed by about 13% in the same direction. This is as expected.

Table 23 – Effect of Ethanol Price Changes on Collocated Cellulosic Ethanol Plant NPV

	Baseline	**5% Decrease**	**5% Increase**	**15% Decrease**	**15% Increase**
Mean	$ 60,700,000	$ 52,800,000	$ 68,600,000	$ 36,500,000	$ 83,900,000
StDev	$ 5,910,000	$ 5,810,000	$ 5,990,000	$ 5,560,000	$ 6,190,000
CV	9.71	11.01	8.74	15.22	7.38
Min	$ 39,200,000	$ 32,000,000	$ 46,500,000	$ 17,500,000	$ 60,900,000
Max	$ 82,200,000	$ 74,100,000	$ 90,300,000	$ 57,100,000	$ 106,000,000

Table 24 summarizes the same collocated plant's sensitivity to the price of sugar. On the upside, the plant is still quite sensitive to sugar, though not so much as in the standalone sugar mill case. For each 5% increase in mean sugar prices, the NPV increases by about 9%.

Table 24 – Effect of Sugar Price Changes on Collocated Cellulosic Ethanol Plant NPV

	Baseline	5% Decrease	5% Increase	15% Decrease	15% Increase
Mean	$ 60,700,000	$ 56,200,000	$ 66,100,000	$ 53,800,000	$ 76,800,000
StDev	$ 5,900,000	$ 5,940,000	$ 5,820,000	$ 5,930,000	$ 5,690,000
CV	9.71	10.56	8.81	11.03	7.41
Min	$ 39,200,000	$ 34,000,000	$ 45,100,000	$ 29,900,000	$ 56,400,000
Max	$ 82,200,000	$ 77,400,000	$ 87,300,000	$ 75,300,000	$ 97,500,000

On the downside, the sugar forfeit price comes back into play. The first 5% decrease reduces NPV by about 7%, but then the decreases in value taper off until they level out at about an 11% reduction overall, when sugar price is essentially constant at the forfeiture price.

Objective 3 – Expanded Ethanol and Sugar Mill Under Uncertainty

For the third objective, the base model for objective two was used to develop a model of a commercial-scale cellulosic ethanol plant with a seventy million gallon annual capacity. To enable the research to study strategic decisions under risk, this larger-capacity plant was modeled as an optional expansion that could be built upon the existing mill if certain conditions were met. Then, systemic shocks were modeled to create conditions of uncertainty under which the expansion decision could be examined.

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. As in the rest of the simulated models, the base case was simulated over a 25-year period and the model was run for ten thousand iterations. 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 25.

Table 25 - Expanded Collocated Cellulosic Ethanol Plant NPV without Uncertainty Shocks

No Shocks - Base Case	
Mean	$149,000,000
StDev	$11,100,000
CV	7.46
Min	$115,000,000
Max	$183,000,000

Because each of the three tested market shocks are truly uncertain and their likelihood cannot be estimated with any accuracy, 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. 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 non-flexible NPV analysis, and can be found on Table 26. The second value is found on Table 27, and is the value of the project when management is able to be flexible and allow the expansion option to expire if market conditions change between the option purchase and expiration date. Finally, Table 28 has the summary statistics for the differences, which describe the value of the real option to expand or not.

Table 26 - Summary of the No-Option Scenario NPV with Shocks

	No-Option case at 25% chance of shocks		
	Oil Price	Eth Subsidy	Sugar Price
Mean	$114,000,000	$133,000,000	$121,000,000
StDev	$62,500,000	$29,100,000	$49,100,000
CV	54.5	21.8	40.3
Min	($50,600,000)	$61,500,000	$8,830,000
Max	$183,000,000	$183,000,000	$183,000,000

Table 27 - Summary of the Real Options Scenario NPV with Shocks

	Real Option Strategy at 25% chance of shocks		
	Oil Price	Eth Subsidy	Sugar Price
Mean	$121,000,000	$124,000,000	$132,000,000
StDev	$ 50,600,000	$ 44,600,000	$ 31,700,000
CV	41.8	35.8	24.0
Min	$8,280,000	$35,500,000	$65,100,000
Max	$183,000,000	$183,000,000	$183,000,000

Table 28 - Value of the Real Option to expand under 25% shock likelihood

	Summary Stats of Differences at 25% shock		
	Oil Price	Eth Subsidy	Sugar Price
Mean	$6,500,000	($9,480,000)	$10,200,000
StDev	$14,000,000	$16,800,000	$18,200,000
Min	($26,000,000)	($58,300,000)	$0.00
Max	$69,100,000	$0.00	$58,900,000

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 28 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 million.

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, 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 certainty 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 29 through 31 have the data for the 25% shock probability case arranged by each shock. Values from the cumulative density function (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. Indeed, Table 32 shows how sensitive the base model (without shocks) is to oil prices. A 15% change in average expected oil price results in an expected value change of 30% in the same direction.

Finally, Table 33 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.

Table 29 – Effect of the Oil Price Shock on project value at 25% likelihood

	Oil Price Shock		
	Must Build	**Real Option**	**difference**
min	($50,600,000)	$8,280,000	$58,900,000
5%	($7,200,000)	$28,800,000	$36,000,000
25%	$80,400,000	$54,300,000	($26,000,000)
50%	$144,000,000	$144,000,000	$0.00
75%	$154,000,000	$154,000,000	$0.00
95%	$167,000,000	$167,000,000	$0.00
mean	**$114,000,000**	**$121,000,000**	**$6,500,000**
SD	$62,500,000	$50,600,000	($11,800,000)
CV	54.5	41.8	(12.7)

Table 30 – Effect of the Ethanol Subsidy Shock on project value at 25% likelihood

	Ethanol Subsidy		
	Build	**Option**	**difference**
min	$61,500,000	$35,500,000	($25,900,000)
5%	$78,900,000	$44,600,000	($34,200,000)
25%	$115,000,000	$60,500,000	($54,900,000)
50%	$144,000,000	$144,000,000	$0.00
75%	$154,000,000	$154,000,000	$0.00
95%	$166,000,000	$166,000,000	$0.00
mean	**$133,000,000**	**$124,000,000**	**($9,480,000)**
SD	$29,100,000	$44,600,000	$15,400,000
CV	21.8	35.8	14.1

Table 31 – Effect of the Sugar Price Shock on project value at 25% likelihood

Sugar Price Shock			
	Build	Option	difference
min	$8,830,000	$65,100,000	$56,300,000
5%	$29,500,000	$75,500,000	$46,000,000
25%	$67,800,000	$92,100,000	$24,200,000
50%	$144,000,000	$144,000,000	$0.00
75%	$154,000,000	$154,000,000	$0.00
95%	$166,000,000	$166,000,000	$0.00
mean	**$121,000,000**	**$132,000,000**	**$10,200,000**
SD	$49,100,000	$31,700,000	($17,300,000)
CV	40.3	24.0	(16.2)

Table 32 – Effect of Oil Price Changes on Collocated Cellulosic Ethanol NPV without Shocks

	Base Model	15% decrease	15% increase
Mean	$149,000,000	$103,000,000	$195,000,000
% diff		-30.60%	30.4%
StDev	10,700,000	10,600,000	10,800,000
CV	7.17	10.2	5.56
Min	$120,000,000	$75,700,000	$165,000,000
Max	$179,000,000	$132,000,000	$225,000,000

Table 33 – Value of Ethanol Plant Expansion Option at tested Shock Likelihoods

Probability	Oil	Eth Subsidy	Sugar
0.05	$1,480,000	($1,970,000)	$2,050,000
0.25	$6,500,000	($9,480,000)	$10,200,000
0.5	$13,000,000	($18,700,000)	$20,200,000
0.75	$19,600,000	($28,100,000)	$30,600,000
0.95	$24,300,000	($35,500,000)	$38,800,000

CHAPTER 5: SUMMARY AND CONCLUSIONS

By 2022, the United States must grow from producing roughly zero gallons of advanced biofuel per year to producing 21 billion gallons per year. In order to reach this capacity, significant investments will have to be made in cellulosic ethanol feedstocks and in processing capacity. Many different parts of the country offer potential opportunities for development of feedstocks and processing capacity, and our domestic fuel needs will require all participating markets to use their natural resource endowments and infrastructural advantages to produce the feedstocks and fuels for which they are best suited.

Louisiana has an agricultural infrastructure that is adept at transporting the vast quantities of moisture-dense biomass that will be required to produce cellulosic ethanol. In addition, the state has many pre-existing bioprocessing facilities in the form of sugar mills, each of which is situated in locations that are ideal for the sourcing of large quantities of feedstocks as well as the delivery of large amounts of end products. If a cellulosic ethanol industry could be built to coexist profitably with this underlying infrastructure, it could derive synergistic benefits from it and in turn provide diversified income streams to local participants in the supply chain.

The first question to examine is whether it would be feasible to simply build a standalone advanced ethanol plant somewhere within the Louisiana sugar belt and operate on locally-sourced feedstocks. A representative cellulosic ethanol plant was modeled based on previous studies and utilizing an alkaline pretreatment process. The plant was tested with three different potential feedstocks: bagasse, sweet sorghum, and energy cane. A net present value analysis showed that the plant was economically feasible when using all three feedstocks, just bagasse and sweet sorghum, and also when using bagasse alone. Just using bagasse was the most profitable with an NPV of nearly $30 million, bagasse plus sweet sorghum was next with an NPV of $15 million, and the combination of all three feedstocks was last, with an NPV of about $4 million. In addition to being a more valuable project overall, the just-bagasse plant was also more robust to changes in market parameters such as ethanol price and transportation costs. However, there is not enough excess bagasse in the state of Louisiana to support more than one small or medium sized cellulosic ethanol plant. In addition, while sweet sorghum proved to be the least costly of the two harvested feedstocks, it grows far less densely than energy cane, and so a vastly-larger number of acres would be required to feed a plant of any given size. Due to these two factors, the lowest performing strategy, using all three feedstocks, is the most feasible long term strategy.

Partly in order to increase the feasibility of using a multiple-feedstock portfolio for a Louisiana cellulosic ethanol plant, a representative Louisiana sugar mill was examined as a possible place to collocate the ethanol plant. A sugar mill offers synergistic benefits to such an ethanol plant from two directions, cost savings via sourcing local bagasse from the mill, and capital savings from reusing the grinders to process the energy cane and sweet sorghum. The sugar mill was examined by itself, and then in conjunction with a Brazilian-style sugar ethanol plant running on the "third strike" of sugar. This was found to be not feasible, which is in line with previous research into the subject. When the cellulosic ethanol plant is incorporated into the sugar mill model running on bagasse, the cost savings from sourcing local material were found to be significant. The plant could not running solely on the excess bagasse produced at the collocated sugar mill, but the cost savings were still substantial, amounting to some $3 million of value over the course of the simulated time period. The sugar mill was found to be profitable on its own, and the ethanol plant was similarly valuable on its own, but the combined operation was the most desired once the plant was able to operate at full capacity. With the ethanol plant operating at just half capacity, the combined mill was still profitable, but the standalone sugar mill was preferred.

Finally, a full-scale cellulosic ethanol plant was examined for potential collocation with a Louisiana sugar mill. This larger mill is completely dependent on a diversified feedstock portfolio, including bagasse, sweet sorghum, and energy cane. This feedstock group increases the value of collocation, since the sugar mill grinders could be used to preprocess both of the harvested feedstocks and the existing sugar mill transportation infrastructure could be used for feedstock acquisition. However, this larger size and increased exposure to uncertain market conditions and production parameters necessitated a reexamination of the risk and uncertainty involved in operation of the collocated ethanol plant. Real options analysis was chosen as a tool to help study the uncertainty surrounding the decision to expand from the smaller-scale plant previously studied to this larger plant with seven times the capacity. In order to study the effects of uncertainty, three negative shocks were modeled, and the mill's responses were examined to place a value on the different strategies. The real option to expand the plant was found to respond as expected to two of the three shocks, but counter to expectations for the third shock. That third shock was the complete removal of the direct ethanol subsidy, and it was found to unexpectedly have no effect on whether or not expanding the plant was the right decision. On the whole, the real options strategy saved millions of dollars in value over the traditional decision making tool (NPV analysis) when examined over thousands of iterations. In the case of the ethanol subsidy shock, the real options strategy lost money, since the option was structured to force the plant not to expand in the absence of the subsidy.

The ethanol industry in the United States is centered entirely around corn, the only significant feedstock currently in use. However, in order to meet both our national renewable fuels mandate and our general need for liquid fuels, our next generation biofuels will need to come from multiple different feedstocks. If Louisiana is going to be a participate in this advanced biofuel industry, it will need to leverage its unique natural resources and agricultural infrastructure to do so competitively. This body of research has shown that producing cellulosic ethanol can be an economically viable option for Louisiana, and has also shown that the state does have advantages that can be successfully leveraged to increase that viability.

There are limitations to this research, and some will need to be addressed to gain a better understanding of the future of cellulosic ethanol in Louisiana. Perhaps most importantly, this research focused strictly on the processor of the ethanol, and simply assumed that producers of the feedstocks could be found if sufficient compensation were offered. While this might be the case, it would be helpful to conduct a survey of various producer groups to gauge attitudes and willingness to participate in this market. Other factors can play a role in producers’ decisions about what crops to grow, and these could potentially change some of the feedstock realities faced by the processor. Additionally, this research assumed that local demand from consumers, blenders, and traders would be large enough to ensure that any quantity of ethanol produced would have a buyer. In reality, the transportation of ethanol over significant distances can be complicated and costly, so securing buyers of the ethanol would be advisable before any significant investment were made. As of now, since there is no local production of ethanol, large buyers likely do not have the capacity to purchase, blend, and transport the fuel from this area. This is unlikely to be an insurmountable issue, but some market research into ethanol buyers would help ascertain the seriousness of the situation.

There are other ways that this research can be expanded and developed further. Results could be incorporated from prior studies into how a cellulosic ethanol industry could affect the crop mix in Louisiana. This would help predict both the viability of any one crop strategy, and also might help pick more optimal strategies for any given location. Results from an optimal plant location study could help identify which locations in the state would be best to study for potential collocation, and some GIS modeling could help give a more complete idea of transportation costs for that plant. Additionally, some research on optimal pricing strategies for biomass could help determine how much room there is for a plant to increase offered prices if a willingness-to-participate study shows that producers are reticent to switch to energy crops.

This research is all targeted towards the Louisiana sugar belt, but the analytical framework developed in this study could be used to study any region, provided there is at least one potentially-viable cellulosic feedstock. Each region is different, and there are almost certainly other areas of the country that could benefit from the development of a local cellulosic ethanol industry. Stakeholders in this and other regions could use the results from this study or the tools developed in this research to help examine potential renewable energy projects in the future. Policymakers might find the results of this and future studies useful when considering renewable energy needs for the country as well as economic development needs for each region. Both the results and the tools developed can help determine how our energy goals can best be met, while also helping to support local industry and agricultural producers.

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APPENDIX A: FORECAST MEANS

Table 34 - Yearly Wholesale Ethanol Price Forecasts over 1,000 iterations. USD/gallon

Year	Mean
2011	2.258819
2012	2.240297
2013	2.395652
2014	2.55192
2015	2.677986
2016	2.776475
2017	2.879741
2018	2.973996
2019	3.080912
2020	3.147907
2021	3.227569
2022	3.305437
2023	3.384977
2024	3.477872
2025	3.55686
2026	3.657385
2027	3.731153
2028	3.835057
2029	3.938628
2030	4.064737
2031	4.169384
2032	4.310554
2033	4.446056
2034	4.572915
2035	4.715463

Table 35 - Yearly Wholesale Sugar Price Forecasts over 1,000 iterations. US cents/pound

Year	Mean
2011	25.99479
2012	26.2405
2013	26.51642
2014	26.8099
2015	27.14681
2016	27.51583
2017	27.89573
2018	28.28676
2019	28.71201
2020	29.14581
2021	29.56914
2022	30.05175
2023	30.54396
2024	31.03412
2025	31.56421
2026	32.08902
2027	32.64479
2028	33.21671
2029	33.8205
2030	34.45348
2031	35.0985
2032	35.77728
2033	36.47498
2034	37.2151
2035	37.97172

Table 36 - Yearly Average Yield Forecast for Sugarcane over 1,000 iterations. Tons/acre

Year	Mean
2011	31.96775
2012	32.34478
2013	32.38596
2014	32.39891
2015	32.42567
2016	32.48701
2017	32.60208
2018	32.66596
2019	32.79536
2020	32.88783
2021	33.07801
2022	33.21816
2023	33.49157
2024	33.5956
2025	33.75356
2026	33.95541
2027	34.09312
2028	34.31991
2029	34.57077
2030	34.77167
2031	34.97613
2032	35.09384
2033	35.33811
2034	35.50721
2035	35.63764

Table 37 - Yearly Average Yield Forecast for Energy Cane over 1,000 iterations. Tons/acre

Year	Mean
2011	35.28371
2012	35.72135
2013	35.87853
2014	35.92166
2015	36.39543
2016	36.7822
2017	37.2582
2018	37.85843
2019	38.27753
2020	38.73206
2021	39.36813
2022	40.01768
2023	40.63695
2024	41.22748
2025	41.74749
2026	42.48347
2027	43.02179
2028	43.75113
2029	44.42829
2030	45.13952
2031	45.92144
2032	46.30593
2033	47.14084
2034	47.6208
2035	48.32249

Table 38 - Yearly Average Yield Forecast for Sweet Sorghum over 1,000 iterations. Tons/acre

Year	Mean
2011	24.86792
2012	25.28084
2013	25.52885
2014	25.83347
2015	26.22774
2016	26.75479
2017	27.29769
2018	27.84735
2019	28.37214
2020	28.90434
2021	29.462
2022	30.05082
2023	30.66054
2024	31.27998
2025	31.85383
2026	32.44748
2027	33.094
2028	33.69718
2029	34.33608
2030	34.95527
2031	35.5736
2032	36.16138
2033	36.7662
2034	37.34514
2035	37.92105

APPENDIX B: EXAMPLE SCENARIO BREAKDOWNS

Table 39 - Standalone Cellulosic Ethanol Plant Average Values Over 25 Years and 1,000 Iterations - Bagasse Only

SALES	
Bagasse Ethanol	$ 35,772,834.78
TOTAL GROSS SALES	**$ 35,772,834.78**
Transportation	$ 1,714,055.16
Feedstock costs	$ 6,269,907.76
Enzyme Costs	$ 588,893.49
Other costs	$ 2,210,540.11
handling and loss	$ 125,000.00
Denaturant Cost	$ 2,087,606.35
TOTAL VARIABLE EXP.	**$ 12,996,002.86**
TOTAL GROSS MARGIN	**$ 22,776,831.92**
Salaries	$ 807,163.55
Benefits	$ 322,865.42
Total Labor	**$ 1,130,028.97**
Production Expenses	$ 12,996,002.86
Total Variable and Conversion Costs	**$ 14,126,031.83**
Maintenance	$ 1,092,110.81
Insurance	$ 819,083.11
Property Tax	$ 273,027.70
Depreciation	$ 1,239,073.85
Interest	$ 1,150,222.69
Total Fixed	**$ 4,573,518.16**
Supplies	$ 6,639.78
Miscellaneous*	$ 10,623.65
Total Other	$ 17,263.42
TOTAL EXPENSES	**$ 18,716,813.42**
NET	**$ 17,056,021.36**

Table 40 - Standalone Cellulosic Ethanol Plant Average Values Over 25 Years and 1,000 Iterations - Bagasse and Sweet Sorghum

SALES	
Bagasse Ethanol	$ 24,763,704.87
S. Sorghum Ethanol	$ 11,009,443.35
TOTAL GROSS SALES	**$ 35,773,148.22**
Transportation	$ 2,417,075.25
Feedstock costs	$ 5,988,673.77
Enzyme Costs	$ 588,893.49
Other costs	$ 2,047,402.16
handling and loss	$ 125,000.00
Grinding Costs (ethanol)	$ 331,459.40
Denaturant Cost	$ 2,087,624.69
TOTAL VARIABLE EXP.	**$ 13,254,669.35**
TOTAL GROSS MARGIN	**$ 22,518,478.87**
Salaries	$ 1,614,327.11
Benefits	$ 645,730.84
Total Labor	**$ 2,260,057.95**
Production Expenses	$ 13,254,669.35
Total Variable and Conversion Costs	**$ 15,514,727.30**
Maintenance	$ 1,219,594.56
Insurance	$ 914,695.92
Property Tax	$ 304,898.64
Depreciation	$ 1,239,073.85
Interest	$ 1,284,489.93
Total Fixed	**$ 4,962,752.90**
Supplies	$ 13,279.56
Miscellaneous*	$ 21,247.29
Total Other	$ 34,526.85
TOTAL EXPENSES	**$ 20,512,007.05**
NET	**$ 15,261,141.17**

Table 41 - Standalone Cellulosic Ethanol Plant Average Values Over 25 Years and 1,000 Iterations - Bagasse, Sweet Sorghum, and Energy Cane

SALES	
Bagasse Ethanol	$ 8,177,075.13
E. Cane Ethanol	$ 16,671,507.92
S. Sorghum Ethanol	$ 11,009,443.35
TOTAL GROSS SALES	**$ 35,858,026.40**
Transportation	$ 3,061,469.53
Feedstock costs	$ 10,658,974.42
Enzyme Costs	$ 588,893.49
Other costs	$ 1,834,101.23
handling and loss	$ 125,000.00
Grinding Costs (ethanol)	$ 870,759.92
Denaturant Cost	$ 2,092,774.40
TOTAL VARIABLE EXP.	**$ 18,361,213.07**
TOTAL GROSS MARGIN	**$ 17,496,813.32**
Salaries	$ 1,614,327.11
Benefits	$ 645,730.84
Total Labor	**$ 2,260,057.95**
Production Expenses	$ 18,361,213.07
Total Variable and Conversion Costs	**$ 20,621,271.02**
Maintenance	$ 1,219,594.56
Insurance	$ 914,695.92
Property Tax	$ 304,898.64
Depreciation	$ 1,239,073.85
Interest	$ 1,284,489.93
Total Fixed	**$ 4,962,752.90**
Supplies	$ 13,279.56
Miscellaneous*	$ 21,247.29
Total Other	$ 34,526.85
TOTAL EXPENSES	**$ 25,618,550.77**
NET	**$ 10,239,475.62**

Table 42 - Collocated Cellulosic Ethanol Plant Average Values Over 25 Years and 1,000 Iterations - Bagasse Ethanol and Sugar

SALES	
Bagasse Ethanol	$ 35,770,669.79
SUGAR	$ 81,444,868.31
TOTAL GROSS SALES	**$ 117,207,317.18**
Transportation	$ 1,495,118.78
Feedstock costs	$ 5,371,844.26
Enzyme Costs	$ 588,893.49
Other costs	$ 2,210,540.11
handling and loss	$ 125,000.00
Denaturant Cost	$ 2,087,606.35
SUGAR PRODUCTION	$ 56,339,343.81
TOTAL VARIABLE EXP.	**$ 68,213,060.07**
TOTAL GROSS MARGIN	**$ 48,994,257.11**
Salaries	$ 1,614,327.11
Benefits	$ 645,730.84
Total Labor	**$ 2,260,057.95**
Production Expenses	$ 68,213,060.07
Total Variable and Conversion Costs	**$ 70,473,118.02**
Maintenance	$ 1,092,110.81
Insurance	$ 819,083.11
Property Tax	$ 273,027.70
Depreciation	$ 1,239,073.85
Interest	$ 1,150,222.69
SUGAR MILL	$ 11,177,153.91
Total Fixed	**$ 15,750,672.07**
Supplies	$ 13,279.56
Miscellaneous*	$ 21,247.29
Total Other	$ 34,526.85
TOTAL EXPENSES	**$ 86,257,617.37**
NET	**$ 30,949,699.81**

Table 43 - Collocated Cellulosic Ethanol Plant Average Values Over 25 Years and 1,000 Iterations - All-Feedstock Cellulosic Ethanol and Sugar

SALES	
Bagasse Ethanol	$ 8,177,075.13
E. Cane Ethanol	$ 16,671,507.92
S. Sorghum Ethanol	$ 11,009,443.35
SUGAR	$ 81,472,602.43
TOTAL GROSS SALES	**$ 117,330,628.82**
Transportation	$ 2,903,489.56
Feedstock costs	$ 9,760,748.16
Enzyme Costs	$ 588,893.49
Other costs	$ 1,834,101.23
handling and loss	$ 125,000.00
Grinding Costs (ethanol)	$ 870,759.92
Denaturant Cost	$ 2,092,774.40
SUGAR PRODUCTION	$ 56,357,196.32
TOTAL VARIABLE EXP.	**$ 73,662,203.16**
TOTAL GROSS MARGIN	**$ 43,668,425.67**
Salaries	$ 2,421,490.66
Benefits	$ 968,596.26
Total Labor	**$ 3,390,086.92**
Production Expenses	$ 73,662,203.16
Total Variable and Conversion Costs	**$ 77,052,290.08**
Maintenance	$ 1,092,110.81
Insurance	$ 819,083.11
Property Tax	$ 273,027.70
Depreciation	$ 1,239,073.85
Interest	$ 1,150,222.69
SUGAR MILL	$ 11,177,149.08
Total Fixed	**$ 15,750,667.24**
Supplies	$ 19,919.34
Miscellaneous*	$ 31,870.94
Total Other	$ 51,790.27
TOTAL EXPENSES	**$ 92,854,747.59**
NET	**$ 24,475,881.23**

Table 44 - Expanded Capacity Collocated Cellulosic Ethanol Plant Average Values Over 25 Years and 1,000 Iterations - All-Feedstock Cellulosic Ethanol and Sugar

SALES	
Bagasse Ethanol	$ 31,777,602.97
E. Cane Ethanol	$ 99,817,290.46
S. Sorghum Ethanol	$ 51,620,298.34
SUGAR	$ 81,472,602.43
TOTAL GROSS SALES	**$ 264,687,794.21**
Transportation	$ 14,415,316.28
Feedstock costs	$ 56,030,419.48
Enzyme Costs	$ 588,893.49
Other costs	$ 8,289,588.28
handling and loss	$ 125,000.00
Grinding Costs (ethanol)	$ 4,511,829.68
Denaturant Cost	$ 10,880,065.58
SUGAR PRODUCTION	$ 56,357,196.32
TOTAL VARIABLE EXP.	**$ 146,686,479.42**
TOTAL GROSS MARGIN	**$ 118,001,314.79**
Salaries	$ 3,228,654.21
Benefits	$ 1,291,461.68
Total Labor	**$ 4,520,115.90**
Production Expenses	$ 146,686,479.42
Total Variable and Conversion Costs	**$ 151,206,595.32**
Maintenance	$ 3,544,588.11
Insurance	$ 2,658,441.08
Property Tax	$ 886,147.03
Depreciation	$ 5,762,045.11
Interest	$ 4,895,145.74
SUGAR MILL	$ 11,177,149.08
Total Fixed	**$ 28,923,516.15**
Supplies	$ 26,559.12
Miscellaneous*	$ 42,494.58
Total Other	$ 69,053.70
TOTAL EXPENSES	**$ 180,199,165.17**
NET	**$ 84,488,629.04**

Table 45 - Expanded Capacity Collocated Cellulosic Ethanol Plant Revenue Details with 25 Sample Iterations - All-Feedstock Cellulosic Ethanol and Sugar

	Bagasse Ethanol	Energy Cane Ethanol	Sweet Sorghum Ethanol	Sugar	**TOTAL GROSS SALES**
Mean	$ 31,777,602.97	$ 99,817,290.46	$ 51,620,298.34	$ 81,840,236.03	**$ 265,584,755.36**
StDev	2,393,027.81	3,247,743.33	1,514,252.90	1,517,285.63	**4,859,044.35**
CV	7.53	3.25	2.93	1.85	**1.83**
Min	$ 25,461,612.18	$ 91,111,870.35	$ 46,623,868.29	$ 78,715,677.06	**$ 256,400,877.96**
Max	$ 38,736,642.17	$109,951,025.08	$ 56,928,381.92	$ 84,429,817.92	**$ 273,306,265.46**
Sample Iterations					
1	29480983.97	97168693.85	51047256.88	$78,715,677.06	$256,412,611.79
2	32315630.15	97427207.75	50140101.95	$79,296,590.66	$259,179,530.53
3	34104562.1	102471716.6	52088034.47	$83,517,644.27	$272,181,957.45
4	31319112.81	97850148.3	50690893.76	$81,407,928.14	$261,268,083.02
5	27728667.71	103155997.3	53447838.4	$83,645,652.77	$267,978,156.21
6	35126120.2	101234672.3	52486189.8	$80,422,468.96	$269,269,451.27
7	35358258.7	103636958.9	53214755.66	$81,096,292.23	$273,306,265.46
8	35011650.64	101549999.3	51388378.97	$82,599,146.23	$270,549,175.14
9	31413907.82	102316367.8	53665613.11	$82,362,565.24	$269,758,453.95
10	31213413.66	101552693.2	53027904.55	$81,871,036.57	$267,665,047.94
11	32481267.51	99915872.08	52423860.46	$79,900,919.46	$264,721,919.52
12	28877678.79	99457830.56	52376652.12	$81,564,917.12	$262,277,078.59
13	31000246.89	100090745.5	50272509.85	$84,011,377.75	$265,374,879.93
14	33327440.21	100928317	52461314.05	$80,033,240.43	$266,750,311.65
15	29367288.93	105608477.9	54371414.83	$81,294,208.46	$270,641,390.10
16	31149185.25	100442881	53034356.61	$84,429,817.92	$269,056,240.75
17	33520487.77	91888224.53	48759048.43	$82,233,117.22	$256,400,877.96
18	29580687.38	98843602.05	51528518.88	$83,105,988.11	$263,058,796.41
19	31571592.73	103994057.2	52497990.99	$82,082,203.70	$270,145,844.61
20	33819485.45	94653691.97	50462238.67	$80,576,656.82	$259,512,072.92
21	32543328.35	100229818.8	51214277.09	$81,951,678.62	$265,939,102.91
22	30908974.05	95427613.66	50867091.27	$81,344,282.83	$258,547,961.79
23	32612588.92	99548894.48	52182534.74	$82,964,593.70	$267,308,611.84
24	31791364.87	100063479.7	51987137.52	$81,412,155.19	$265,254,137.31
25	30912101.24	100577810.3	51405272.31	$84,165,741.18	$267,060,925.00

Table 46 - Expanded Capacity Collocated Cellulosic Ethanol Plant Expense and Net Income Details with 25 Sample Iterations - All-Feedstock Cellulosic Ethanol and Sugar

Total Variable and Conversion Costs	Total Fixed	**TOTAL EXPENSES**	**NET**
$ 151,359,322.15	$ 28,931,867.53	**$ 180,360,243.38**	**$ 84,488,629.04**
2,107,727.53	50,448.32	**2,135,923.32**	**3,890,415.55**
1.39	0.17	**1.18**	**4.60**
$ 147,473,376.57	$ 28,823,979.07	**$ 176,448,961.66**	**$ 72,481,390.71**
$ 155,687,717.25	$ 29,015,732.20	**$ 184,708,947.35**	**$ 96,365,990.97**
Sample Iterations			
$149,638,064.62	$28,881,664.30	$178,588,782.62	77823829.17
$147,473,376.57	$28,906,531.39	$176,448,961.66	82730568.87
$152,550,707.60	$28,977,676.30	$181,597,437.60	90584519.85
$150,835,090.78	$28,906,292.02	$179,810,436.50	81457646.52
$154,030,540.17	$28,989,422.53	$183,089,016.41	84889139.8
$151,407,478.70	$28,847,867.98	$180,324,400.37	88945050.9
$150,600,573.48	$28,973,434.79	$179,643,061.97	93663203.49
$152,567,303.69	$28,896,961.04	$181,533,318.42	89015856.72
$152,418,353.32	$28,965,502.14	$181,452,909.15	88305544.8
$151,045,908.82	$28,977,495.30	$180,092,457.82	87572590.12
$148,602,407.33	$28,873,886.58	$177,545,347.61	87176571.91
$152,401,112.80	$28,965,735.84	$181,435,902.34	80841176.25
$155,687,717.25	$28,952,176.40	$184,708,947.35	80665932.58
$148,140,760.95	$28,897,985.73	$177,107,800.37	89642511.28
$151,592,426.42	$28,869,978.15	$180,531,458.27	90109931.83
$153,358,281.91	$28,981,635.10	$182,408,970.72	86647270.03
$148,293,617.05	$28,930,707.81	$177,293,378.56	79107499.4
$152,406,937.16	$28,970,590.16	$181,446,581.02	81612215.39
$152,637,661.24	$28,971,256.87	$181,677,971.81	88467872.8
$149,362,331.00	$28,823,979.07	$178,255,363.77	81256709.15
$151,675,026.10	$28,928,051.77	$180,672,131.56	85266971.35
$149,425,880.23	$28,973,854.68	$178,468,788.61	80079173.18
$152,730,753.06	$28,938,504.03	$181,738,310.79	85570301.05
$150,318,091.73	$28,879,766.04	$179,266,911.47	85987225.84
$154,782,651.88	$29,015,732.20	$183,867,437.78	83193487.22

VITA

Paul is originally from Lafayette, Louisiana, where he grew up in and around sugarcane fields. Upon completion of high school in 2000, he moved to New Orleans to attend Tulane University on a full academic scholarship to study computer engineering. After two years, he transferred to University of Louisiana at Lafayette to pursue his new calling, economics. In 2005, he graduated with his Bachelor of Science in economics. From there, he chose to continue his education at Louisiana State University to pursue an advanced degree in economics. After two years in the economics department, he discovered agricultural economics and switched departments shortly thereafter.

During his academic career at LSU, Paul has authored or coauthored four articles currently in peer-review and given many presentations at academic conferences in multiple disciplines. The majority of his research has been focused on bioenergy and bioprocessing, including cellulosic ethanol production, renewable electricity production, and the green economy. His dissertation conducts an in-depth examination of the economic feasibility of cellulosic ethanol production in south Louisiana, focusing on the possibility of collocating a processing facility with an existing sugar mill. He also spent over a year working on a $2.3 million federal grant project studying renewable energy and green jobs in Louisiana and Mississippi.

Paul will be graduating from Louisiana State University in December of 2011. In the fall of that year, he will begin work on another federal grant project studying economic issues related to the production of non-ethanol bioenergy and bioproducts in Louisiana, Kentucky, and other areas.