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# An Assessment of the Economic Feasibility of Establishing a Biofuel Industry in the State of Louisiana

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# AN ASSESSMENT OF THE ECONOMIC FEASIBILITY OF ESTABLISHING A BIOFUEL INDUSTRY IN THE STATE OF LOUISIANA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfilment of the
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in

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by
Alessandro Holzapfel
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# ABSTRACT

As national interests continue to encourage the development of advanced cellulosic biofuels, through legislation, research support and other means, a wide range of alternative agricultural crops are being evaluated in various regions of the country as potential feedstock material for biofuel processing facilities. Previous research has shown that both energy cane and sweet sorghum can be successfully grown in Louisiana. This study evaluated the economic feasibility of utilizing energy cane and sweet sorghum as biofuel feedstock crops. Economic analysis focused on two primary factors: estimation of feedstock cost and optimal location of processing facilities. Five cropping sequences were evaluated in the production of energy cane and sweet sorghum as feedstock crops. Production costs per acre were similar across the two crops and alternative cropping sequences. Estimated feedstock costs per dry ton were more variable for sweet sorghum, as compared with energy cane, due to the wider range of expected yields observed for sweet sorghum across alternative production periods. Transportation costs from field to processing facility along with the percent of idle land not enrolled in conservation programs were found to be two of the major factors which will influence optimal location of feedstock processing facilities.

# CHAPTER 1 - INTRODUCTION

## 1.1 General Introduction

Our society is depending on crude oil more than ever in today's world. Either out of convenience as in producing plastics and many other man-made materials that can be fabricated into items that make our life easier or out of necessity such as heating a home during cold winters or generating electricity with a generator when a natural disaster has damaged power lines. However, one of the primary uses for crude oil is still as the basis for refinement into fuels for cars, trucks, trains, ships, motorcycles and even airplanes; basically anything that offers mobility. Crude oil is the main factor that enables our society private as well as public transportation of goods and of course people.

The cost of extracting oil from the ground has become rapidly more expensive in recent years due to the decreasing scarcity of oil reserves, forcing oil companies deep into the harsh cold of arctic tundras and the blistering heat of deserts among other places on earth devoid of life. Oil companies have even ventured far out into the oceans of the world where many drilling platforms can be found alongside the coastlines of the Gulf of Mexico or Alaska as well as at high sea in the Atlantic in between Scotland and Norway. The tough and unforgiving environments of these locations often bring the operating crews as well as the drilling equipment to their respective limits. For example, it is now considered common practice to drill for oil in depths exceeding 10,000 feet of water where high water pressures take heavy tolls on the equipment or in politically unstable locations in the Middle East where the threat of attacks through terrorist organisations and social unrest are common place. Even small mistakes can have huge repercussions, especially in extreme locations such as the aforementioned ones and more and more often such mistakes have resulted in quite terrible accidents such as oil spills. In fact, careless operation in such risky locations has caused the biggest environmental disasters in recorded history. Examples of such instances are the oil tanker “Exxon Valdez” that ran aground a reef outside the coast of Alaska in 1989 and the explosion of the “Deepwater Horizon” oil platform in the Gulf of Mexico in 2010. The higher costs associated with paying tall risk premiums additionally to the salaries of employees working in those locations as well as the procurement of more robust equipment capable of handling the tasks at hand are usually redirected to the final consumer, resulting in substantial price increases.

The automotive industry alongside other industries depending on fossil fuels has of course taken note of the recent developments and has started to experiment with alternative means of propulsion. For example, Mercedes-Benz and BMW have both developed several prototype vehicles that use liquid hydrogen as fuel and emit nothing but water vapour and even though the engineering advances that allow an internal combustion engine to burn a resource that is heavily abundant on this planet and causes no pollution sounds fantastic, it is unfortunately rather unfeasible. In order for such a technology to become common place the entire existing supply network would have to be altered to accommodate the liquid hydrogen fuel and, most importantly, of course everyone would have to buy a vehicle equipped with such an engine first. While liquid hydrogen as a fuel would seem to be the perfect replacement for crude oil, it is too costly and too complex to implement. There has to be a more efficient transitional solution which the majority of the automotive industry seems to believe is electricity. The idea to move about using electric motors makes a lot of sense since they are far more efficient than an internal combustion engine could ever be. Additional benefits electric motors bring to the table is the fact that they are much quieter, eliminating the problem of noise pollution. In fact, eliminating all traffic related pollution problems since electric motors have virtually no emissions at all, not even water vapour. Noteworthy is also that electricity is readily available in most homes, removing the need of fuel stations. But yet again, the major problem with this technology is that everyone would have to buy such a vehicle in the first place. Both concepts are very promising but will most likely fail due to the high cost and energy needed to implement either technology successfully. The amount of energy needed to produce liquid hydrogen, or in other words, to separate the hydrogen atoms from the oxygen atoms in water is tremendous when considering the scale of operations that would be necessary to meet the demand requested should this technology become a reality. The fabrication of batteries is also quite complex and costly as resources from many different parts of the world are required in the production process, but this is not the biggest problem as far as batteries are concerned. Since the invention of the first battery, the Achilles heel has been the capacity, the amount of usable electrical power that a battery can hold. In terms of electric vehicles, capacity directly translates into the amount of range that is available. It is important to note that the current electric vehicles available on the market all fall rather short in regards to range and cannot yet compete with their conventional counterparts. This is in a nutshell why electric vehicles are still rendered as not fully matured yet, because once depleted of its electrical charge; it cannot simply be recharged in a matter of minutes unlike a conventional car which can be refuelled at a fuelling station, instantly providing new range.

The new inventions are certainly promising but unfortunately still at the very beginning of their development stage. It is for this reason that the current focus is on man-made fuels that could be used as a replacement to petrol and diesel fuels. One such option is biofuels which are derived from regenerative energy crops such as sugar cane and rapeseed among others. These biofuels are, however, rather hard to come by as they are produced in a comparably rather small amount as the number of energy crops planted and harvested is limited. A case in point for this very statement would be Brazil which is so far the only country in the world utilising pure ethanol derived from crops as a fuel. The oil industry is therefore employing an idea that the automotive industry is currently utilising in a similar fashion in order to either reduce the consumption of fuel in their vehicles while driving or avoid it completely. There are several drivetrain designs which can realise a lower or non-existent consumption of fuel such as a hybrid system that employs both, an electric motor as well as an internal combustion engine. In such a hybrid system the two motors share the workload, either by working in unison to create an equal or greater performance level while reducing consumption or by switching to pure electric drive should the internal combustion engine fall under a certain threshold of workload, therefore avoiding any consumption of fuel. This example about hybrid systems showcased that by supporting the internal combustion engine with an electrical motor, it was possible to reduce the amount of fuel that was necessary to achieve a certain range in comparison to if that exact range was to be achieved just using one engine. The same methodology is currently applied by oil companies in order to refine more fuel from the same amount of crude oil used previously. This is most commonly done by mixing the refined petrol with a certain amount of ethanol derived from energy crops in order to stretch the amount of fuel that can be created with a certain amount of crude oil. In this example the petrol is synonymous for the internal combustion engine and the ethanol for the electric motor. Both fuels together in unison create a hybrid fuel that makes it possible to allocate the crude oil that was initially needed to create just one gallon of fuel to create multiple gallons. This form of stretching the amount of crude oil is already common practice in the United States of America, where the pump-petrol available throughout the country contains up to 10% ethanol whereas just before the Energy Policy Act was passed in 2005 pump-petrol contained no ethanol at all and was completely pure. Another, albeit more intense, application of the same methodology is a fuel by the name of E85. In theory, this fuel is just like common pump-petrol, a blend out of petrol and ethanol. However, whereas common pump-petrol contains only up to 10% of ethanol, this fuel is a mixture composed out of 85% ethanol and only 15% of petrol. Simple mathematics proves that this allows stretching the amount of crude oil needed to create one gallon of 100% pure petrol into about six gallons of E85. The availability of E85 is less compared to the availability of common pump-petrol at fuelling stations in the United States of America; however, the number of fuelling stations offering E85 alongside conventional fuels has steadily grown since the market introduction and can be expected to continue to do so over the next years. Actually, the success of E85 has been so noticeable that many automotive manufacturers are presently offering E85 capable vehicles, more commonly referred to flex-fuel vehicles, in their current model line-up. A flex-fuel vehicle is able to operate on common pump-petrol as well as on E85 while not being any more expensive than a conventional modern car. Furthermore, should there be interest in converting a recent conventional car into a flex-fuel vehicle so can this be done relatively inexpensively. Such a conversion only requires minor changes to the vehicles on-board electronics and its engine management system, which in turn allows the continued use of a vehicle and does not require the purchase of a new one. In this aspect the concept of biofuels differs strongly from the concept of liquid hydrogen as a fuel or that of a pure electric vehicle, since those two engineering philosophies would require a potential prospective buyer to purchase a new vehicle instead of retaining the current one.

There are of course many more than just one kind of energy crop and as so often, this will lead various experts in the industry to debate which type is best suited for use. The final product of all energy crops will obviously be some form of fuel, however, the intermediate product that can be manufactured out of the various types of energy crops differs depending on the type of crop that is used. For example, the intermediate products which can be manufactured out of sugar cane can be ethanol as well as butanol. Both of these chemical compounds are somewhat similar and can therefore be used as a fuel for an internal combustion engine, however, they also strongly differ in the manner in which they burn or combust as well as behave at various temperatures. There are various philosophies existing which all make the case for one or another specific crop or intermediate product; however, this research study will primarily focus on energy cane and sweet sorghum as a biofuel feedstock for production into butanol. This is due to the fact that energy cane and sweet sorghum seem to offer the greatest window of production possibilities and both are crops capable of growing in the state of Louisiana. The implementation of biofuels and regenerative energy crops as a primary source of fuel would be comparatively inexpensive and could guarantee a secure as well as steady supply in addition to a stable price of fuel in the future. A reason such as this, alongside many others, seems to suggest the possibility of replacing crude oil as a source of energy for our society's transportation needs. This research study, therefore, proposes to evaluate the economic feasibility of establishing a biofuel industry in the state of Louisiana.

An answer to the question if the state of Louisiana is indeed capable of establishing and maintaining a viable biofuel industry will be found by conducting research about renewable energy crops such as energy cane and sweet sorghum as well as their current and predicted future use. Further research focusing on the economic impact energy cane and sweet sorghum pose to the agricultural industry in terms of costs faced by the farmer during crop production on the field and later by an agribusiness during crop processing in a mill, will provide additional insight into this subject matter. A biofuel industry in the state of Louisiana would not be feasible or even persist in the long-run if it hinders or obstructs existing industries and markets. It is therefore vital to not interfere with the agricultural industry's primary obligations, such as food supply, and it is for this reason that only idle farmland will be considered for crop production.

The scope of the research efforts will hereby exclusively focus on the state of Louisiana in terms of production of energy cane and sweet sorghum crops and the amount of arable idle farmland that is available for the cultivation of these renewable energy crops. The cause for this decision has of course multiple reasons, one of which is the certainty that increasing the boundaries of this study beyond the state of Louisiana will yield too much information and data. While it is certainly true that too little information is of much more concern than too much information, the latter will most likely complicate the process of producing and evaluating results and therefore dilute the conclusions and recommendations of this study. Another reason for this decision is the desire to work together with the agricultural economics department at Louisiana State University and its research facilities, such as the Sugar Research Station in St. Gabriel, Louisiana.

The process of gathering information and researching data pertaining to biofuels grown from energy crops will be aided by the use of already existing information referring to this subject matter. Such information can be found in many places but particularly in several forms of literature, for example in scientific journals and technical publications but also in research studies and investigations conducted by scientific institutions and governments.

Especially agricultural journals and similar agricultural-specific publications will hereby be of great importance as the authors of articles and essays circulated through those mediums are often well-recognised and highly awarded scientists themselves who hail from various internationally recognised and accredited academic institutions from around the world. Many of them have prior experience in this field and conducted notable research before and the conclusions and recommendations these men and women offer in their works can be regarded as accurate and trustworthy as most scientists are independent from the companies and corporations in the oil and agricultural industry.

Equally important will be information taken from governmental agencies, such as the U. S. Department of Agriculture or the U. S. Energy Information Administration, which provide a vast amount of data and statistics pertaining to the agricultural industry as well as the energy consumption of the United States of America. Especially interesting will hereby be agricultural census' from various years that provide information on the total cropland that is known to be available in Louisiana as well as idle cropland that is currently not harvested, pastured, or grazed. In the reports issued by the U. S. Energy Information Administration, one can find statistics about market trends and issues related to the consumption of hydrocarbon gas liquids in the state of Louisiana alongside other similar information. The chemical compound described as hydrocarbon gas liquids hereby refers to conventional pump-petrol. Other statistics could, for example, pertain to the amount of fuel consumed as well as the fraction of the total amount of fuel consumed that is already designated as biofuel or fuel generated out of renewable energy crops as well as the future usage predictions of those types of fuels.

Previous research will, however, also be expected to have some limitations for direct application in this study.  Research that presents biased or skewed results and proposes suboptimal recommendations would be regarded as a limitation, basically, any form of information that cannot be fully trusted and has to be carefully analysed first. The reality is that such information exists because entities such as the oil and agricultural industry as well as the government of the United States of America will have a biased viewpoint on the use of biofuels and regenerative energy crops. This phenomenon can be explained rather simply, as all oil companies and agribusinesses share one common goal, which is to sell as much of their products as possible. The oil industry will yield a higher profit the more oil it sells and if the market for biofuels increases, the sales of crude oil will eventually decline. The oil industry is also one of the most powerful lobbying partners for the government of the United States of America and therefore will, through lobbying, try to preserve their interests, for example, by blocking incentives supporting the growth of renewable energy crops. The automotive industry can similarly influence opinions held by the oil industry and the U. S. government as it has over the recent years invested a lot of their wealth into the development and production of expensive prototypes utilising either advanced hybrid systems or even pure electric drivetrain concepts. The main interest of automotive manufacturers lies therefore within overcoming those major costs and breakeven to not sustain any losses and remain lucrative. Preferably though, automotive manufacturers would like to generate profits with those newly developed vehicles and could therefore restrict or hold development and production of flex-fuel vehicles. The agricultural industry can similarly influence the government of the United States of America, an instance of this would be agribusinesses advocating the viewpoint that an increase in the efforts put forth towards energy crop production will not be as beneficial and worthwhile in comparison to other endeavours. Additionally, there is a certain problematic with obtaining valuable information and data in the first place. The scientific field that renewable energy crops and biofuels are is not necessarily very rich and abundant with research and proven information yet. This is in large part due to this field of study being relatively young and the amount of published research and information is smaller compared to that of other scientific fields.

## 1.2 Problem Statement

Previous research has shown that both energy cane and sweet sorghum can be successfully grown in Louisiana. With both crops being similar to sugarcane in terms of both plant characteristics and required production practices, the long history of sugarcane production in the state would suggest that the required production knowledge, harvest machinery and transportation logistics is in place to support the production of these feedstock crops. What is unknown at this time relates to the economic viability of the production and processing of feedstock crops to support a biofuel industry. More specifically, questions exist related to the expected production costs of energy cane and sweet sorghum, the estimated feedstock input cost to a processing facility, optimal locations of processing facilities within the state, and the expected transportation costs of supplying feedstock to an operational facility. The research presented in this study attempts to address these critical economic questions.

### 1.3 Literature Review

The literature reviewed in this section was taken from many different sources such as scientific studies and journal articles focusing on various topics, for example, bio-butanol and its many applications or on processing facilities such as already existing refineries used by the oil industry and their capabilities of refining fuel from feedstock. The review of such documents gives great insight into many aspects of this topic, case in point is a study evaluating a collection of diesel blends among of which was also one particular biodiesel refined from bio-butanol. This research was conducted by a team of scientists lead by Dimitrios Rakopoulos (2015) who evaluated the collection of biofuels on their behaviour during the combustion stroke, the performance output measured, and the cleanliness of exhaust emitted and then compared the test data to that of data collected using traditional diesel fuel. The testing was done in a laboratory utilising a Mercedes-Benz direct injected diesel engine and lead the team to recommend and encourage the use of biofuels as in most cases a less harmful exhaust emission was recorded while the performance level remained equal to that of traditional diesel fuel.

A quite similar study was published by Peter Duerre (2007) who set out to compare ethanol-petrol as well as butanol-petrol blends intended for the use in conventional combustion engines against one another in an effort to determine the advantages and disadvantages of either fuel blend. Interesting hereby is that the ethanol-petrol blend used in his study is equivalent to the E85 flex-fuel mentioned prior in section 1.1 of this research study. Peter Duerre concluded his research by strongly endorsing the use of a butanol-petrol over an ethanol-petrol blend as the bio-butanol derived fuel would offer many advantages over the other, such as a higher energy content and a better blending ability while most importantly not requiring any modification at all to the engine or automobile.

In order to conduct the types of research similar to the examples of Dimitrios Rakopoulos and Peter Duerre, one is in need of a major component, which is the fuel in itself. More specifically, a biofuel blend based on either conventional petrol or diesel fuel and bio-butanol. This section therefore also presents some literature which focuses on the production side of bio-butanol, in detail then, with the process of turning feedstock crops into biofuels. The procedure of turning either energy cane or sweet sorghum crops into bio-butanol can be done fermentatively as well as petrochemically, or in other words, by either fermenting the feedstock crops over time by using various species of bacteria or refining fuel from the feedstock crops using existing processing facilities such as oil refineries.

Several research studies published by Edward M. Green (2011) or by Kumar and Gayen (2011) as well as by a team under the supervision of Yue Wang (2012) focus on various processes and new methods pertaining to fermentation techniques and the species of bacteria used therein. The scientists all vouch for the production of biofuels in a fermentative manner as it offers many cost benefits and is considered to be quite economical.

There are on the other hand also scientists which focus their efforts on the refinement of biofuels utilising existing processing facilities, for example, A. Mahmoud and M. Shuhaimi (2013) who have published a study in which the current costs associated with biofuel refinery facilities and ways with which the operating costs could be severely reduced are discussed. Specifically, two scenarios are introduced and compared, one in which there is a standalone refinery plant which is only capable of producing biofuels and another in which the technology needed to create biofuels is introduced into an existing refinery plant and consequently enables this plant to produce fuel from feedstock as well as crude oil. This of course poses the question of which scenario is best to be chosen and consequently realised and which scenario is not. A non-linear programming model is therefore made use of in order to determine which scenario might be better suited for realisation. There is not a straightforward answer though, as the costs vary depending on if a facility is to be newly build or an existing facility to receive technological updates.

Similar research, however, focusing on the production capabilities of mills used to process sugar cane was published by Kim Misook and Donald F. Day (2010). Their study centres on the current production capabilities of sugar mills in the state of Louisiana and the possibilities to increase the scope of production further, while retaining current equipment, but including a wider variety of feedstock. Currently, a sugar mill will operate about three months out of the year, however, sit idle the rest of the time while being fully functional. Some of the downtime is of course used for mill and equipment maintenance; yet, this is typically not a nine month affair. For example, using feedstock capable of different cropping sequences such as energy cane and sweet sorghum, would bridge the gaps in between production periods allowing a greater production window and consequently a greater profit margin.

A review of literature pertaining to the feedstock crops of interest in this study is indispensable and because of this, studies published by research teams lead by Chad Penn (2004) or S. P. Rao (2009) are also evaluated. These studies assessed several key attributes of sweet sorghum and its potential as a biofuel feedstock crop. Their research found that biomass yields and economic returns increased with higher levels of plant nutrient rates and that the use of poultry litter as a feedstock crop nutrient source could be economically sustainable. This, specifically, would have a positive influence on the energy security and energy self-sufficiency of emerging economies as well as existing ones.

Equally important is the review of energy cane specific material since much of the focus of biofuel feedstock production potential in the Mid-South region has focused on the production of energy cane, Mark, et al., (2014) and Salassi, et al., (2014). Salassi, et al. (2015), evaluated the potential for energy cane production as a biofuel feedstock in the Mid-South region of the United States by estimating feedstock acreage potential as well as expected production costs. With a low seed cane expansion planting ratio and harvest through a fourth stubble crop, total energy cane production costs were estimated to be $113 per dry metric ton of feedstock. At higher planting ratios, projected total energy cane production costs were below $70 per metric ton.

### 1.4 Study Objectives

While the evaluation of the feasibility of establishing an economically viable biofuel industry in the state of Louisiana utilising idle farmland as well as energy cane and sweet sorghum crops is the major aim of this research study, four specific objectives have been established alongside also. These research objectives are:

1. To identify potential cropping sequences and related production costs associated with the production of energy cane and sweet sorghum as biofuel feedstock crops.
2. To determine the total cost of producing selected biofuel feedstock materials in the state of Louisiana as inputs into alternative biofuel production.
3. To determine the current total land area available for feedstock crop production in the state of Louisiana.
4. To determine the optimal locations of feedstock crop processing facilities in the state of Louisiana.

## 1.5 Methodology

The first objective will be achieved through the review and evaluation of recent as well as current agronomic research involving energy cane and sweet sorghum crop production. Based on these findings, potential annual feedstock cropping sequences will be specified for further evaluation and the expected variable and fixed production costs for energy cane and sweet sorghum crops estimated.

The second objective will be achieved through the evaluation of possible feedstock availability scenarios. These scenarios will provide an indication of production possibility frontiers which in turn will allow for an evaluation of potential total production costs of selected biofuel products. Also included in this objective will be a cost estimation for the conversion of feedstock material into a preliminary syrup or dry matter product which could then be processed further into a variety of bio-based products.

The third objective will be achieved by determining various categories of farmland available for feedstock crop production in the state of Louisiana. The aforementioned desire to not intervene with any food production activities will hereby limit all attention to idle farmland. Data publications such as the Census of Agriculture will be the primary source of information for identifying idle farmland acreage levels in each parish. Additionally, an evaluation of the comparative economic production advantages of energy cane and sweet sorghum crops will be conducted to gain a perspective on the potential ability of these feedstock crops to compete for land resources once a biofuel industry has been established.

The fourth objective will be achieved through the use of a linear programming model utilising expected feedstock production levels alongside alternative processing facility capabilities as input data. The goal of this linear programming model is to calculate the transportation costs encountered when shipping feedstock from a supply location to a demand location. The application of several linear programming techniques to this transportation model will allow for the identification of required feedstock processing facilities as well as their optimal location within the state of Louisiana to minimise transportation costs.

# CHAPTER 2 – BIOFUEL FEEDSTOCK COST ESTIMATION

This chapter presents estimates of the expected cost of biofuel feedstock as inputs into a biofuel production process. Crop yields for energy cane and sweet sorghum from field trials conducted in Louisiana are used to establish average expected feedstock crop yields. The variable and fixed costs associated with producing these crops are then estimated. Alternative cropping sequences are selected to represent alternative annual production processes. Finally, feedstock costs as inputs into a biofuel production process are estimated.

## 2.1 Biofuel Feedstock Yield Estimation

One of the feedstock crops which has the greatest potential for being economically viable as a raw material input into a biofuel process would be energy cane. Energy cane is similar to sugarcane, with the major difference being that energy cane varieties have a higher fibre (dry matter) content, as well as a lower sucrose content, than traditional sugarcane varieties. This allows for energy cane to be grown in all areas of the state as, for example, a higher fibre content directly translates to a greater cold resistance compared to sugarcane. Tables 2.1 – 2.6 present energy cane yield data utilised in this study to be used as a factor in estimating energy cane feedstock production costs per ton of dry matter. Yield data for the five energy cane varieties listed in the tables were taken from actual field trials conducted at the Sugar Research Station in St. Gabriel, Louisiana.

A quite interesting detail about energy cane is also that, being a perennial crop, it can be harvested multiple times, the particular varieties chosen for this study even up to six times. The harvest yield of energy cane will vary depending on the number of previous harvests. Once a crop has reached maturity, one can expect to harvest the plant cane which is the first growth of the energy cane shoot and will generally bear one of the highest annual yields along with the first and second stubble crops. Table 2.1 illustrates the yields of this first growth for the various varieties of energy cane.

Table 2.1 Plant Cane Crop Yields for Energy Cane

| Variety | Cane Yield (tons/ac) | Fiber Content (%) | Dry Matter (tons/ac) |
|---|---|---|---|
| Ho 02-144 | 30.5 | 20.6% | 6.27 |
| Ho 02-147 | 44.2 | 17.8% | 7.87 |
| Ho 06-9001 | 28.9 | 26.4% | 7.58 |
| Ho 06-9002 | 25.5 | 25.3% | 6.44 |
| HoCP 72-114 | 42.8 | 20.7% | 8.84 |
| Average | 34.4 | 22.2% | 7.40 |

Source: Gravois, et al., “Yield and Fiber Content of High-Fiber Sugarcane Clones.” *Sugar Station Annual Report, 2014*. LSU AgCenter.

After harvesting the plant cane, one can anticipate additional growths, most commonly referred to as stubble crops. The nomenclature of these crops is relatively simple with the first growth after plant cane being referred to as the first stubble crop, the second growth as the second stubble crop, et cetera. Tables 2.2 – 2.6 illustrate the yields of these additional growths for the various varieties of energy cane.

Table 2.2 First Stubble Crop Yields for Energy Cane

| Variety | Cane Yield (tons/ac) | Fiber Content (%) | Dry Matter (tons/ac) |
|---|---|---|---|
| Ho 02-144 | 25.0 | 25.9% | 6.49 |
| Ho 02-147 | 47.0 | 19.5% | 9.15 |
| Ho 06-9001 | 26.0 | 29.7% | 7.70 |
| Ho 06-9002 | 24.4 | 29.6% | 7.22 |
| HoCP 72-114 | 35.8 | 24.0% | 8.58 |
| Average | 31.6 | 25.7% | 7.83 |

Source: Gravois, et al., “Yield and Fiber Content of High-Fiber Sugarcane Clones.” *Sugar Station Annual Report, 2014*. LSU AgCenter.

Table 2.3 Second Stubble Crop Yields for Energy Cane

| Variety | Cane Yield (tons/ac) | Fiber Content (%) | Dry Matter (tons/ac) |
|---|---|---|---|
| Ho 02-144 | 55.3 | 23.6% | 6.58 |
| Ho 02-147 | 72.4 | 18.4% | 9.48 |
| Ho 06-9001 | 57.2 | 28.7% | 5.49 |
| Ho 06-9002 | 50.7 | 28.3% | 4.66 |
| HoCP 72-114 | 57.1 | 22.6% | 6.34 |
| Average | 58.5 | 24.3% | 6.51 |

Source: Gravois, et al., “Yield and Fiber Content of High-Fiber Sugarcane Clones.” *Sugar Station Annual Report, 2014*. LSU AgCenter.

Table 2.4 Third Stubble Crop Yields for Energy Cane

| Variety | Cane Yield (tons/ac) | Fiber Content (%) | Dry Matter (tons/ac) |
|---|---|---|---|
| Ho 02-144 | 34.6 | 23.2% | 7.99 |
| Ho 02-147 | 49.7 | 19.6% | 9.74 |
| Ho 06-9001 | 27.3 | 24.8% | 6.85 |
| Ho 06-9002 | 28.0 | 25.7% | 7.24 |
| HoCP 72-114 | 39.4 | 21.5% | 8.46 |
| Average | 35.8 | 23.0% | 8.06 |

Source: Gravois, et al., “Yield and Fiber Content of High-Fiber Sugarcane Clones.” *Sugar Station Annual Report, 2014*. LSU AgCenter.

Table 2.5 Fourth Stubble Crop Yields for Energy Cane

| Variety | Cane Yield (tons/ac) | Fiber Content (%) | Dry Matter (tons/ac) |
|---|---|---|---|
| Ho 02-144 | 36.5 | 23.2% | 8.52 |
| Ho 02-147 | 40.7 | 19.8% | 8.14 |
| Ho 06-9001 | 38.2 | 27.8% | 10.57 |
| Ho 06-9002 | 28.3 | 26.4% | 7.41 |
| HoCP 72-114 | 38.0 | 23.1% | 8.75 |
| Average | 36.3 | 24.1% | 8.68 |

Source: Gravois, et al., “Yield and Fiber Content of High-Fiber Sugarcane Clones.” *Sugar Station Annual Report, 2014*. LSU AgCenter.

Table 2.6 Fifth Stubble Crop Yields for Energy Cane

| Variety | Cane Yield (tons/ac) | Fiber Content (%) | Dry Matter (tons/ac) |
|---|---|---|---|
| Ho 02-144 | 35.2 | 27.0% | 9.51 |
| Ho 02-147 | 44.8 | 21.3% | 9.53 |
| Ho 06-9001 | 34.9 | 31.0% | 10.81 |
| Ho 06-9002 | 31.5 | 30.0% | 9.43 |
| HoCP 72-114 | 39.5 | 24.3% | 9.64 |
| Average | 37.2 | 26.7% | 9.78 |

Source: Gravois, et al., "Yield and Fiber Content of High-Fiber Sugarcane Clones." *Sugar Station Annual Report, 2014*. LSU AgCenter.

More specifically, the information given in Table 2.1 is the harvest yield values in tons per acre, fibre content in percent, as well as dry tons per acre. The table presents this information for each individual energy cane variety in addition to an average value calculated from those harvest yield values. The same information but instead for the first, second, third, fourth, and fifth stubble crop harvest yields are given in the Tables 2.2 – 2.6 in this chapter.

Tables 2.1 – 2.6 also showcase that the greatest harvest yields fluctuate depending on the energy cane variety planted. This is quite important as it eliminates the assumption that one energy cane variety is better than another. In Table 2.1, for example, the energy cane variety Ho 02-147 has the highest plant cane harvest yield of 44.2 tons per acre but on the other side the lowest fibre content in percent of only 17.8%. Should a farmer therefore have a great interest in harvesting as much wet matter in tons per acre of plant cane as possible, then the energy cane variety Ho 02-147 would be the ideal choice for this prerequisite. However, should the farmer's greatest interest lie within harvesting as much dry matter in tons per acre of plant cane as possible, then a different variety of energy cane, specifically, the variety HoCP 72-114 would the recommended choice as it offers the highest dry matter yield of 8.84 tons per acre with a fibre content of 20.7%.

The energy cane variety which promises the greatest return through the plant cane harvest might not be as high yielding through the second stubble crop harvest. Such an instance can be seen in Table 2.3 where the energy cane variety Ho 02-147 now promises the highest yield of wet as well as dry matter in tons per acre for second stubble crops compared to HoCP 72-114.

The data presented in Table 2.7 is dealing in particular with the average yield of energy cane through the third, fourth, and fifth stubble harvest. At first this will seem not quite as straight-forward as the information given in previous tables, yet, the procedure used to calculate these values can be quickly explained.

For example, the word “through” in through third stubble harvest designates that the information given is not only the yield data of the third stubble harvest but a weighted average yield data of all harvests leading up to and including the third stubble harvest. The same philosophy applies to the through fourth or fifth stubble harvests as well, however, then also using yield data of the fourth or fifth stubble harvest too. For instance, in order to calculate the through third stubble harvest yield, one will use the yield data of a certain variety of energy cane for the plant cane as well as the first, second, and third stubble harvests. Once these four values have been found, one will then multiply each individually by a percentage value which represents the fraction of the total harvest yield each of these values denote. The resulting four values are then added up to a sum which will then be divided by the sum of all percentage values used in the previous step of the calculation. The same mathematical calculation was also used to calculate a weighted average of the dry tons per acre yield which, too, can be seen in Table 2.7.

Table 2.7 Weighted Average Energy Cane Yields through Harvest of Third, Fourth and Fifth Stubble

| Variety | Cane Yield (tons/ac) | Dry Matter (tons/ac) |
|---|---|---|
| Through 3rd Stubble | | |
| Ho 02-144 | 36.68 | 6.86 |
| Ho 02-147 | 53.79 | 9.12 |
| Ho 06-9001 | 35.17 | 6.87 |
| Ho 06-9002 | 32.50 | 6.38 |
| HoCP 72-114 | 43.86 | 8.02 |
| Average | 40.40 | 7.45 |
| Through 4th Stubble | | |
| Ho 02-144 | 36.64 | 7.21 |
| Ho 02-147 | 51.06 | 8.91 |
| Ho 06-9001 | 35.80 | 7.64 |
| Ho 06-9002 | 31.63 | 6.60 |
| HoCP 72-114 | 42.64 | 8.17 |
| Average | 39.55 | 7.71 |
| Through 5th Stubble | | |
| Ho 02-144 | 36.39 | 7.60 |
| Ho 02-147 | 49.98 | 9.02 |
| Ho 06-9001 | 35.65 | 8.19 |
| Ho 06-9002 | 31.60 | 7.09 |
| HoCP 72-114 | 42.10 | 8.42 |
| Average | 39.14 | 8.06 |

The calculation of a weighted average energy cane yield per harvested acre over the entire farm (i.e., over the entire crop cycle) for each of the three energy cane harvest crop cycle lengths can be stated mathematically as follows:

$$AYld3 = (0.1639YldPc + 0.1967YldSt1 + 0.2000YldSt2 + 0.2000YldSt3) / 0.7606 \quad [2.1]$$

$$\begin{aligned} AYld4 = (&0.1366YldPc + 0.1639YldSt1 + 0.1667YldSt2 + 0.1667YldSt3 \\ &+ 0.1667YldSt4) / 0.8006 \end{aligned} \quad [2.2]$$

$$\begin{aligned} AYld5 = (&0.1171YldPc + 0.1405YldSt1 + 0.1429YldSt2 + 0.1429YldSt3 \\ &+ 0.1429YldSt4 + 0.1429YldSt5) / 0.8292 \end{aligned} \quad [2.3]$$

where *Ayld3*, *Ayld4* and *Ayld5* represents the weighted average energy cane crop yield per acre through harvest of a third, fourth and fifth stubble crop, *YldPc* is the harvested yield per acre for the plant cane crop, *YldSt1*, *YldSt2*, *YldSt3*, *YldSt4* and *YldSt5* are the harvested yields per acre for the first stubble through fifth stubble crops and the equation coefficients represent the percentage of farm acreage harvested of each crop stage.

Upon having spent some time looking at Table 2.7 as well as other tables in this study, one will notice that there are several varieties of the same crop as well as three alternative crop cycles being analysed. This is of course not coincidence but has reason and purpose, mostly to allow the highest possible yield to be harvest. However, one must not simply label one variety as better as another as the energy cane varieties will differ in their fibre content of the stalk as well as the amount of cane the variety can yield where, quite interestingly, a high fibre content of the stalk does equal a greater cane yield. A case in point would be the variety Ho 02-147 which, when compared to any other variety of energy cane examined in this study, offers the least amount of fibre content in percent. On several occasions even up to 10% less than other varieties. Important differences between the energy cane varieties are hereby also the amount of yield they provide depending on the crop cycle employed by the farmer. For example, the variety “a” might result in large yields in through third stubble harvests compared to the variety “b” but may still produce a lesser total yield than variety “b” if the crop cycle is extended to through fifth stubble harvests. In a nutshell then, the different varieties and crop cycles enable a farmer to most efficiently grow energy cane depending on the demands given by the amount of land or time available. It is important to note hereby that the word “demand” not only refers to the amount of product requested by the biofuel industry, but also the physical state the product is in. For example, a producer of biofuels may choose to receive the harvested feedstock material in either a liquid form as a juice extracted from the stalks of energy cane and sweet sorghum or in a solid form as a bagasse. The objective of the farmer would be to select a crop variety and crop cycle length which would minimize the average production cost per ton of feedstock produced.

Similarly to the Tables 2.1 – 2.6, Table 2.8 also pertains to data about the yields of multiple harvests, however, with the key difference that Table 2.8 does not focus on various varieties of energy cane but instead on sweet sorghum, an annual crop. Similar to Tables 2.1 – 2.6, there is also an average value calculated from the harvest yields in Table 2.8.

Another key difference is that, unlike the energy cane varieties in this study, a sweet sorghum crop cannot be harvested multiple times. Nevertheless, these crops do offer the benefit of a flexible planting period which makes it possible to plant sweet sorghum as early as the beginning of April or as late as the end of June. This is an advantage as it allows sweet sorghum to be planted at a point in time of the greatest convenience to the farmer as long as it is within the before mentioned three month timeframe permitting farmers as well as agribusinesses, such as mills and refineries, to increase the length of their production season and simultaneously increase their profit margin.

Additionally, there are also three maturity groups which are simply just references to the point in time at which the crop is planted and that can be at an early, medium, as well as late stage in the month. The harvest of sweet sorghum can begin as soon as the crop has matured which on average takes about 90 days or three months.

Sweet sorghum will always require the same amount of time to maturity regardless of when it was planted, therefore, the earlier a crop is planted the earlier it can be harvested. Yet, there is a distinctive difference in the amount of yield a crop can provide depending on when it was planted, with crops planted in May offering on average the greatest return. This is evidenced by the values given in Table 2.8 which show around 30 tons per acre of cane yield for the months of April and June but show around 40 tons per acre of cane yield for the month of May.

Table 2.8 Estimated Crop Yields for Sweet Sorghum

| Planting Date | Maturity Group | Sorghum Yield (tons/ac) | Dry Matter (tons/ac) | Fiber Content (%) | Harvest Period |
|---|---|---|---|---|---|
| April | Early | 18.6 | 4.8 | 25.8% | July 15 - Aug 1 |
| April | Medium | 31.5 | 7.4 | 23.5% | Aug 1 - Aug 15 |
| May | Medium | 42.9 | 8.9 | 20.7% | Aug 15 - Aug 31 |
| May | Late | 38.9 | 9.1 | 23.4% | Sept 1 - Sept 15 |
| June | Medium | 32.1 | 6.0 | 18.7% | Sept 15 - Sept 30 |
| June | Late | 30.0 | 6.7 | 22.3% | Oct 1 - Oct 15 |
| Average | | 32.3 | 7.2 | 22.4% | |

Source: H.P. Sonny Viator, "Logistics for Sustainable Sweet Sorghum Biomass Production," *Louisiana Agriculture Magazine*, Spring 2015, pp. 12-13.

## 2.2 Biofuel Feedstock Production Cost Estimation

Using energy cane and sweet sorghum as the selected feedstock crop alternatives, this section discusses the methodology and results of the estimation of the farm level production costs associated with each of these crops. The information shown in Table 2.9 is referring to the distribution of farmland over a single farming operation necessary for the three alternative energy cane crop production cycle lengths. More specifically, the amount of farmland required for production through third, fourth, and fifth stubble crop harvests. The values given in this table are percentages calculated from the total amount of farmland available for production on a given farming operation and the amount of farmland necessary for the various specific crop production phases required in the production of energy cane. These values are of great importance as they will allow the calculation of further information, primarily weighted average feedstock crop production costs, necessary for this study.

Table 2.9 Distribution of Farm Acreage for Energy Cane Production

| Crop Production Phase | Farm Acreage Distribution for Crop Cycles Through Harvest of: Third Stubble | Fourth Stubble | Fifth Stubble |
|---|---|---|---|
| | - - - - - - -(% of farm acreage)- - - - - - - - | | |
| Specific Field Operations: | | | |
| Cultured seedcane planting | 0.33 | 0.27 | 0.23 |
| Cultured seedcane harvest | 0.66 | 0.55 | 0.47 |
| 1st seedcane expansion (mplt) | 3.28 | 2.73 | 2.34 |
| Seed cane harvest (wholestalk) | 3.28 | 2.73 | 2.34 |
| 2nd seedcane expansion (mplt) | 16.39 | 13.66 | 11.71 |
| Plantcane harvest for seed | 3.61 | 3.01 | 2.58 |
| Plantcane harvest for mill | 16.39 | 13.66 | 11.71 |
| 1st stubble harvest for seed | 0.33 | 0.27 | 0.23 |
| 1st stubble harvest for mill | 19.67 | 16.39 | 14.05 |
| 2nd stubble harvest for mill | 20.00 | 16.67 | 14.29 |
| 3rd stubble harvest for mill | 20.00 | 16.67 | 14.29 |
| 4th stubble harvest for mill | 0.00 | 16.67 | 14.29 |
| 5th stubble harvest for mill | 0.00 | 0.00 | 14.29 |
| Farm Acres Distribution: | | | |
| Total acres planted | 20.00 | 16.67 | 14.29 |
| Acres hand planted | 0.33 | 0.27 | 0.23 |
| Acres mechanically planted | 19.67 | 16.39 | 14.05 |
| Total acres harvested | 80.00 | 83.33 | 85.71 |
| Acres harvested for seed | 3.93 | 3.28 | 2.81 |
| Acres harvested for biomass | 76.07 | 80.05 | 82.90 |
| Total farm acres | 100.00% | 100.00% | 100.00% |

Information used to estimate energy cane feedstock production costs were taken from published production cost estimates for sugarcane production in Louisiana for the 2015 crop year (Salassi, et. al., 2015). Table 2.10 displays such production cost information estimated for energy cane, specifically, the weighted average variable, fixed, and total costs one would be expected to incur for a crop cycle through harvest of third stubble. These values were calculated by multiplying the percentage values for the various production phases from Table 2.9 with the variable and fixed costs estimated for the specific crop production phase. The total costs were then calculated using simple accounting procedures which denotes that variable costs and fixed costs added together to one value will equal total costs. Values in

Table 2.10 therefore represent weighted average costs per total farm acre for the production of energy cane through a third stubble harvest. Total farm variable cost for energy cane production was estimated to be $415.93 per farm acre and total fixed costs were estimated to be $133.58 per farm acre. Total estimated farm costs per acre for energy cane production through harvest of a third stubble crop were estimated to be $549.51 per acre. These values are necessary for cost evaluation based on the desired cropping sequences chosen.

Table 2.10 Projected Energy Cane Production Costs through Harvest of Third Stubble Crop

| Crop Production Phase | Weighted Average Production Cost per Farm Acre Through Harvest of Third Stubble: Variable Cost | Fixed Cost | Total Cost |
|---|---|---|---|
| | - - - - -(weighted dollar cost per farm acre)- - - - - | | |
| Production Costs: | | | |
| Cultured seedcane planting | 2.38 | 0.28 | 2.66 |
| Cultured seedcane harvest | 0.48 | 0.32 | 0.81 |
| 1st seedcane expansion (mplt) | 5.52 | 1.81 | 7.33 |
| Seed cane harvest (wholestalk) | 2.42 | 1.62 | 4.04 |
| 2nd seedcane expansion (mplt) | 27.60 | 9.04 | 36.64 |
| Field operations for: | | | |
| Plantcane for seed | 9.03 | 1.52 | 10.56 |
| Plantcane for biomass | 41.06 | 6.92 | 47.98 |
| 1st stubble for seed | 1.04 | 0.15 | 1.19 |
| 1st stubble for biomass | 62.32 | 9.04 | 71.36 |
| 2nd stubble for biomass | 62.28 | 8.52 | 70.79 |
| 3rd stubble for biomass | 62.28 | 8.52 | 70.79 |
| 4th stubble for biomass | -- | -- | -- |
| 5th stubble for biomass | -- | -- | -- |
| Plowout / fallow | 21.09 | 13.14 | 34.23 |
| Harvest for biomass | 118.44 | 72.70 | 191.14 |
| Total farm production cost | 415.93 | 133.58 | 549.51 |

Tables 2.11 and 2.12 display the same type information one can find in Table 2.10, yet, with the distinct difference that it relates to the through fourth as well as fifth stubble crop harvests respectively. The procedures used to calculate the values in Table 2.11 and 2.12 are identical to those used in Table 2.10 as is the intended use of these values in this study.

Estimated variable, fixed and total production costs for energy cane production through harvest of a fourth stubble crop were calculated to be $424.46, $134.34, and $558.80 per total farm acre (Table 2.11). Estimated variable, fixed and total production costs for energy cane production through harvest of a fifth stubble crop were calculated to be $430.55, $134.89, and $565.44 per total farm acre (Table 2.12). Although the production cost estimate per acre for each production phase was identical in the calculation, differences in total estimated farm costs for alternative crop cycle lengths was due to the differences in the percent of farm land in each production phase as the crop cycle length changed.

Table 2.11 Projected Energy Cane Production Costs through Harvest of Fourth Stubble Crop

| Crop Production Phase | Weighted Average Production Cost per Farm Acre Through Harvest of Fourth Stubble: Variable Cost | Fixed Cost | Total Cost |
|---|---|---|---|
| | - - - - -(weighted dollar cost per farm acre)- - - - - | | |
| Production Costs: | | | |
| Cultured seedcane planting | 1.98 | 0.23 | 2.22 |
| Cultured seedcane harvest | 0.40 | 0.27 | 0.67 |
| 1st seedcane expansion (mplt) | 4.60 | 1.51 | 6.11 |
| Seed cane harvest (wholestalk) | 2.01 | 1.35 | 3.36 |
| 2nd seedcane expansion (mplt) | 23.00 | 7.53 | 30.53 |
| Field operations for: | | | |
| Plantcane for seed | 7.53 | 1.27 | 8.80 |
| Plantcane for biomass | 34.22 | 5.77 | 39.98 |
| 1st stubble for seed | 0.87 | 0.13 | 0.99 |
| 1st stubble for biomass | 51.93 | 7.54 | 59.47 |
| 2nd stubble for biomass | 51.90 | 7.10 | 59.00 |
| 3rd stubble for biomass | 51.90 | 7.10 | 59.00 |
| 4th stubble for biomass | 51.90 | 7.10 | 59.00 |
| 5th stubble for biomass | -- | -- | -- |
| Plowout / fallow | 17.57 | 10.95 | 28.53 |
| Harvest for biomass | 124.65 | 76.51 | 201.16 |
| Total farm production cost | 424.46 | 134.34 | 558.80 |

Table 2.12 Projected Energy Cane Production Costs through Harvest of Fifth Stubble Crop

| Crop Production Phase | Weighted Average Production Cost per Farm Acre Through Harvest of Fifth Stubble: | | |
|---|---|---|---|
| | Variable Cost | Fixed Cost | Total Cost |
| | - - - - -(weighted dollar cost per farm acre)- - - - - | | |
| Production Costs: | | | |
| Cultured seedcane planting | 1.70 | 0.20 | 1.90 |
| Cultured seedcane harvest | 0.35 | 0.23 | 0.58 |
| 1st seedcane expansion (mplt) | 3.94 | 1.29 | 5.23 |
| Seed cane harvest (wholestalk) | 1.73 | 1.16 | 2.88 |
| 2nd seedcane expansion (mplt) | 19.71 | 6.46 | 26.17 |
| Field operations for: | | | |
| Plantcane for seed | 6.45 | 1.09 | 7.54 |
| Plantcane for biomass | 29.33 | 4.94 | 34.27 |
| 1st stubble for seed | 0.74 | 0.11 | 0.85 |
| 1st stubble for biomass | 44.51 | 6.46 | 50.97 |
| 2nd stubble for biomass | 44.48 | 6.08 | 50.97 |
| 3rd stubble for biomass | 44.48 | 6.08 | 50.97 |
| 4th stubble for biomass | 44.48 | 6.08 | 50.57 |
| 5th stubble for biomass | 44.48 | 6.08 | 50.57 |
| Plowout / fallow | 15.06 | 9.39 | 24.45 |
| Harvest for biomass | 129.09 | 79.23 | 208.32 |
| Total farm production cost | 430.55 | 134.89 | 565.44 |

The estimated production costs associated with planting and harvesting sweet sorghum as a biofuel feedstock crop can be found in Tables 2.13 and 2.14. Comparable to the tables concerned with energy cane crop production, Table 2.13 also provides information about the variable, fixed, and total costs for the individual sweet sorghum crop production phases as well as total production cost values calculated from the other values in the table. These production costs were estimated using 2015 cost data for relevant production practices expected to be utilised in producing sweet sorghum. It is important to note hereby that all of the values in Table 2.13 exclude any post-harvest activity and their corresponding costs as those are not necessarily essential to the production process. Table 2.14 does include the costs associated with post-harvest activities, which primarily related to disking costs during the period between the end of a sweet sorghum harvest and the end of the calendar year. Another variation of Table 2.14 is instead of providing cost information about the individual sweet sorghum crop production phases, it provides cost information about the five alternative cropping sequences based primarily on alternative planting dates and crop maturity. The information is, once again, provided as variable, fixed, and total cost values as well as total production cost values calculated from the other values in the table.

Table 2.13 Projected Sweet Sorghum Production Costs through Harvest [1]

| Crop Production Phase | Variable Cost | Fixed Cost | Total Cost |
|---|---|---|---|
| | - - - - - - -(dollars per acre)- - - - - - - - | | |
| Fallow Costs | 76.28 | 46.26 | 122.54 |
| Planting Costs | 16.76 | 4.90 | 21.66 |
| Fertilization Costs | 103.00[2] | 0.00 | 103.00 |
| Herbicide Costs | 31.00[2] | 0.00 | 31.00 |
| Harvest Costs | 155.71 | 95.57 | 251.28 |
| Total Costs | 382.75 | 146.73 | 529.48 |

[1] Production costs presented here exclude post-harvest disc costs.

[2] Custom application costs included in variable cost.

Table 2.14 Projected Total Sweet Sorghum Production Costs

| Crop Production Phase | Post-Harvest Diskings [1] | Total Production Costs<br>Variable Cost | <br>Fixed Cost | <br>Total Cost |
|---|---|---|---|---|
| | | - - - - -(dollars per acre)- - - - | | |
| (1) Sweet sorghum April early [1]<br>Harvest = July 15 -July 30 (15 days) | 3 | 397.51 | 158.97 | 556.48 |
| (2) Sweet sorghum April medium [2]<br>Harvest = Aug 1 - Aug 15 (15 days) | 2 | 392.59 | 154.89 | 547.48 |
| (3) Sweet sorghum May medium [2]<br>Harvest = Aug 16 - Aug 30 (15 days) | 2 | 392.59 | 154.89 | 547.48 |
| (4) Sweet sorghum May late [3]<br>Harvest = Sept 1 - Sept 15 (15 days) | 1 | 387.67 | 150.81 | 538.48 |
| (5) Sweet sorghum June medium [3]<br>Harvest = Sept 16 - Sept 30 (15 days) | 1 | 387.67 | 150.81 | 538.48 |
| (6) Sweet sorghum June late [4]<br>Harvest = Oct 1 - Oct 15 (15 days) | 0 | 382.75 | 146.73 | 529.48 |

[1] Cost per post-harvest disking pass: variable cost - $4.92/acre, fixed cost - $4.08/acre, total cost - $9.00/acre.

## 2.3 Biofuel Feedstock Cropping Sequences

Assumptions were made in this study relative to the particular cropping sequences of energy cane and sweet sorghum which would be analysed. The information given in Tables 2.15 – 2.17 pertains to the alternative cropping sequences possible with energy cane and sweet sorghum crops. Through the use of cropping sequences, a farmer is able to establish several scenarios pertaining to the length of the crop processing season as well as the types of crops to be planted and harvested. For example, a farmer is able to choose a scenario in which either energy cane or sweet sorghum is to be planted and harvested but also a scenario in which both types of crops can be planted and harvested in the same season. The alternative cropping sequencing scenarios evaluated in this study are therefore energy cane only (scenarios 1-3), sweet sorghum only (scenario 4), or an equal production of both crops (scenario 5). Noteworthy is hereby that should a farmer choose to plant only one crop the processing season will have a duration of three month or 90 days and if both crops are to be planted then the processing season will extend to a duration of six month or 180 days.

Table 2.15 Specified Biofuel Feedstock Production Cropping Sequences

| | Feedstock Production Scenarios[1] | | | | |
|---|---|---|---|---|---|
| Biofuel Feedstock Crop | 1 | 2 | 3 | 4 | 5 |
| | (percent of production days) | | | | |
| Energy cane through 3rd stubble<br>Harvest = Oct 1 - Dec 31 (90 days) | 100.0% | -- | -- | -- | -- |
| Energy cane through 4th stubble<br>Harvest = Oct 1 - Dec 31 (90 days) | -- | 100.0% | -- | -- | -- |
| Energy cane through 5th stubble<br>Harvest = Oct 1 - Dec 31 (90 days) | -- | -- | 100.0% | -- | 50.0% |
| Sweet sorghum April early<br>Harvest = July 15 -July 30 (15 days) | -- | -- | -- | 16.7% | 8.3% |
| Sweet sorghum April medium<br>Harvest = Aug 1 - Aug 15 (15 days) | -- | -- | -- | 16.7% | 8.3% |
| Sweet sorghum May medium<br>Harvest = Aug 16 - Aug 30 (15 days) | -- | -- | -- | 16.7% | 8.3% |
| Sweet sorghum May late<br>Harvest = Sept 1 - Sept 15 (15 days) | -- | -- | -- | 16.7% | 8.3% |
| Sweet sorghum June medium<br>Harvest = Sept 16 - Sept 30 (15 days) | -- | -- | -- | 16.7% | 8.3% |
| Sweet sorghum June late<br>Harvest = Oct 1 - Oct 15 (15 days) | -- | -- | -- | 16.7% | 8.3% |
| Total Days | 90 | 90 | 90 | 90 | 180 |

[1] Scenario 1-3 = 3-month processing season, 100% energy cane
Scenario 4 = 3-month processing season, 100% sweet sorghum
Scenario 5 = 6-month processing season, 50% energy cane and 50% sweet sorghum

Table 2.16 Estimated Feedstock Yields for Alternative Production Scenarios

| | Feedstock Production Scenarios[1] | | | | |
|---|---|---|---|---|---|
| Biofuel Feedstock Crop | 1 | 2 | 3 | 4 | 5 |
| | | | (wet tons per acre) | | |
| Energy cane through 3rd stubble<br>Harvest = Oct 1 - Dec 31 (90 days) | 40.40 | -- | -- | -- | -- |
| Energy cane through 4th stubble<br>Harvest = Oct 1 - Dec 31 (90 days) | -- | 39.55 | -- | -- | -- |
| Energy cane through 5th stubble<br>Harvest = Oct 1 - Dec 31 (90 days) | -- | -- | 39.14 | -- | 39.14 |
| Sweet sorghum April early<br>Harvest = July 15 -July 30 (15 days) | -- | -- | -- | 18.60 | 18.60 |
| Sweet sorghum April medium<br>Harvest = Aug 1 - Aug 15 (15 days) | -- | -- | -- | 31.50 | 31.50 |
| Sweet sorghum May medium<br>Harvest = Aug 16 - Aug 30 (15 days) | -- | -- | -- | 42.90 | 42.90 |
| Sweet sorghum May late<br>Harvest = Sept 1 - Sept 15 (15 days) | -- | -- | -- | 38.90 | 38.90 |
| Sweet sorghum June medium<br>Harvest = Sept 16 - Sept 30 (15 days) | -- | -- | -- | 32.10 | 32.10 |
| Sweet sorghum June late<br>Harvest = Oct 1 - Oct 15 (15 days) | -- | -- | -- | 30.00 | 30.00 |
| Weighted Average Yield | 40.4 | 39.55 | 39.14 | 30.15 | 34.06 |

[1] Scenario 1-3 = 3-month processing season, 100% energy cane
Scenario 4 = 3-month processing season, 100% sweet sorghum
Scenario 5 = 6-month processing season, 50% energy cane and 50% sweet sorghum

Table 2.17 Acreage Required to Supply Biomass Processing Plant Fixed Amount per Day

| | Feedstock Production Scenarios[1] | | | | |
|---|---|---|---|---|---|
| Biofuel Feedstock Crop | 1 | 2 | 3 | 4 | 5 |
| | | | (acres) | | |
| Energy cane through 3rd stubble<br>Harvest = Oct 1 - Dec 31 (90 days) | 32,079 | -- | -- | -- | -- |
| Energy cane through 4th stubble<br>Harvest = Oct 1 - Dec 31 (90 days) | -- | 32,769 | -- | -- | -- |
| Energy cane through 5th stubble<br>Harvest = Oct 1 - Dec 31 (90 days) | -- | -- | 33,112 | -- | 33,112 |
| Sweet sorghum April early<br>Harvest = July 15 -July 30 (15 days) | -- | -- | -- | 11,613 | 11,613 |
| Sweet sorghum April medium<br>Harvest = Aug 1 - Aug 15 (15 days) | -- | -- | -- | 6,857 | 6,857 |
| Sweet sorghum May medium<br>Harvest = Aug 16 - Aug 30 (15 days) | -- | -- | -- | 5,035 | 5,035 |
| Sweet sorghum May late<br>Harvest = Sept 1 - Sept 15 (15 days) | -- | -- | -- | 5,553 | 5,553 |
| Sweet sorghum June medium<br>Harvest = Sept 16 - Sept 30 (15 days) | -- | -- | -- | 6,729 | 6,729 |
| Sweet sorghum June late<br>Harvest = Oct 1 - Oct 15 (15 days) | -- | -- | -- | 7,200 | 7,200 |
| Total Acres | 32,079.2 | 32,768.6 | 33,111.9 | 42,986.7 | 76,098.6 |
| Total Days | 90 | 90 | 90 | 90 | 180 |
| Total Biomass (wet tons) | 1,296,000 | 1,296,000 | 1,296,000 | 1,296,000 | 2,592,000 |
| Weighted Average Yield | 40.4 | 39.55 | 39.14 | 30.15 | 34.06 |

[1] Required daily feedstock supply = 14,400 tons (600 tons/hour for 24 hours/day).
Scenario 1-3 = 3-month processing season, 100% energy cane
Scenario 4 = 3-month processing season, 100% sweet sorghum
Scenario 5 = 6-month processing season, 50% energy cane and 50% sweet sorghum

Table 2.15 displays percentage values representing the amount of days spend on each individual crop production phase for each of the alternative cropping sequencing scenarios. In scenarios 1 – 3, 100% of the farm production is devoted to energy cane production with harvest from October 1 through December 31 of each year. In scenario 4, 100% of the farm production is devoted to sweet sorghum production with harvest from July 15 to October 15 of each year. Land devoted to sweet sorghum production is divided equally across the six sweet sorghum production periods resulting in 16.7% of the farm land planted to each production sequence. In scenario 5, 50% of the farm land is devoted to energy cane production through harvest of a fifth stubble crop and the remaining 50% is devoted equally (8.3%) to each of the six sweet sorghum production phases. Feedstock production scenarios 1 – 4 each represent 90 days of annual biofuel feedstock crop harvest time, while scenario 5 represents 180 days of annual biofuel feedstock crop harvest time.

Tables 2.16 and 2.17 follow the same feedstock production scenario schematic as in Table 2.15, however, displaying information about the harvest yield measured in wet tons per acre and the amount of farmland acreage necessary for production per day to meet a specified daily feedstock harvest supply, respectively for each of the alternative cropping sequences. Table 2.16 includes the weighted average crop yields for each production scenario which will be used to determine feedstock production cost per yield unit. Using the weighted average yields from Table 2.16, acreage values in Table 2.17 represent the harvested acreage required under each production scenario to meet a specified daily harvested feedstock demand from the processing facility. Feedstock processing demand required by a process facility was assumed to be similar to that of existing sugar mills in the state. Required daily feedstock supply was assumed to be 14,400 tons per day, based on a 600 ton per hour processing rate and 24 hours per day processing time. Production scenarios 1-4 at 90 days of processing would require 1,296,000 total tons of harvested biomass per season, while scenario 5 at 180 days of processing would require 2,592,000 total tons of harvested biomass per season. Required feedstock harvested acreage to meet this demand over an entire season was determined by dividing total required biomass supply by the weighted average yield of each production scenario. The information provided in the Tables 2.15 – 2.17 were then applied to further cost calculations and the estimation of relative feedstock cost differences between alternative feedstock crop production scenarios.

### 2.4 Biofuel Feedstock Cost per Unit

This section presents estimates of biofuel feedstock cost per dry yield unit. Input cost per dry matter ton would be the cost to a biofuel processor of purchasing feedstock crop raw material. Estimated feedstock input costs estimated here exclude any charges for transport of harvested feedstock material from a farm to a processing facility. Estimated costs are presented here for each feedstock crop evaluated in this study. Energy cane feedstock cost estimates are presented in Table 2.18 and sweet sorghum feedstock cost estimates are presented in Tables 2.19 and 2.20 for each production scenario evaluated.

Feedstock cost per dry ton are estimated in a similar manner for both of the feedstock crops evaluated in this study using the following cost estimation model:

$$TPCPA = VCPA + FCPA \tag{2.4}$$

$$RENTPA = TPCPA / 5 \tag{2.5}$$

$$TPCRT = TPCPA + RENTPA \tag{2.6}$$

$$TPCRTWT = TPCRT / WTYLD \tag{2.7}$$

$$TPCRTDT = TPCRT / DTYLD \tag{2.8}$$

$$REQACRES = PCDAY * DAYS / WTYLD \tag{2.9}$$

where *TPCPA* = total crop production cost per acre, *VCPA* = variable crop production cost per acre, *FCPA* = fixed crop production cost per acre, *RENTPA* = land rent charge per acre at a 1/6 share of breakeven revenue, *TPCRT* = total crop production costs plus land rent, *TPCRTWT* = total feedstock input cost per wet ton of feedstock material, *WTYLD* = feedstock crop wet ton yield per acre, *TPCRTDT* = total feedstock input cost per dry ton of feedstock material, *DTYLD* = feedstock crop dry ton yield per acre, *REQACRES* = number of acres required to supply a processing facility a specified tonnage of feedstock per day for a specified time period, *PCDAY* = processing capacity per day (14,400 tons), and *DAYS* = the number of processing days in a given season (90 or 180 days).

Table 2.18 Energy Cane Costs per Unit for Alternative Cropping Sequences

| | Cropping Sequences | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Energy Cane Costs | | | | | |
| Variable Cost per Acre | $415.93 | $424.46 | $430.55 | -- | $430.55 |
| Fixed Cost per Acre | $133.58 | $134.34 | $134.89 | -- | $134.89 |
| Total Production Cost per Acre | $549.51 | $558.80 | $565.44 | -- | $565.44 |
| Rent @ breakeven revenue (1/6) | $109.90 | $111.76 | $113.09 | -- | $113.09 |
| Total Acres | 32,079.2 | 32,768.6 | 33,111.9 | -- | 33,111.9 |
| Yield - wet tons per acre | 40.40 | 39.55 | 39.14 | -- | 39.14 |
| Yield - dry tons per acre | 7.45 | 7.71 | 8.06 | -- | 8.06 |
| Variable Cost per wet ton | $10.30 | $10.73 | $11.00 | -- | $11.00 |
| Fixed Cost per wet ton | $3.31 | $3.40 | $3.45 | -- | $3.45 |
| Total Cost per wet ton | $13.60 | $14.13 | $14.45 | -- | $14.45 |
| Rent per wet ton | $2.72 | $2.83 | $2.89 | -- | $2.89 |
| Total Cost plus Rent per wet ton | $16.32 | $16.95 | $17.34 | -- | $17.34 |
| Variable Cost per dry ton | $55.83 | $55.05 | $53.42 | -- | $53.42 |
| Fixed Cost per dry ton | $17.93 | $17.42 | $16.74 | -- | $16.74 |
| Total Cost per dry ton | $73.76 | $72.48 | $70.15 | -- | $70.15 |
| Rent per dry ton | $14.75 | $14.50 | $14.03 | -- | $14.03 |
| Total Cost plus Rent per dry ton | $88.51 | $86.97 | $84.18 | -- | $84.18 |

Table 2.19 Sweet Sorghum Costs per Unit for Alternative Cropping Sequences - Early Planting

| | Sweet Sorghum Cropping Sequence | | |
|---|---|---|---|
| | April Pltg. Early Mat. | April Pltg. Medium Mat. | May Pltg. Medium Mat. |
| Sweet Sorghum Costs | | | |
| Variable Cost per Acre | $397.51 | $392.59 | $392.59 |
| Fixed Cost per Acre | $158.97 | $154.89 | $154.89 |
| Total Production Cost per Acre | $556.48 | $547.48 | $547.48 |
| Rent @ breakeven revenue (1/6) | $111.30 | $109.50 | $109.50 |
| Total Acres | 11,612.90 | 6,857.10 | 5,035.00 |
| Yield - wet tons per acre | 18.60 | 31.50 | 42.90 |
| Yield – dry tons per acre | 4.80 | 7.4 | 8.9 |
| Variable Cost per wet ton | $21.37 | $12.46 | $9.15 |
| Fixed Cost per wet ton | $8.55 | $4.92 | $3.61 |
| Total Cost per wet ton | $29.92 | $17.38 | $12.76 |
| Rent per wet ton | $5.98 | $3.48 | $2.55 |
| Total Cost plus Rent per wet ton | $35.90 | $20.86 | $15.31 |
| Variable Cost per dry ton | $82.81 | $53.05 | $44.11 |
| Fixed Cost per dry ton | $33.12 | $20.93 | $17.40 |
| Total Cost per dry ton | $115.93 | $73.98 | $61.51 |
| Rent per dry ton | $23.19 | $14.80 | $12.30 |
| Total Cost plus Rent per dry ton | $139.12 | $88.78 | $73.82 |

Table 2.20 Sweet Sorghum Costs per Unit for Alternative Cropping Sequences - Late Planting

| | Sweet Sorghum Cropping Sequence | | |
|---|---|---|---|
| | May Pltg.<br>Late Mat. | June Pltg.<br>Medium Mat. | June Pltg.<br>Late Mat. |
| Sweet Sorghum Costs | | | |
| Variable Cost per Acre | $387.67 | $387.67 | $382.75 |
| Fixed Cost per Acre | $150.81 | $150.81 | $146.73 |
| Total Production Cost per Acre | $538.48 | $538.48 | $529.48 |
| Rent @ breakeven revenue (1/6) | $107.70 | $107.70 | $105.90 |
| Total Acres | 5,552.70 | 6,729.00 | 7,200.00 |
| Yield - wet tons per acre | 38.90 | 32.10 | 30.0 |
| Yield - dry tons per acre | 9.10 | 6.00 | 6.7 |
| Variable Cost per wet ton | $9.97 | $12.08 | $12.76 |
| Fixed Cost per wet ton | $3.88 | $4.70 | $4.89 |
| Total Cost per wet ton | $13.84 | $16.78 | $17.65 |
| Rent per wet ton | $2.77 | $3.36 | $3.53 |
| Total Cost plus Rent per wet ton | $16.61 | $20.13 | $21.18 |
| Variable Cost per dry ton | $42.60 | $64.61 | $57.13 |
| Fixed Cost per dry ton | $16.57 | $25.14 | $21.90 |
| Total Cost per dry ton | $59.17 | $89.75 | $79.03 |
| Rent per dry ton | $11.83 | $17.95 | $15.81 |
| Total Cost plus Rent per dry ton | $71.01 | $107.70 | $94.83 |

For the energy cane production scenarios, production through harvest of a third stubble crop has estimated feedstock input costs of $16.32 per wet ton of feedstock material and estimated costs of $88.51 per dry ton of feedstock material, based on an average yield of 40.40 wet tons per acre and 7.45 dry tons per acre (Table 2.18). Estimated total feedstock costs on a wet ton basis increased to $16.95 per ton for a crop cycle through harvest of a fourth stubble crop and increased further to $17.34 per ton for a crop cycle through harvest of a fifth stubble crop. This increase in cost per wet ton of feedstock material was due primarily to the slight decline in average yields from 40.40 wet tons per acre for production scenario 1 to 39.55 and 39.14 wet tons per acre for production scenarios 2 and 3. Total feedstock costs estimated on a dry ton basis actually declined slightly across the three production scenarios. Energy cane feedstock costs for a crop cycle through harvest of a fifth stubble crop was estimated to be $84.18 per dry ton compared with $88.51 and $86.97 per dry ton for crop cycles through harvest of a third and fourth stubble crop. This decline in cost per dry ton was due to the slight increase in dry ton yields from 7.45 dry tons per acre for scenario 1, 7.71 dry tons per acre for scenario 2, and 8.06 dry tons per acre for scenario 3. These estimates of total feedstock cost per dry ton (total production cost plus land rent) would represent a breakeven price paid to the feedstock crop producer, based on the production, yield and cost assumptions utilised in this study.

Similar estimated feedstock crop production costs are presented in Tables 2.19 and 2.20 for the six alternative production seasons. These costs were estimated in a manner similar to that just presented for energy cane. Unlike cost estimates for energy cane which were very similar in magnitude due to the small variation in yield across production scenarios, cost estimates for sweet sorghum varied greatly due to the wide variation in expected yields across the six sweet sorghum production periods. Total crop production plus land rent charges on a wet ton basis ranged from $35.90 per ton, for the April planting early maturity production scenario which had the lowest expected average yield of 18.60 wet tons per acre, to $15.31 per ton, for the May planting medium maturity production scenario which had the highest expected average yield of 42.90 wet tons per acre. On a dry ton basis, the April planting early maturity production scenario again had the highest estimated cost at $139.12 per dry ton of feedstock material, due primarily to the low expected average yield of 4.80 dry tons per acre. The lowest estimated cost on a dry ton basis was observed for the May planting late maturity production scenario. This scenario had estimated total feedstock costs of $71.01 per dry ton, based on the highest observed average yield of 9.10 dry tons per acre. A simple average of the cost estimates over the six production scenarios would yield an average expected cost of $21.67 per wet ton or $95.88 per dry ton of feedstock crop material.

# CHAPTER 3 – OPTIMAL FEEDSTOCK PROCESSING FACILITY LOCATION

Objectives three and four of this research study were related to the determination of the current total land area available for feedstock crop production in Louisiana and to determine the optimal locations of feedstock crop processing facilities in the state. This chapter presents the methodology utilised to address these objectives as well as the results of the analysis. Transportation of harvested biomass is a major consideration in the potential locations of feedstock processing facilities due to the significant share of total cost processing which transportation cost represents. The first section of this chapter identifies land areas within the state of Louisiana which would offer potential for feedstock crop production while minimizing the impact on existing food crop production in the state. The next sections of the chapter discusses a locational mathematical programming model which was utilised to identify potential optimal feedstock processing locations within the state as well as selected results of the facility location analysis.

## 3.1 Potential State Land Area Available for Feedstock Production

The development of a biofuel industry in the state which utilises harvested feedstock crop material as the primary input in cellulosic biofuel processing facilities would represent a new agricultural production sector in the state. One of the assumptions employed in this analysis was that the initiation and expansion of biofuel feedstock crop production would not compete with existing crop production in the state. As a result, the identification of potential land area in the state which might be available for feedstock crop production focused on idle cropland currently not devoted to existing crop production.

The primary data set utilized to determine quantities of idle cropland in Louisiana which might provide potential areas of feedstock crop production was the 2012 Census of

Agriculture. The Census of Agriculture provides information and data on a wide array of characteristics of agriculture and farming operations on a national, state and county/parish basis. Data on land use categories within farms in the state, on both the state and parish level, were utilised to estimate potential land areas which might be available for feedstock crop production.

Table 3.1 presents state-level estimates of acreage levels of various land use categories on farms within Louisiana obtained from the 2012 Census of Agriculture. In 2012, Louisiana had a total of 7,900,864 acres of land area in farms. Of that total farm land area, cropland accounted for just over one-half of the total land area in farms, 4,275,637 acres or 54.1% of land in farms. Approximately 80.6% of the total cropland area was harvested cropland, representing 3,447,617 acres. The remaining cropland area was divided between idle cropland, failed cropland and summer fallow. The Census of Agriculture reported that Louisiana had 443,430 acres of idle cropland in the state in 2012. This idle cropland base represented 5.6% of total land in farms and 10.4% of total cropland. This idle cropland base was assumed, for purposes of this study, to represent the potential land area available for production of biofuel feedstock crops in the state.

A complicating factor in the use of reported idle cropland acres from the Census of Agriculture was the existence of land enrolled in CRP and other conservation programs. The 2012 Census reported that there were 309,282 acres of farm land enrolled in the CRP and other conservation programs in the state. This land use category tabulation was reported separately from the land in farms tabulation as reported in the Census. Communication with USDA-NASS personnel verified that conservation land areas were included in the land in farms tabulation under the idle cropland category as well as several other land use categories. As a result, an estimation was required to determine how much of the reported idle cropland was and was not enrolled in conservation programs. This determination is relevant for this study due to the long term nature of enrolment of land in conservation programs, the varying expiration dates of specific land tracts enrolled in conservation programs and the resulting impact on the percentage of idle cropland actually available for new crop production.

Table 3.1 Potential Idle Land Available for Feedstock Production in Louisiana [1]

| Land Use Category | Total State Acres |
|---|---|
| Total cropland | 4,275,637 |
| Harvested cropland | 3,447,617 |
| Other cropland | 610,875 |
| Idle cropland | 443,430 |
| Failed cropland | 37,225 |
| Summer fallow | 130,220 |
| Permanent pasture | 1,738,667 |
| Woodland pastured | 225,654 |
| Other pasture/grazing land | 217,145 |
| Woodland not pastured | 1,029981 |
| Land in farmsteads | 630,925 |
| | |
| Land in farms | 7,900,864 |
| | |
| Idle cropland | 443,430 |
| CRP land[2] | 309,282 |
| CRP acres in idle cropland[3] | 228,609 |
| Idle cropland not in CRP[4] | 214,821 |

[1] Source: 2012 Census of Agriculture, Vol. 1, State Data, Louisiana, Table 8.
[2] CRP land included in idle cropland as well as other land use categories.
[3] Equals idle acres, if CRP acres > idle acres, otherwise equals CRP acres.
[4] Equals idle acres minus CRP acres in idle cropland.

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To evaluate optimal biofuel feedstock processing facility locations which would receive harvested feedstock produced on currently existing idle cropland which may have some acreage enrolled in conservation programs, three alternative available acreage levels were analysed: (1.) 0% of CRP acres in idle cropland available for production, (2.) 50% of CRP acres in idle cropland available for production and (3.) 100% of CRP acres in idle cropland available for production. The mathematical model used to determine idle cropland acres which might be available for feedstock crop production can be specified as follows:

$$IDLECRP = if\ (CRP > IDLE, then\ IDLE, else\ CRP) \qquad [3.1]$$

$$IDLENCRP = IDLE - IDLECRP \qquad [3.2]$$

$$IDLEAVL = IDLENCRP + AF\ (IDLECRP) \qquad [3.3]$$

where *IDLE* = idle cropland acres, *CRP* = conservation program acres, *IDLECRP* = idle cropland acres enrolled in conservation programs, *IDLNCRP* = idle cropland acres not enrolled in conservation programs, *AF* = conservation acres in idle land availability factor for feedstock production (0%, 50%, 100%), and *IDLEAVL* = total idle cropland acres available for feedstock production. These calculations were performed using parish-level Census data. Results of parish-level estimates alternative idle cropland which might be available for feedstock production are shown in Table 3.2. These parish-level estimates of available land for feedstock production formed the basis for the estimation of feedstock supplies available across parishes in the state as part of the parameter set of coefficients required for the optimal processing facility location models discussed in the next section.

Table 3.2 Idle Land Acreage Available for Feedstock Production by Parish

| Parish | Percent of CRP Acres in Idle Land Available for Production<br>0% | 50% | 100% |
|---|---|---|---|
| | (acres) | (acres) | (acres) |
| Acadia | 25,331 | 26,042 | 26,752 |
| Allen | 9,667 | 9,986 | 10,305 |
| Ascension | 380 | 380 | 380 |
| Assumption | 1,047 | 1,047 | 1,047 |
| Avoyelles | 4,805 | 12,173 | 19,541 |
| Beauregard | 0 | 3,613 | 7,226 |
| Bienville | 421 | 510 | 598 |
| Bossier | 941 | 1,523 | 2,105 |
| Caddo | 1,897 | 2,294 | 2,692 |
| Calcasieu | 15,405 | 15,725 | 16,044 |
| Caldwell | 955 | 3,536 | 6,117 |
| Cameron | 13,498 | 13,906 | 14,313 |
| Catahoula | 0 | 10,806 | 21,611 |
| Claiborne | 1,458 | 1,586 | 1,714 |
| Concordia | 0 | 8,184 | 16,367 |
| De Soto | 1,079 | 1,395 | 1,711 |
| East Baton Rouge | 2,412 | 2,984 | 3,555 |
| East Carroll | 0 | 4,324 | 8,647 |
| East Feliciana | 0 | 1,313 | 2,625 |
| Evangeline | 12,788 | 14,916 | 17,043 |
| Franklin | 0 | 8,064 | 16,127 |
| Grant | 0 | 718 | 1,435 |
| Iberia | 1,417 | 1,714 | 2,011 |
| Iberville | 768 | 973 | 1,178 |
| Jackson | 41 | 41 | 41 |
| Jefferson | 10 | 12 | 14 |
| Jefferson Davis | 45,513 | 47,058 | 48,603 |
| Lafayette | 2,565 | 2,591 | 2,617 |
| Lafourche | 1,316 | 1,431 | 1,545 |
| La Salle | 45 | 334 | 623 |
| Lincoln | 0 | 517 | 1,033 |
| Livingston | 77 | 313 | 549 |
| Madison | 0 | 6,913 | 13,826 |
| Morehouse | 0 | 4,547 | 9,093 |
| Natchitoches | 0 | 2,302 | 4,604 |
| Orleans | 0 | 0 | 0 |
| Ouachita | 1,381 | 2,669 | 3,957 |
| Plaquemines | 249 | 249 | 249 |

Table 3.2 Idle Land Acreage Available for Feedstock Production by Parish

| (Continued) | Percent of CRP Acres in Idle Land Available for Production | | |
|---|---|---|---|
| Parish | 0% | 50% | 100% |
| | (acres) | (acres) | (acres) |
| Pointe Coupee | 2,046 | 2,367 | 2,689 |
| Rapides | 118 | 2,068 | 4,017 |
| Red River | 0 | 1,300 | 2,600 |
| Richland | 6,277 | 19,401 | 32,525 |
| Sabine | 0 | 112 | 225 |
| St. Bernard | 858 | 858 | 858 |
| St. Charles | 0 | 0 | 0 |
| St. Helena | 0 | 548 | 1,095 |
| St. James | 2,684 | 2,684 | 2,684 |
| St. John | 149 | 149 | 149 |
| St. Landry | 18,881 | 24,157 | 29,432 |
| St. Martin | 767 | 928 | 1,089 |
| St. Mary | 1,636 | 1,720 | 1,804 |
| St. Tammany | 513 | 588 | 663 |
| Tangipahoa | 1,795 | 2,624 | 3,453 |
| Tensas | 0 | 5,480 | 10,959 |
| Terrebonne | 1,076 | 1,301 | 1,527 |
| Union | 697 | 901 | 1,105 |
| Vermilion | 28,940 | 30,841 | 32,741 |
| Vernon | 1,363 | 1,649 | 1,935 |
| Washington | 0 | 1,662 | 3,324 |
| Webster | 1,074 | 1,074 | 1,074 |
| West Baton Rouge | 479 | 479 | 479 |
| West Carroll | 0 | 9,244 | 18,487 |
| West Feliciana | 0 | 270 | 540 |
| Winn | 0 | 39 | 77 |
| State Total | 214,821 | 329,125 | 443,430 |

[1] Idle cropland available for feedstock production under alternative assumptions regarding the estimated quantity of idle cropland enrolled in conservation programs and not available for feedstock production.

## 3.2 Specification of Optimal Facility Location Model

The determination of optimal locations of potential biofuel feedstock processing facilities was evaluated using a linear programming formulation of the basic transportation model. The objective of the model was to determine the location of one or more processing facilities across the state which would receive feedstock material from alternative supply points (parishes) with the goal of meeting a specified demand quantity received while minimizing total transportation costs. The basic optimal facility location model utilized in this study can be specified in general form as follows:

$$Min\ T = \sum_{s=1}^{m} \sum_{d=1}^{n} c_{sd}\ x_{sd} \tag{3.4}$$

s. t.

$$\sum_{d=1}^{n} x_{s_i d} \leq S_i \qquad for\ i = 1\ to\ m \tag{3.5}$$

$$\sum_{s=1}^{m} x_{sd_j} - D_j y_{d_j} \geq 0 \qquad for\ j = 1\ to\ n \tag{3.6}$$

$$\sum_{y=1}^{n} y_{d_j} = P \qquad for\ j = 1\ to\ n \tag{3.7}$$

where $T$ represents the total biomass transportation cost for all locations, in total dollars; $c_{sd}$ represents the biomass transportation cost per unit for shipment from supply location $s$ to demand location $d$, in dollars per ton; $x_{sd}$ represents the quantity of biomass shipped from supply location $s$ to demand location $d$, in tons; $S_i$ represents the total biomass supply available at supply point $i$, in tons; $D_j$ represents the total biomass quantity demanded at demand point $j$, in tons; $y_{dj}$ is a binary variable representing whether processing occurs at a given demand point; and $P$ represents the number of biomass processing plant locations to be evaluated.

The model's objective function minimizes total transportation costs for a specified number of optimally located processing facilities. The objective function coefficients were estimated to represent transportation cost per ton of feedstock transported from one parish to another. Hauling cost parameters were estimated using a transportation cost function similar in form and magnitude to existing cost functions utilised in the sugarcane industry of Louisiana. The specific cost function utilized in this study to estimate objective function coefficient parameters was specified as the hauling cost per ton from parish “a” to parish “b” and is equal to $0.085 per mile + $1.36 per ton. The amount of tons of feedstock which can be transported per haul are hereby regulated by the United States Department of Transportation which limits the total gross vehicle weight of a semi-trailer truck to 80,000 pounds or 40 tons. A standard semi-trailer truck will weigh on average 33,000 pounds or 16.5 tons which would therefore yield an average load weight of 47,000 lbs or 23.5 tons of feedstock per haul. The mileage distance from a centroid location of one parish to a centroid location of another parish was obtained from GIS sources. The feedstock supply volumes available in each parish were calculated as the product of idle cropland available for production and an assumed average feedstock yield of 40 tons/acre for a 3-month energy cane production season and an assumed average 36 tons/acre yield for a 6-month sweet sorghum/energy cane production season. These assumed yields were used to represent typical expected average harvest yields over the harvest period for each of the two production scenarios evaluated. Feedstock demand volumes in potential parish facility locations were specified for a 3-month and 6-month processing season. Daily processing capacity was based on similar capacities for existing sugarcane processing mills, at 600 tons per hour for 24 hours per day. As a result, total feedstock demand volume for one facility processing for 3 months was specified to be 1.29 million tons per season and for 6 months at 2.59 million tons per season.

If all existing idle cropland were utilised for feedstock production, several processing facilities could theoretically be in operation. However, it would seem to be more typical that one or a small number of facilities would likely begin operation and may or may not expand over time as economic conditions warrant. Since the instance of all idle land being devoted to feedstock production is probably not very likely, the optimal facility location model was analysed for optimal locations of one, two, and three processing facilities.

### 3.3 Optimal Biomass Processing Facility Locations

The locations of processing facilities were determined through the use of a linear programming model focusing on the minimisation of feedstock transportation costs. This section presents the results of that very model in the Tables 3.3 – 3.8 where Tables 3.3 – 3.5 pertain to a processing season with a duration of three months and Tables 3.6 – 3.8 to a duration of six months. Additionally, the tables also separate the information on the basis of 0%, 50%, and 100% CRP land availability.

Even though the linear programming model encompassed all 64 parishes of the state of Louisiana in its calculations, one will notice that there is only very little variation in the demand locations deemed as most suitable for processing facilities. For example, Jefferson Davis Parish is an optimal choice in all data tables presented in this section, regardless of the amount of CRP land available for farming or the duration of the processing season. This can be explained by the physical location of Jefferson Davis Parish as well as other demand locations, as all of those are very central to the various supply locations hence minimising the distance the feedstock has to be shipped and consequently minimising the transportation cost. A location was deemed as optimal when the cost associated with shipping feedstock to this location was the least expensive compared to other locations.

Table 3.3 Optimal Feedstock Processing Facility Locations in Louisiana, 3-Month Processing Season, 0% of CRP Land Available for Production

| Number of Processing Facilities | Total Transportation Cost ($) | Supply Location (parish) | Quantity Shipped (tons) | Acreage Required (acres) | Demand Location (parish) |
|---|---|---|---|---|---|
| 1 | 3,965,760 | Jeff Davis | 1,296,000 | 32,400 | Jeff Davis |
| 2 | 8,157,924 | Jeff Davis | 1,296,000 | 32,400 | Jeff Davis |
| | | Acadia | 35,800 | 895 | Vermilion |
| | | Lafayette | 102,600 | 2,565 | Vermilion |
| | | Vermilion | 1,157,600 | 28,940 | Vermilion |
| 3 | 12,474,100 | Acadia | 977,440 | 24,436 | Acadia |
| | | Jeff Davis | 318,560 | 7,964 | Acadia |
| | | Jeff Davis | 1,296,000 | 32,400 | Jeff Davis |
| | | Acadia | 35,800 | 895 | Vermilion |
| | | Lafayette | 102,600 | 2,565 | Vermilion |
| | | Vermilion | 1,157,600 | 28,940 | Vermilion |

Table 3.4 Optimal Feedstock Processing Facility Locations in Louisiana, 3-Month Processing Season, 50% of CRP Land Available for Production

| Number of Processing Facilities | Total Transportation Cost ($) | Supply Location (parish) | Quantity Shipped (tons) | Acreage Required (acres) | Demand Location (parish) |
|---|---|---|---|---|---|
| 1 | 3,965,760 | Jeff Davis | 1,296,000 | 32,400 | Jeff Davis |
| 2 | 8,031,952 | Jeff Davis | 1,296,000 | 32,400 | Jeff Davis |
| | | Lafayette | 62,380 | 1,560 | Vermilion |
| | | Vermilion | 1,233,620 | 30,841 | Vermilion |
| 3 | 12,238,232 | Jeff Davis | 1,296,000 | 32,400 | Jeff Davis |
| | | Franklin | 322,540 | 8,064 | Richland |
| | | Morehouse | 90,660 | 2,267 | Richland |
| | | Ouachita | 106,760 | 2,669 | Richland |
| | | Richland | 776,040 | 19,401 | Richland |
| | | Lafayette | 62,380 | 1,560 | Vermilion |
| | | Vermilion | 1,233,620 | 30,841 | Vermilion |

Table 3.5 Optimal Feedstock Processing Facility Locations in Louisiana, 3-Month Processing Season, 100% of CRP Land Available for Production

| Number of Processing Facilities | Total Transportation Cost ($) | Supply Location (parish) | Quantity Shipped (tons) | Acreage Required (acres) | Demand Location (parish) |
|---|---|---|---|---|---|
| 1 | 3,965,760 | Jeff Davis | 1,296,000 | 32,400 | Jeff Davis |
| 2 | 7,931,520 | Jeff Davis | 1,296,000 | 32,400 | Jeff Davis |
| | | Richland | 1,296,000 | 32,400 | Richland |
| 3 | 11,897,280 | Jeff Davis | 1,296,000 | 32,400 | Jeff Davis |
| | | Richland | 1,296,000 | 32,400 | Richland |
| | | Vermilion | 1,296,000 | 32,400 | Vermilion |

Table 3.6 Optimal Feedstock Processing Facility Locations in Louisiana, 6-Month Processing Season, 0% of CRP Land Available for Production

| Number of Processing Facilities | Total Transportation Cost ($) | Supply Location (parish) | Quantity Shipped (tons) | Acreage Required (acres) | Demand Location (parish) |
|---|---|---|---|---|---|
| 1 | 8,987,896 | Acadia | 911,916 | 25,331 | Jeff Davis |
| | | Calcasieu | 41,616 | 1,156 | Jeff Davis |
| | | Jeff Davis | 1,638,468 | 45,513 | Jeff Davis |
| 2 | 19,782,896 | Acadia | 860,976 | 23,916 | Acadia |
| | | Evangeline | 460,368 | 12,788 | Acadia |
| | | Lafayette | 92,340 | 2,565 | Acadia |
| | | St. Landry | 136,476 | 3,791 | Acadia |
| | | Vermilion | 1,041,840 | 28,940 | Acadia |
| | | Acadia | 50,940 | 1,415 | Jeff Davis |
| | | Allen | 348,012 | 9,667 | Jeff Davis |
| | | Calcasieu | 554,580 | 15,405 | Jeff Davis |
| | | Jeff Davis | 1,638,468 | 45,513 | Jeff Davis |

Table 3.7 Optimal Feedstock Processing Facility Locations in Louisiana, 6-Month Processing Season, 50% of CRP Land Available for Production

| Number of Processing Facilities | Total Transportation Cost ($) | Supply Location (parish) | Quantity Shipped (tons) | Acreage Required (acres) | Demand Location (parish) |
|---|---|---|---|---|---|
| 1 | 8,919,223 | Acadia | 897,912 | 24,942 | Jeff Davis |
| | | Jeff Davis | 1,694,088 | 47,058 | Jeff Davis |
| 2 | 19,515,753 | Acadia | 937,494 | 26,042 | Acadia |
| | | Evangeline | 536,958 | 14,916 | Acadia |
| | | Lafayette | 93,276 | 2,591 | Acadia |
| | | Vermillion | 1,024,272 | 28,452 | Acadia |
| | | Allen | 331,830 | 9,218 | Jeff Davis |
| | | Calcasieu | 566,082 | 15,725 | Jeff Davis |
| | | Jeff Davis | 1,694,088 | 47,058 | Jeff Davis |
| 3 | 30,862,564 | Acadia | 937,494 | 26,042 | Acadia |
| | | Evangeline | 536,958 | 14,916 | Acadia |
| | | Lafayette | 93,276 | 2,591 | Acadia |
| | | Vermilion | 1,024,272 | 28,452 | Acadia |
| | | Allen | 331,830 | 9,218 | Jeff Davis |
| | | Calcasieu | 566,082 | 15,725 | Jeff Davis |
| | | Jeff Davis | 1,694,088 | 47,058 | Jeff Davis |
| | | Caldwell | 127,296 | 3,536 | Richland |
| | | Catahoula | 229,176 | 6,366 | Richland |
| | | East Carroll | 155,646 | 4,324 | Richland |
| | | Franklin | 290,286 | 8,064 | Richland |
| | | Jackson | 1,476 | 41 | Richland |
| | | Lincoln | 18,594 | 517 | Richland |
| | | Madison | 248,868 | 6,913 | Richland |
| | | Morehouse | 163,674 | 4,547 | Richland |
| | | Ouachita | 96,084 | 2,669 | Richland |
| | | Richland | 698,436 | 19,401 | Richland |
| | | Tensas | 197,262 | 5,480 | Richland |
| | | Union | 32,436 | 901 | Richland |
| | | West Carroll | 332,766 | 9,244 | Richland |

Table 3.8 Optimal Feedstock Processing Facility Locations in Louisiana, 6-Month Processing Season, 100% of CRP Land Available for Production

| Number of Processing Facilities | Total Transportation Cost ($) | Supply Location (parish) | Quantity Shipped (tons) | Acreage Required (acres) | Demand Location (parish) |
|---|---|---|---|---|---|
| 1 | 8,858,041 | Acadia | 842,292 | 23,397 | Jeff Davis |
| | | Jeff Davis | 1,749,708 | 48,603 | Jeff Davis |
| 2 | 17,971,351 | Acadia | 842,292 | 23,397 | Jeff Davis |
| | | Jeff Davis | 1,749,708 | 48,603 | Jeff Davis |
| | | Franklin | 580,572 | 16,127 | Richland |
| | | Madison | 370,728 | 10,298 | Richland |
| | | Morehouse | 327,348 | 9,093 | Richland |
| | | Ouachita | 142,452 | 3,957 | Richland |
| | | Richland | 1,170,900 | 32,525 | Richland |
| 3 | 28,309,878 | Acadia | 698,364 | 19,399 | Evangeline |
| | | Allen | 220,536 | 6,126 | Evangeline |
| | | Evangeline | 613,548 | 17,043 | Evangeline |
| | | St. Landry | 1,054,552 | 29,293 | Evangeline |
| | | Acadia | 264,708 | 7,353 | Jeff Davis |
| | | Calcasieu | 577,584 | 16,044 | Jeff Davis |
| | | Jeff Davis | 1,749,708 | 48,603 | Jeff Davis |
| | | Franklin | 580,572 | 16,127 | Richland |
| | | Madison | 370,728 | 10,298 | Richland |
| | | Morehouse | 327,348 | 9,093 | Richland |
| | | Ouachita | 142,452 | 3,957 | Richland |
| | | Richland | 1,170,900 | 32,525 | Richland |

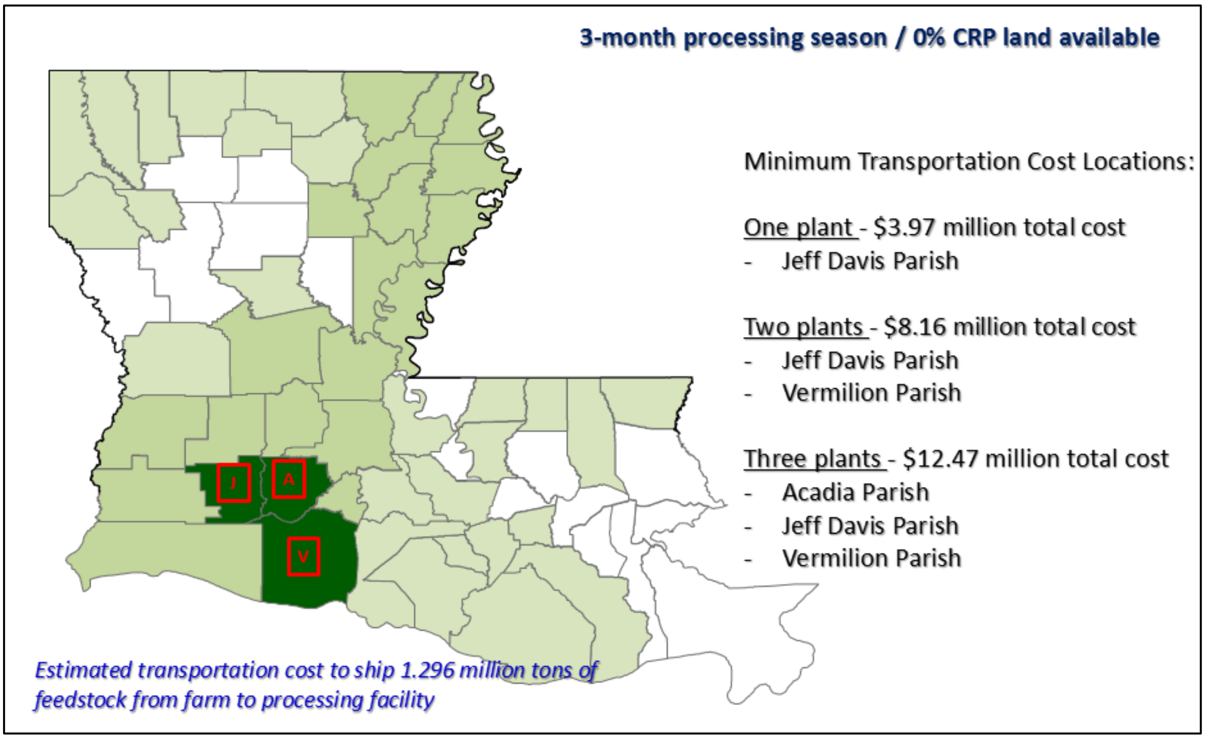


Figure 3.1 - Optimal Feedstock Processing Facility Locations in Louisiana,
3-Month Processing Season, 0% of CRP Land Available for Production

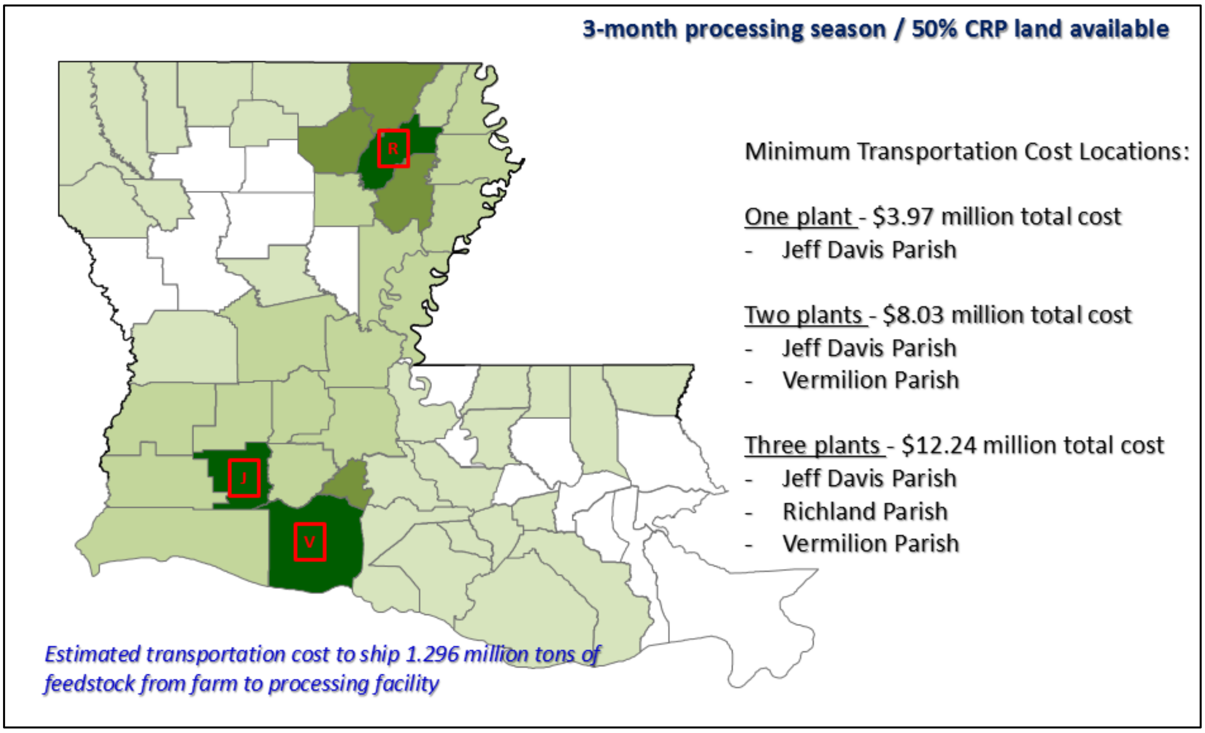
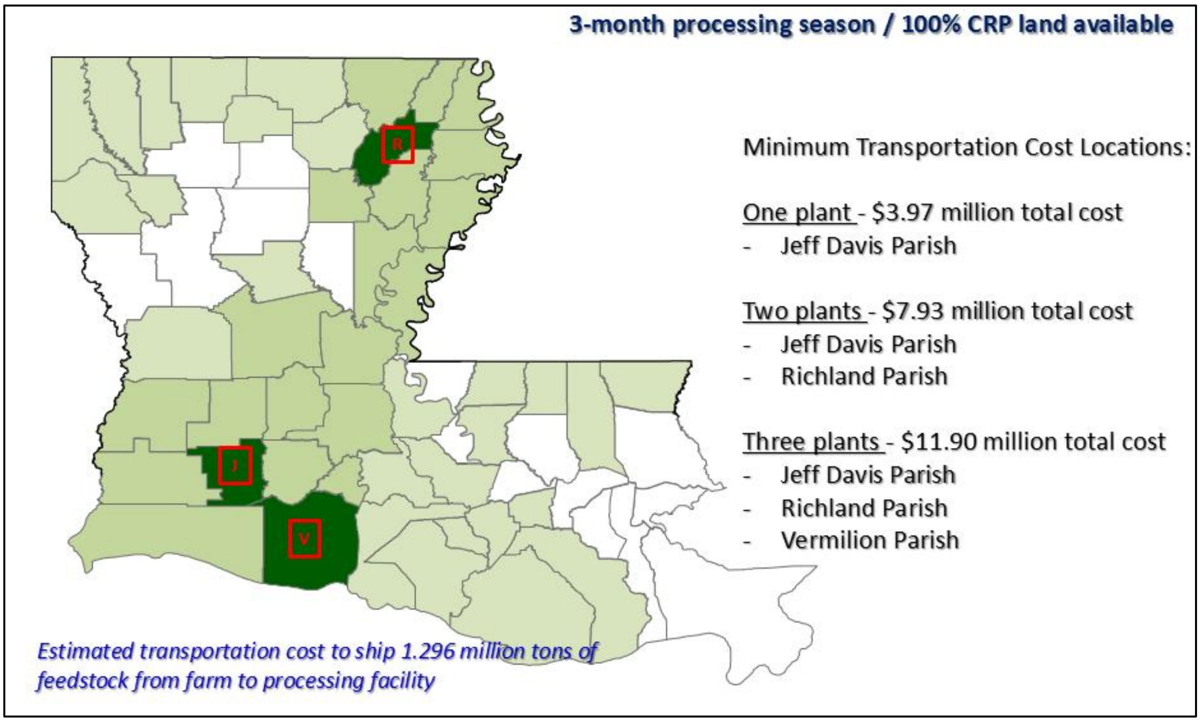


Figure 3.2 - Optimal Feedstock Processing Facility Locations in Louisiana,
3-Month Processing Season, 50% of CRP Land Available for Production



**3-month processing season / 100% CRP land available**

Minimum Transportation Cost Locations:

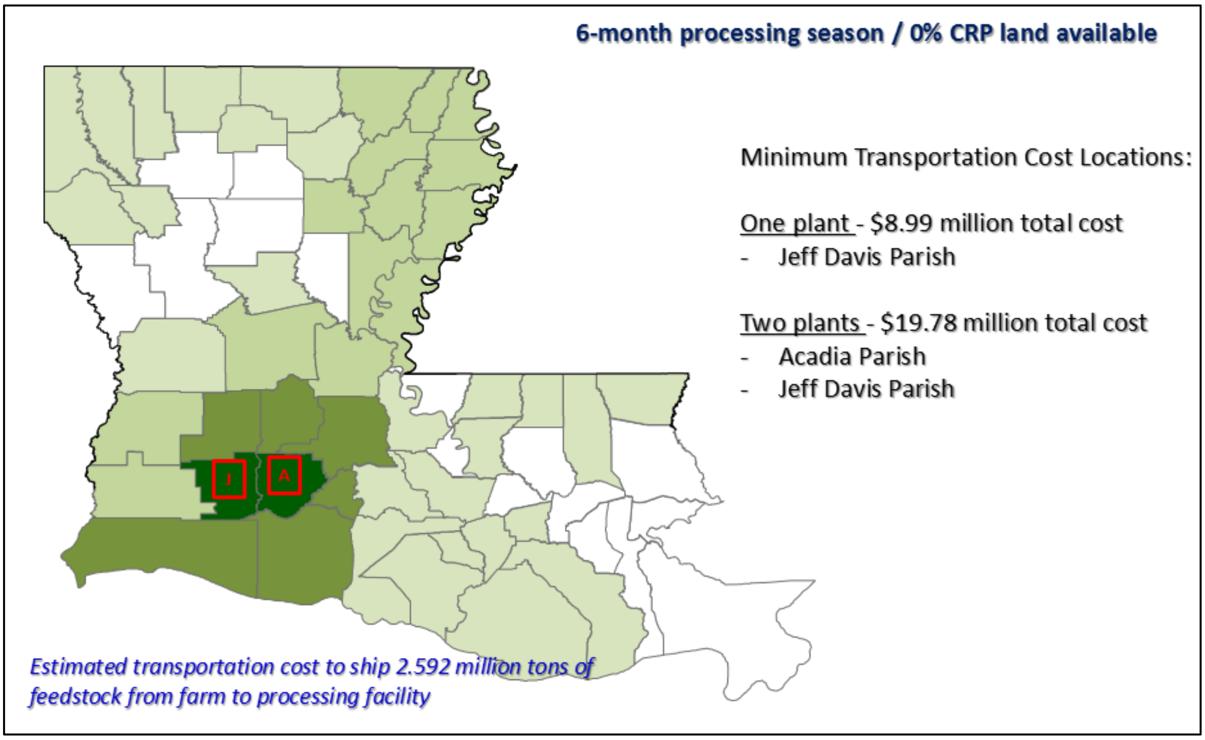
One plant - $3.97 million total cost
- Jeff Davis Parish

Two plants - $7.93 million total cost
- Jeff Davis Parish
- Richland Parish

Three plants - $11.90 million total cost
- Jeff Davis Parish
- Richland Parish
- Vermilion Parish

*Estimated transportation cost to ship 1.296 million tons of feedstock from farm to processing facility*

Figure 3.3 - Optimal Feedstock Processing Facility Locations in Louisiana, 3-Month Processing Season, 100% of CRP Land Available for Production



**6-month processing season / 0% CRP land available**

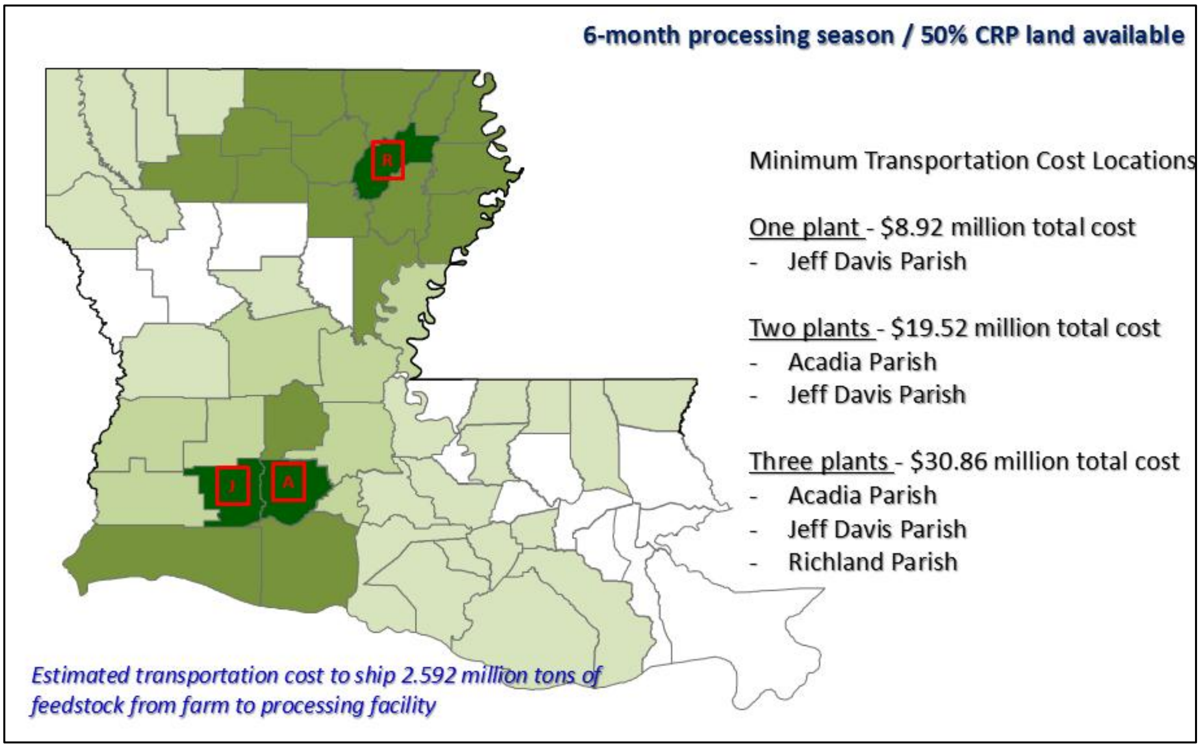
Minimum Transportation Cost Locations:

One plant - $8.99 million total cost
- Jeff Davis Parish

Two plants - $19.78 million total cost
- Acadia Parish
- Jeff Davis Parish

*Estimated transportation cost to ship 2.592 million tons of feedstock from farm to processing facility*

Figure 3.4 - Optimal Feedstock Processing Facility Locations in Louisiana, 6-Month Processing Season, 0% of CRP Land Available for Production



**6-month processing season / 50% CRP land available**

Minimum Transportation Cost Locations

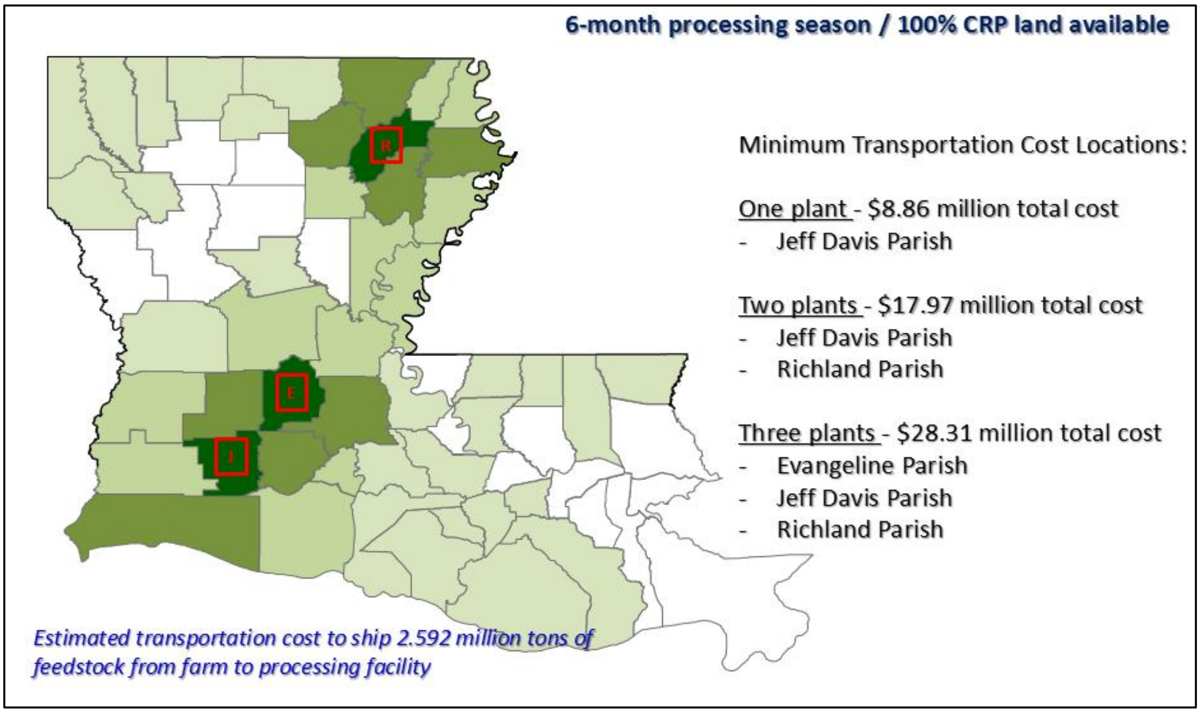
One plant - $8.92 million total cost
- Jeff Davis Parish

Two plants - $19.52 million total cost
- Acadia Parish
- Jeff Davis Parish

Three plants - $30.86 million total cost
- Acadia Parish
- Jeff Davis Parish
- Richland Parish

*Estimated transportation cost to ship 2.592 million tons of feedstock from farm to processing facility*

Figure 3.5 - Optimal Feedstock Processing Facility Locations in Louisiana, 6-Month Processing Season, 50% of CRP Land Available for Production



**6-month processing season / 100% CRP land available**

Minimum Transportation Cost Locations:

One plant - $8.86 million total cost
- Jeff Davis Parish

Two plants - $17.97 million total cost
- Jeff Davis Parish
- Richland Parish

Three plants - $28.31 million total cost
- Evangeline Parish
- Jeff Davis Parish
- Richland Parish

*Estimated transportation cost to ship 2.592 million tons of feedstock from farm to processing facility*

Figure 3.6 - Optimal Feedstock Processing Facility Locations in Louisiana, 6-Month Processing Season, 100% of CRP Land Available for Production

# CHAPTER 4 – SUMMARY AND CONCLUSION

## 4.1 Summary

A new approach to satisfy the worldwide ever-increasing demand for energy and tackle the problems which our society's rapid consumption creates is presented by the biofuel industry. It offers many new opportunities, such as the ability to extract fuels and consequently generate energy from an infinite resource. Simple crops that have been known to mankind for many generations and grown for numerous centuries enable our society to generate energy in a future-oriented and sustainable manner. The use of energy cane and sweet sorghum crops in biofuel production also allows for production sites to no longer be limited to remote places in often difficult terrain but to be established in almost every nation or country around the world assuming input factors necessary for production are present. Furthermore do these crops allow for flexible production cycles and offer many final product possibilities as the intermediate product can be extracted juice as well as a bagasse, therefore in liquid or in dry form.

An important element of this study is the need to ensure that biofuel production must not interfere with food production. Any and all energy cane or sweet sorghum crops are therefore exclusively planted on idle farmland which can be explained as arable farmland that is currently not undergoing any agricultural activity. The amount of idle farmland available for crop production in the state of Louisiana was estimated based on information taken from the 2012 Census of Agriculture.

The yields of energy cane and sweet sorghum crops where estimated based on field trials conducted at the Sugar Research Station in St. Gabriel, Louisiana. These yields were then multiplied by the amount of acres of idle farmland available to establish a production possibility frontier. These yield estimates as well as the estimated values for the variable and fixed production costs both reflect the use of alternative crop cycles as well as flexible planting dates in order to maximize crop production. Similarly to the yield values, the cost values are also multiplied by the amount of acres of idle farmland available in order to estimate total production cost figures.

Finally, a linear programming model was employed to calculate the costs one would encounter when transporting feedstock from a supply location such as a field or a farm, to a demand location such as a mill or processing facility. The transit routes which minimise the transportation costs would then be used to establish optimal processing facility locations.

## 4.2 Conclusion

The economic feasibility of establishing a biofuel industry in the state of Louisiana depends strongly on the magnitude of total costs encountered during crop production and their relation to the total costs one is faced with during the production of conventional fuels from sources such as crude oil. The objectives of this study were therefore first and foremost expense-related such as the identification of potential cropping sequences and their corresponding variable and fixed costs for energy cane and sweet sorghum crop production. Another expense-related objective was the estimation of total production costs. However, not every objective in this study was focusing on costs, but also on the identification of total land area available for production and on optimal processing facility locations.

The objectives set out to be achieved in Section 1.4 of this study have been met and can be summarised as follows:

1. Five potential cropping sequences for the production of energy cane and sweet sorghum as biofuel feedstock crops, individually or in combination, have been identified and their corresponding production costs calculated. Two durations pertaining to the length of the production season have been established, lasting

either three or six month. Energy cane production cost estimates ranged from $550/acre to $565/acre, depending on crop cycle length. Sweet sorghum production cost estimates ranged from $529/acre to $556/acre, depending on time of production.

2. Biofuel feedstock input cost estimates ranged from $84 to $89 per dry ton for energy cane and from $71 to $139 per dry ton for sweet sorghum. Greater yield variability based on harvest date for sweet sorghum lead to greater variability in estimated feedstock cost.
3. Utilising idle cropland not currently in production as a base for potential feedstock crop production, the total amount of idle farmland available for feedstock crop production in the state has been determined to be 443,430 acres.
4. Optimal locations for processing facilities are primarily a function of acreage available for production of feedstock crops were determined to be in Jefferson Davis, Acadia, Evangeline, Vermillion, and Richland Parishes depending on the amount of feedstock demanded as well as the cropping sequence and duration of processing season chosen.

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# VITA

Alessandro Holzapfel, a native of Wiesenthau, Germany, received his Bachelor of Science in International Trade & Finance from Louisiana State University (LSU). Upon completion of his undergraduate studies, he decided to further his education and pursue an additional degree. He was accepted into the LSU Graduate School majoring in Agricultural Economics. He is a candidate to graduate with a Master of Science degree in August 2016.