AN ANALYSIS OF PRODUCING ETHANOL AND ELECTRIC POWER FROM WOODY RESIDUES AND AGRICULTURAL CROPS IN EAST TEXAS

A Dissertation

by

RUBABA MAMMAD ISMAYILOVA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2007

Major Subject: Urban and Regional Science

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May 2007

Major Subject: Urban and Regional Science

ABSTRACT

An Analysis of Producing Ethanol and Electric Power

From Woody Residues and Agricultural Crops in East Texas. (May 2007)

Rubaba Mammad Ismayilova, B.S., Baku State University;

M.S., Texas A&M University

Chair of Advisory Committee: Dr. George O. Rogers

The increasing U.S. dependence on imported oil; the contribution of fossil fuels to the greenhouse gas emissions and the climate change issue; the current level of energy prices and other environmental concerns have increased world interest in renewable energy sources. Biomass is a large, diverse, readily exploitable resource. This dissertation examines the biomass potential in Eastern Texas by examining a 44 county region. This examination considers the potential establishment of a 100-megawatt (MW) power plant and a 20 million gallon per year (MMGY) ethanol plant using lignocellulosic biomass. The biomass sources considered are switchgrass, sugarcane bagasse, and logging residues. In the case of electricity generation, co-firing scenarios are also investigated. The research analyzes the key indicators involved with economic costs and benefits, environmental and social impacts. The bioenergy production possibilities considered here were biofeedstock supported electric power and cellulosic ethanol production. The results were integrated into a comprehensive set of information that addresses the effects of biomass energy development in the region.

The analysis indicates that none of the counties in East Texas have sufficient biomass to individually sustain either a 100% biomass fired power plant or the cellulosic ethanol plant. Such plants would only be feasible at the regional level. Co-firing biomass with coal, however, does provide a most attractive alternative for the study region. The results indicate further that basing the decision solely on economics of feedstock availability and costs would suggest that bioenergy, as a renewable energy, is not a viable energy alternative. Accounting for some environmental and social benefits accruing to the region from bioenergy production together with the feedstock economics, however, suggests that government subsidies, up to the amount of accruing benefits, could make the bioenergies an attractive business opportunity for local farmers and investors.

DEDICATION

This dissertation is gratefully dedicated to:

my father Mamed Ismayilov and my mother Jamila Ismayilova
for their prayers, endless support, and love extended throughout my life;

my wonderful husband and close friend Mustafa Kazim Demirtas for sacrifysing so much and providing every help possible so that I complete my Ph.D. program;
and

my beautiful and cute daughter Nur Necmiye
for filling my life with love and joy.

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Many people provided assistance, inspiration, and support that contributed to the completion of this dissertation. I would like to thank Dr. George Rogers, my committee chair, for his tremendous help in guiding me through the entire research. Frequent discussion of the research issues with him added a new twist and improved it substantially. I extend my deepest thanks to Dr. Bruce McCarl for his constant guidance through innumerable ups and downs of my Ph.D. program and for valuable advice at every step of this research. His moral and financial support was very critical in completing this journey.

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I am indebted to Dr. Raghavan Srinivasan for sharing the SWAT models which I adapted to run simulations for my study region. Adapting the models rather than building new ones saved me tremendous amount of time which I dedicated to other issues in my research.

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CHAPTER I

INTRODUCTION

The world's energy markets rely heavily on the fossil fuels coal**,** petroleum crude oil, and natural gas as sources of energy, fuels, and chemicals. Fossil fuels have been playing a key role in meeting global economic development and addressing the energy security concerns. Global energy use is projected to increase by more than half during the next 30 years (World Energy Council, 2005). However, many countries in the world have to import fossil fuels to meet their energy demands. As stated in the World Energy Assessment report, "dependence on imported fuels leaves these countries vulnerable to disruption in supply, which can create physical hardships and economic burdens" (UNDP, 2004, p. 12). The United States, as many other industrialized countries, depends on imported oil. The U.S. while containing up less than 5% of the world's population produces 21% of Gross World Product (U.S. CIA, 2003) and consumes 25% of world primary energy (Lovins, 2003). Currently, the U.S. dependence on imported oil and petroleum products is in excess of 50% of its use and is expected to reach 61% by 2015 (CFDC, 2003). This increasing dependence on imported energy sources creates risks and concerns with respect to the security of the nation's energy supply.

This dissertation follows the style and format of the *Journal of Environmental Policy and Planning.*

Environmental impacts pose another significant concern, especially greenhouse gas emissions which arise mostly from the production and use of fossil fuels. For example, Mintzer et al. (2003) estimates show that in 2002 alone, 98.0 percent of total U.S. carbon dioxide (CO_2) emissions arose from fossil fuel combustion. The source of these emissions is divided nearly evenly between electrical generation burning coal and use of petroleum products. There is a growing consensus that these greenhouse gas emissions contribute to global warming and climate change problems (IPCC, 2001). Among the greenhouse gases, CO_2 is responsible for most of the greenhouse effect. McCarl et al. (2000) argue that "electricity generation emits a large proportion of U.S. CO_2 (with coal usage alone accounting for over 25%)" (p. 1). In addition, transportation consumes 63% of all oil used in the U.S. (IFAS, 2004) and "accounts for one-third of all U.S. end-use sector CO2 emissions, and if projections hold, this share will rise to 36 percent by 2020" (Greene & Schafer, 2003, p. iii; U.S. EPA, 2005).

In addition to these concerns, it takes millions of years to form fossil fuels in the earth. Possible depletion of fossil fuel resources within the next 40-50 years (Anonymous, 1998), increasing petroleum prices, growing global concerns regarding the environmental and economic consequences of dependence on fossil fuels have increased the world interest in renewable energy sources which are considered clean, safe and environmentally friendly. Klass argues that biomass is the only naturally occurring, energy containing "carbon resource that is large enough to be used as a substitute for fossil fuels" (Klass, 2004, p. 193) and it is very diverse and readily exploitable renewable resource (World Bank, 1996).

The idea of using renewable biomass as a substitute for fossil fuels is not new. In the mid-1800s, woody biomass provided over 90% of U.S. energy and fuel needs, slowly decreasing "as fossil fuels became the preferred energy resources" (Klass, 2004, p. 195).

However, the energy crisis during the 1970s revived interest in the use of wood and other biomass resources for energy production. In the late 1970s, biomass energy produced in the U.S. was "more than 850,000 barrels of oil equivalent per day, or more than 2% of total primary energy consumption at that time" (Klass, 2004, p. 196). This contribution has recently risen to nearly 4 percent of all energy consumed in the U.S. (Climate Change Technologies, 2000) and is expected to increase further.

Numerous national and regional level studies have been undertaken to assess the possible contribution of biomass to the future global energy supply and environmental issues. This dissertation adds to the body of the regional studies and involves the evaluation of critical economic, environmental, and social effects of biomass fuel potential in the East Texas region.

1.1 Purpose and approach

The purpose of this study is to examine the potential of providing biofuels from agricultural and forestry lands of the Eastern part of Texas. In particular, the study will address the following question: "Is there a potential for biomass to produce electric power and cellulosic ethanol in East Texas?" In addition, the purpose of this study develops information for use by people who make decisions on energy issues about potential of bioenergies as renewables in the region. The background on the study region, which consists of 44 Eastern Texas counties, appears in Chapter III.

In addressing the study question, the following approach will be used. We will look comprehensively at the possibility of pursuing power generation and cellulosic ethanol production analyzing economic, environmental, and social aspects of production and use. More specifically, for ethanol production, the feasibility of constructing an ethanol producing plant will be examined. In the U.S., ethanol plants vary in size from as small as 1.5 million gallons per year using beverage waste to as large as 100 million gallons per year using corn as a biomass crop (Great Valley Center, 2004). However, plant size of 20 MMGY represents what is currently thought to be the smallest practical plant size for biomass-to-ethanol conversion. Therefore, the size of the hypothetical cellulosic ethanol plant will be assumed 20 million gallons of ethanol a year (MMGY), and the technology used in the production process will be discussed. In terms of electricity generation, three alternatives will be investigated:

- Co-firing coal with biomass (i.e., supplementing coal use in coal-fired boilers with biomass sources);
- Retrofitting an existing power plant to use biomass; and
- Building a new biomass dependent power plant.

The DOE-EPRI-industry biomass co-firing program considers the power plant sizes that are typically in the 100-300 MW_e range (Hughes, 2000). In this study, a 100 MW power plant was chosen to examine all three cases.

The biomass feeedstocks that will be evaluated in the East Texas region are switchgrass, sugarcane bagasse, and logging residues. Currently, only logging residues are used for energy production in the region, but at a modest level. Switchgrass and sugarcane are feedstocks of interest for energy production; however, currently these crops do not grow in the study region although their production has been proposed and studied agronomically. The study will examine scenarios of:

- Wide spread collection of the logging residues for further delivery to power generating and ethanol producing plants.
- Converting the land currently under rice to grow switchgrass for further delivery to power generating and ethanol producing plants
- Converting the land currently under rice to grow sugarcane for further delivery to power generating and ethanol producing plants
- Expanding the land base for growing switchgrass and sugarcane by adding acreage from all other conventional crops in the rice growing counties.

These scenarios will help in evaluating the availability of biomass in the study region.

The study will be conducted unifying economic, environmental and social analyses. From an *economic* perspective, we will estimate the biomass feedstock availability and production costs, hauling distances and costs, costs of feedstock delivery to the plant gate as well as plant construction and retrofitting costs. From an *environmental* perspective, we will evaluate the impacts of biomass feedstock production on surface and groundwater, and soil quality. In addition, life cycle greenhouse gas emissions from electricity generation and ethanol production will be quantified. From a *social* perspective, we will quantify the impacts of bioenergy production on employment and determine health concerns due to air pollution and surface and groundwater contamination in the region.

Although this approach does not do an exhaustive study of all possible issues related to bioenergies, we think that it analyzes the issues critical for bioenergy decision-making. We will discuss the biomass potential in the region based on how the full range of impacts and benefits comes together. This “big picture” or comprehensive view approach to the bioenergy impacts and benefits underlines the contribution of this study. The concept of the approach is depicted in Figure 1.

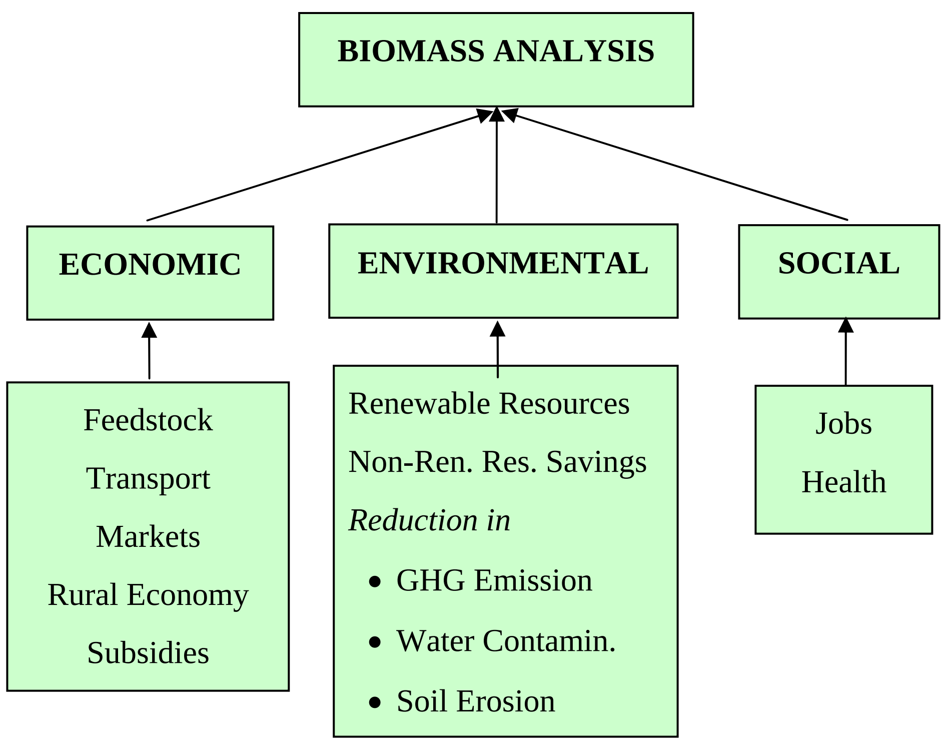

Figure 1. Conceptual presentation of an analysis of producing ethanol and electric power from woody residues and agricultural crops in East Texas

1.2 Assumptions used in the study

In conducting this study, two broad sets of assumptions are used. The first set is comprised of general assumptions related to environmental benefits stemming from growing feedstocks; transportation of feedstocks to biorefineries; reduction of GHG emissions, and the size of the power and ethanol plants. The second set is comprised of assumptions that we use in estimating, evaluating, or quantifying certain variables. These assumptions can be found further in chapters as we address the assessment of unknown variables. For example, we introduce the assumption about switchgrass yield of 4.33 tons/ac/year in Chapter VI, Analysis of feedstock production, in the section on "Feedstock yields, availability, and costs". A general broad listing of the key assumptions is presented in Table 1.

Table 1. List of general assumptions used in the study

Assumptions	Electric Power	Ethanol
Biorefinery size:		
Power plant of 100 MW		
Ethanol plant of 20 MMGY	+	+
Benefits from use of feedstocks:		
Reduction in soil erosion	+	+
Reduction in water contamination	+	+
Transportation of feedstocks:		
Maximum hauling distance 200 miles	+	+
Reduction of GHG emissions from:		
Co-firing feedstocks with coal	+	
Replacing gasoline with ethanol		+
Benefits from new biorefineries:		
New jobs for local community	+	+
Health benefits resulting from:		
Reduction in air pollution	+	+
Reduction in water contamination	+	+

1.3 Organization of the dissertation

The remainder of this dissertation is organized as follows. Chapter II presents a general literature background on bioenergy and its effects. It includes the background on biomass and discusses energies that can use biomass along with important issues such as food versus fuels, effects of conventional energy generation on community health, and environmental policy on conventional energy effects. Chapter III discusses electricity and ethanol as types of energy that can be produced from biomass along with their production technologies. It also presents the literature review on key issues such as feedstock availability and costs, energy production, energy balance and various environmental issues. Chapter IV introduces the theoretical background of the research along with introduction of the study region. Chapter V discusses the general methodology applied in the study, which also includes different modeling tools and techniques utilized to estimate and evaluate various parameters. Chapter VI presents the analysis of feedstocks that have been selected for this study including feedstock availability, hauling distance and cost, greenhouse gases emitted during production of feedstocks and environmental impacts related to selected scenarios. In turn, individual investigation of each energy type, electricity and ethanol, at the biorefinery is presented in Chapters VII and VIII, respectively. Investigation includes comparison of region's feedstock potential with requirements of biorefineries, estimation of costs of hauling biomass to the biorefineries, and life-cycle greenhouse gas emissions which includes emissions from all energy production stages (at the farm and at the biorefinery) as well as environmental and community impact analysis. Finally, conclusions and the implications of this study are summarized in Chapter IX.

CHAPTER II

LITERATURE BACKGROUND ON BIOENERGY AND ITS EFFECTS

2.1 Background on biomass

Biomass is a scientific term for living matter, which includes all non-fossil organic materials that have intrinsic chemical energy content. “The solar energy stored in the chemical compounds of biomass can make liquid fuels (like ethanol) for cars, gaseous fuels (like methane) that can be burned in place of natural gas, or solid fuels like wood chips that can be burned like coal” (SECO Fact Sheet, No. 8, 2005, p. 3). Klass (2004) lists biomass sources as “all water- and land-based organisms, vegetation, and trees, or virgin biomass, and all dead and waste biomass such as municipal solid waste (MSW), municipal biosolids (sewage) and animal waste (manures), forestry and agricultural residues, and certain types of industrial wastes” (p. 193). In addition, one may grow energy crops, also known as “power crops”. These are the fast-growing crops that are grown specifically for their fuel value and are used to produce energy (electricity or liquid fuels). They include fast-growing trees, shrubs, and nonfood crops such as hybrid poplar, hybrid willows, and switchgrass, respectively, as well as some food crops.

Biomass has a potential to address the economic, environmental and community well-being issues in relation with energy producing processes. From the environmental point of view, biomass, especially energy crops, can benefit through reduction in air and water pollution, soil quality improvement, soil erosion reduction, and improving habitat for wildlife. Biomass requires less fertilizers and pesticides than traditional agricultural crops. It also reduces the soil erosion as well as water pollution cutting the agricultural runoff to the nearby water bodies. For example, since some energy crops are replanted only every 10 years, they require minimal plowing that causes soil erosion. Hohenstein and Write (1994) estimate an approximate 95% reduction in erosion rates and a 90% reduction in the use of pesticides in the production of herbaceous energy crops relative to annual row crops. Finally, there is the important issue of increasing concentrations of atmospheric CO_2. The population increase and anthropogenic activities such as land use changes due to urbanization, conversion of forests to agricultural and pasture lands, and other appear to contribute to atmospheric CO_2 build-up. According to the United Nations Intergovernmental Panel on Climate Change, “about three-quarters of the anthropogenic emissions of CO_2 to the atmosphere during the past 20 years are due to fossil fuel burning. The rest is predominantly due to land-use change, especially deforestation.” Numerous studies argue that biomass reduces air pollution through participation in the carbon cycle. It reduces carbon dioxide emissions by 90 percent compared to fossil fuels. It also substantially reduces amounts of sulfur dioxide and other pollutants in the air (UCS, 2004). Kline et al. (1998) argue that switching to biomass-fueled power plants would reduce net emissions by 95% in comparison with the emissions from extraction and combustion of an equivalent amount of fossil fuels.

From an economic point of view, biomass energies will become more widely used only if they are economically competitive with traditional energy sources. Economics, i.e. the estimated market price of biomass-derived energy versus the market price of fossil fuel-derived energy, is a key constraint to the commercial use of biomass feedstocks to produce energy in the U.S. (Walsh, 1998, p. 341). Biomass energy cost depends on numerous factors, such as the feedstock type, availability and yields, transportation costs, conversion process used, etc. In addition, the process of converting the biofuels into energy has to be reliable and efficient. The cost-effectiveness of biofuels as an energy resource depends largely on site-specific circumstances. Since biofuels have low energy content per ton compared to fossil fuels, using them close to their course of production can significantly reduce transportation and handling costs (Biofuels as a Source of Energy, 2004, p. 4). Additionally, reduction in the cost of the conversion processes through introduction of more advanced technologies could be a big factor in reducing the cost of biofuel energy.

From the point of view of the social aspect, biofuels can make a positive contribution to the economic well-being, environmental quality, population health, and provision of jobs, which all together determine community's overall well-being. Along with the environmental benefits mentioned above, bioenergy producing process can benefit the local job market creating new work places; especially in the rural areas, increasing and stabilizing the farmers' income. For example, a study by Northwestern University's Kellogg School of Management shows that U.S. production of ethanol in 1993 only created almost 200,000 jobs a year. Since that time, ethanol production has expanded by 20%, creating even more jobs (Ethanol Fact Book, 2003). In 2004, the ethanol industry supported the creation of more than 147,000 jobs in all sectors of the U.S. economy, boosting U.S. household income by $4.4 billion (EF, 2005, p. 2). New jobs would mean higher income levels for community households; expansion of the base for the local economy and additional tax revenue (Urbanchuk & Kapell, 2002). Community healthcare costs could reduce if renewable bioenergies are used instead of traditional air and water polluting transportation and electricity fuels.

2.2 Energy that can use biomass

Biomass is used for heating, cooking, transportation, and for electric power production. Biofuels address better the transportation needs. According to the U.S. Department of Energy, "the U.S. could produce four percent of its transportation fuels from biomass by 2010, and as much as 20 percent by 2030. For electricity, U.S. DOE estimates that energy crops and crop residues alone could supply as much as 14 percent of the U.S. power needs" (UCS, 2004, p. 6). The U.S. capacity of biomass power generation amounts to about 7,000 MW, "much of which is presently found in the pulp and paper industry, in combined heat and power (cogeneration) systems" (ORNL, 2004, p. 5).

As this study focuses on production of ethanol and electric power, these energy types will be discussed in more detail in the next sections.

2.2.1 Electric power generation

Currently, coal is a source of more than 55% of electricity produced in the United States (Tillman, 2000). In addition, coal-fired power plants consume 87% of all coal produced in the U.S. (U.S. DOE, 1998). Traditional power plants produce air pollution, emit toxic chemicals and greenhouse gases into the atmosphere, and create toxic and nuclear waste. Power production from coal at these plants is the source of 93.4% and 80.2% of SO_2 and NOx emissions, respectively (Mann & Spath, 2001). In addition, use of coal by the plants emits 35.8% of all CO_2 emissions, and 73.5% of the CO_2 from power plants (US DOE, 1998).

About 99% of electricity produced in Texas comes from coal, oil, natural gas, and nuclear power, which makes Texas the largest producer of carbon dioxide and toxic air pollution in the country (Musil et al., 2003). For example, in 2000 alone, "46 percent of electricity came from natural gas-fired plants, 41 percent coal, and 13 percent from ,nuclear. Since 1995, 56 new power plants have been built in the state with another 14 permitted power plants put on hold", all of which were to use fossil fuels as source of energy (Texas Environmental Profiles, 2005, p. 1). According to the U.S. EPA, each year the Texas power plants release 263 million tons of greenhouse gas emissions into the air (Public Citizen, 2005, p. 1). In addition, the EPA Emissions Trend Report argues that the Texas electric generation in 1995 only "accounted for 43 percent of sulfur dioxide (SO_2) emissions (associated with acid rain) and 21 percent of oxides of nitrogen (NO_x) emissions (associated with ozone formation)" (Guide to Electric Power in Texas, 2003, p. 49). In contrast, when a power plant burns biomass, carbon dioxide is emitted into the atmosphere, which is then removed from atmosphere by biomass plant growth through photosynthesis," fixing it into the biomass" (McCarl et al., 2000, p. 1).

Texas has vast amount of biomass resources, and “produces and uses more electricity than any other state in the country” (Texas Environmental Profiles, 2005, p. 1). However, no biomass-fired electricity generating plant exists in the State. Various scenarios of producing electric power from biomass will be considered in this study.

2.2.2 Ethanol

Ethanol is a renewable fuel that can be produced from starches, sugars, and cellulosic biomass. Conventional feedstocks that are used for ethanol production include crops such as corn, wheat, and sorghum. With recent advances in cellulosic technology, ethanol can also be produced from agricultural waste products such as sugarcane bagasse, corn stover, and rice hulls; from forestry and paper wastes; and from energy crops such as switchgrass, willow, and poplar. Currently, corn is the largest source of biomass for ethanol production in the U.S. with production grown from 175 million gallons in 1980 to 1.4 billion gallons in 1998 (DiPardo, 2001) and to nearly 3.5 million gallons in 2004 (Wisconsin AgConnection News, 2004). This level of production was achieved through the Federal and State ethanol tax subsidies and mandated use of high-oxygen gasoline’s (DiPardo, 2001).

The National Energy Act in 1978 exempted ethanol blended gasoline from the U.S. federal excise tax. Since then, the tax exemption has been revised several times. Currently the tax exemption is 5.3 cents of the 18.3 cents of total excise tax, which is scheduled to expire in 2007 (Table 2).

Table 2. Federal excise tax exemption schedule

Years	$/Gallon of Blended Product
2001-2002	$0.053
2003-2004	$0.052
2005-2007	$0.051

Source: BBI, 2001.

The use of ethanol as fuel in the U.S. is goes back to the early years of the twentieth century. However, rising gasoline prices, concerns regarding security of oil supply along with environmental concerns regarding use of lead in gasoline revived interest in ethanol in the late 1970s. As an oxygenate, ethanol competes with the petroleum-derived additive methyl tertiary-butyl ether (MTBE). However, numerous cases of groundwater contamination from use of MTBE were reported, including the contamination of thousands of private drinking water wells in Maine and the pollution of the city water supply of Santa Monica, California (McCarthy & Tiemann, 1998). Addressing rising concerns about the presence of MTBE in groundwater which could put under risk people and the environment, the U.S. Environmental Protection Agency (EPA) recommended to remove MTBE from all gasoline, which further increased demand for ethanol.

Ethanol is produced from biomass sources through fermenting and distilling simple sugars, and is mixed with gasoline to produce cleaner burning fuel called “gasohol” or “E10”. In the U.S., about 3 billion gallons of ethanol is consumed each year most of which is E10 (American Coalition for Ethanol, 2004). “E85”, a mixture of 85 percent ethanol and 15 percent gasoline, is another alternative fuel used in the U.S.

Currently, in the U.S. there are 84 ethanol plants in 20 states capable of producing more than 3 billion gallons of ethanol each year (Environmental Entrepreneurs (E2), 2006). However, there is no existing ethanol plant in Texas. Construction of the State's first ethanol plant, Panhandle Energies of Dumas LP, began in November 2004, which will be under construction throughout 2005 (Ethanol Producer Magazine, 2005). The plant is scheduled to start its operations in year 2006 and will use corn as its main feedstock. Two more plants have been proposed in Texas, in Levelland and Stephenville, but there has been no plant considered for the East Texas region. The proposed plants are expected to use corn and grain sorghum as their main biomass feedstock. Unlike previous studies, this study will examine switchgrass, sugarcane bagasse and logging residue as the biomass feedstocks for a hypothetical ethanol plant in East Texas. Although the study will not intend to determine the feasibility of a specific plant site in the region, it will discuss the critical factors that must be addressed before proceeding with an ethanol project.

2.3 Food vs. fuels - conflicting interests?

Land use is a very crucial issue in the context of bioenergy programs. It raises many questions about land opportunity between food and fuel production. "Do we have enough land, and of the right type, to grow a needed amount of biomass? Will it conflict with existing food and fodder production? Will it conflict with the interests of the farmers, or of the industries?" (Pasztor & Kristoferson, 1990, p. 18). This food versus fuel conflict has been addressed in many studies that have investigated the biomass potential for bioenergy. The answer to this debate between the agricultural and energy systems is that “there is unlikely to be a food versus fuel conflict, as the agricultural food system is more likely to intensify its production on the existing land base, thus liberating land that is currently in agricultural production, but marginal for food crops” (Overend, p. 3). The challenge for bioenergy research is to explore how marginal land and surplus agricultural land can be used for production of energy crops. Another challenge is to find the ways of integrating dedicated energy crops into agricultural systems to produce food and fuels (McCormick, 2005).

Although land use conflicts appear as a major problem, there is no food problem in meeting the needs of people around the world, especially in the U.S. According to the USDA’s estimates, “the United States can produce more than 900 million dry tons of biomass annually from agricultural lands and still continue to meet food, feed, and export demands. This projection includes 425 million dry tons of annual crop residues, 377 million dry tons of perennial crops, 56 million dry tons of grains used for biofuels, and 75 million dry tons of animal manures, process residues”, and other residues generated in the consumption food products (ORNL, 2005, p. 1).

This ethical dilemma of turning land under traditional food crops to grow energy crops is less of consideration for this study. The study analyzes scenarios where rice growing farmers who are in search of alternative crops replace rice with switchgrass and sugarcane. These farmers would transfer rice land to grow other crops in any event, as long as these crops could improve their desperate financial situation.

2.4 Community health issues

Health risk is one of several important factors that need to be considered in making decisions about future energy sources. Conventional energy generation through fossil fuel combustion produces noxious gases and a wide range of toxic pollutants that are the largest source of atmospheric pollution. Pollutants include nitrogen oxides, sulfur dioxide, carbon dioxide, particular matter, and other toxic substances. These pollutants create environmental problems such as acid rain, urban ozone, particulate emissions, and global warming which in turn are responsible for various human health problems. They can cause a wide range of respiratory disorders and illnesses including asthma, irritation of the lungs, and cancer as well as damage plants and marine life in surrounding ecosystems. The World Health Organization estimates indicate that “annual deaths due to indoor and outdoor air pollution from energy use account for 6% of the total 50 million annual global deaths” (Health and Energy Company, 2005, p. 1). Furthermore, if ingested heavy metal pollutants such as lead, arsenic, and mercury emitted from burning coal and oil can cause various health disorders (Health and Energy Company, 2005). According to the American Lung Association, “more than 64,000 Americans die prematurely each year due to inhalation of microscopic particles that are legally emitted by Americans into the atmosphere from factories, electric power plants, diesel engines, etc...” (Health and Energy Company, 2005, p. 1). Substitution of fossil fuels by biomass feedstocks, which possess several environmentally friendly characteristics, is one of the options of energy generation, which has a potential to address the health risks through reduction of air pollution related impacts.

2.5 Environmental policy

A number of air pollutants, including sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter, heavy metals, and carbon dioxide (CO_2), which is emitted to the atmosphere by power plants and transportation sector are being regulated by several important environmental acts and regulations. For example, the federal Clean Air Act Amendments of 1990 (CAAA) attempted to prevent acid rain by imposing plant-by-plant limits on SO_2 emissions from fossil fuel fired power plants. The CAAA also imposed emission controls on NO_x, which is another acid rain precursor. Under these requirements, “co-firing biomass at existing coal-fired power plants is viewed as one of many possible compliance options” (USDOE, 2004, p. 2-36).

In addition, the CAAA mandated the sale of oxygenated fuels in areas of the country with unhealthy levels of carbon monoxide. The provisions of the CAAA established the Oxygenated Fuels Program and the Reformulated Gasoline (RFG) Program in an effort to control carbon monoxide (CO) and ground level ozone problems. These programs require certain oxygen levels in gasoline. Because ethanol is an effective oxygenate, these programs promote ethanol use and gave a major boost to its production. MTBE, the only other widely used oxygenate, is being phased out because of its pollution of ground and surface water from leaky storage tanks (Blue Ribbon Panel, 1999).

To date, emissions of GHG such as CO_2 have not been regulated under the CAAA. CO_2, which is believed to be the key manmade air pollutant contributing to global warming and climate change problem, is regulated under the Kyoto Agreement of

1997, along with methane (CH_4) and nitrous oxide (N_2O). This international agreement set emission limits on CO_2 and other GHGs for developed countries between 5 to 8 percent relative to the 1990 levels during 2008 – 2012. However, in 2001, the U.S. decided not to participate in the implementation of the Kyoto Agreement (White House, 2001). Although the U.S. administration did not ratify the Kyoto protocol, later, President Bush announced the “Clear Skies Initiative”, an emission reduction program that involves an 18 percent reduction in GHG emission intensity (emissions per dollar GDP) by 2012 (White House, 2002).

Overall, these regulations have created a demand for environmentally benign renewable energies. Biofuels as renewable fuels have a potential to address the emissions problem substantially reducing the amounts of above-mentioned pollutants in the air and water.

CHAPTER III

MAKING ENERGY FROM BIOMASS

In the United States, there are currently two leading technological options that convert large quantities of biomass to energy – conversion of biomass to ethanol and to electricity. The conversion of biomass into energy can be achieved in a number of ways. Biomass power technologies convert renewable biomass fuels into heat and electricity using modern boilers, gasifiers, turbines, generators, fuel cells, and other methods. Advanced ethanol producing technologies convert sugar, starch, and cellulosic biomass to supply the transportation industry with liquid biofuels.

Next section provides a background on both types of biomass to energy conversion processes.

3.1 Biomass conversion to power

Electricity may be produced from a variety of biomass resources, including woody and herbaceous energy crops grown in dedicated plantations, wood-, municipal-, and agricultural wastes, and other bioprocessed gases and liquids. Currently, these biomass resources are used for conversion to electric power through existing combustion technology. According to a DOE database, "the biomass power industry in the U.S. is composed of about 350 plants with combined capacity of about 7,800 MW. In addition, another 650 industrial plants generate electricity with biomass for their own use" (ODOE, 2005, p. 32). One estimate indicates that "50,000 megawatts of biopower could be generated by 2010 using advanced technologies and improved feedstock supplies" (ODOE, 2005, p. 32).

The main technologies to convert biomass feedstocks into electric power include direct combustion, co-firing, gasification, and pyrolysis. Several organizations such as the Electric Power Research Institute, the Gas Research Institute, the National Renewable Energy Laboratory, Battelle Columbus and private industry have conducted research to characterize these biomass conversion technologies (King et al., 1998). It is indicated in the literature that majority of today's biomass power plants are of direct combustion type. "Direct combustion involves the oxidation of coal or biomass with air, giving off hot flue gases that are used to produce steam. Steam is used to produce electricity in a Rankine cycle. Older direct combustion systems were based on pile burner technology using stationary grates. The majority of utility power boilers now in service are fired by pulverized coal, cyclone, or stokergrate systems. Increasingly, new steam-cycle power plants are using fluidized bed and improved pulverized systems" (King et al., 1998, p. 233).

Co-firing is the process of substituting biomass for some portion of coal in an existing power plant boiler. "It is the most economic near term option for introducing new biomass power generation" (US DOE/ EERE, 2005, p. 2). The co-firing process utilizes much of the existing power plant equipment without significant modifications; therefore, it is less expensive than building a new biomass power plant. When biomass replaces coal, it reduces sulfur dioxide (SO_2), nitrogen oxides (NO_x), and other emissions. However, coal-fired power plants generally have higher efficiencies, lower capital requirements, and lower electricity costs than combusting the same fuels in dedicated biomass and waste fuel power plants (King et al., 1998).

3.2 Biomass conversion to ethanol

Ethanol derived from biomass feedstocks is a biofuel that can be mixed with or substituted directly for gasoline to address the concerns of the transportation industry. The ethanol industry's history goes back to the oil crisis in the 1970s that raised the concern about a lack of reliable energy sources in the U.S. Since then, the technology used in the ethanol production process has improved substantially with newer plants generally having more efficient production processes. Today, ethanol is produced from various crops such as corn, grain sorghum, wheat, sugar, and other agricultural feedstocks**.** Currently, about 90 percent of the ethanol production processes in the U.S. use corn as the major feedstock. The rest comes mainly from using grain sorghum, barley, wheat, and other crops as feedstocks (Northeast Regional Biomass Program, 2001). Currently, most of the nation's ethanol production capacity is concentrated in the Midwest, where the Corn Belt provides abundant and cheap corn feedstock.

3.2.1 Sugar ethanol production technology

Modern ethanol technology is quite well established and efficient with the basic process being similar to that of making alcoholic beverages. Traditional ethanol production facilities include both wet- and dry-milling operations. These two processes differ mainly by the initial treatment of the grain and the feed co-products. In the wet-mill process, corn is soaked to separate the grain into many parts. Then starch is fermented into ethanol, similar to the dry mill process, or processed into cornstarch or corn syrup (Ethanol Industry Outlook, 2002). Wet-mill facilities are plants that produce various high-valued products such as high-fructose corn syrup (HFCS), dextrose, glucose syrup, vitamins, food and feed additives, corn gluten meal, corn oil, etc. In the dry-mill process, “the clean corn is ground and mixed with water to form a mash. The mash is cooked, and enzymes are added to ferment the sugars, producing a mixture containing ethanol and solids. The beer (alcohol-water mixture) is then distilled and dehydrated to create fuel-grade 99-percent ethanol. The solids remaining after distillation are dried to produce distillers’ dried grains (DDG) with 27-percent protein and are sold as an animal feed supplement” (Shapouri, Gallagher, et al., 2002, p. 2)

Most of the new ethanol plants in the U.S. are in the form of dry mills. The well-established design of dry-mill facilities has reduced the capital cost substantially. Some new plants cost about $1.07 per annual gallon unlike the earlier facilities that cost between $1.75 to $2.00 per annual gallon (Shapouri, Gallagher, et al., 2002). In addition, “new dry-mill ethanol plants are more energy efficient, requiring about 36,000 Btu’s of thermal energy and 1.1. Kilowatts of electricity to produce one gallon of ethanol” (Shapouri, Gallagher, et al., 2002, p. 2).

3.2.2 Cellulosic ethanol production technology

As it was mentioned earlier, the U.S. ethanol industry is starch-based with corn being a primary feedstock. However, corn and other starches and sugars are only a small fraction of biomass that can be used to make ethanol. The starch-based ethanol industry may not be economically viable without subsidies and/or mandates that required using ethanol blends to satisfy octane and oxygenate levels (NRC, 1999). The National Research Council has suggested that the ethanol production research and development programs produce technology that will foster production of products that are cost competitive with fossil fuel alternatives. The U.S. Department of Energy is also promoting the development of ethanol from cellulosic feedstocks as an alternative to conventional petroleum transportation fuels, because conversion of lignocellulosic biomass such as crop residue (corn stover, wheat straw) and perennial grasses is theoretically much more efficient than conversion of corn grain. A lignocellulosic-based system could use virtually all of the harvested plant material, feedstocks produced on less productive land, and materials that would be considered waste (e.g., waste from wood products processing and crop residue).

Advanced bioethanol technology allows fuel ethanol to be made from cellulosic (i.e. plant fiber) biomass, such as agricultural and forestry residues, industrial waste, material in municipal solid waste, trees, and grasses. Cellulose and hemicellulose, the two main components of plants, which give plants their structure, are also made of sugars, but those sugars are tied together in long chains. Advanced bioethanol technology can break those chains down into their component sugars and then ferment them to make ethanol. In general, cellulosic feedstock is converted to ethanol through processes that are very similar to those used in traditional ethanol production. However, unlike traditional ethanol conversion, sugars must be formed from the cellulosic material as a first step. Once formed, these sugars can be fermented and distilled into ethanol. A simplified generic configuration of the hydrolysis fermentation process is given in Figure 2.

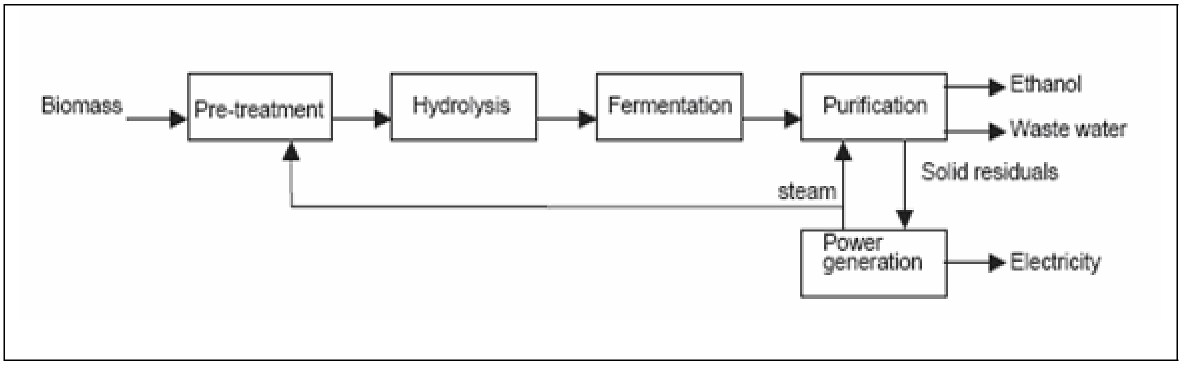

Figure 2. Generalized biomass to ethanol process

(Source: Hamelinck et al. 2005)

A number of developers in the ethanol industry have advanced the bioethanol technology. Among these developers are BC International (BCI), Arkenol, Masada Resource Group, Iogen/Petro Canada, to name a few. Currently there are several commercial companies which are in the planning or construction phase of commercial bioethanol plants. For example, Arkenol will use the concentrated acid methods in its ethanol plant at RioLinda (Sacramento County, California), which will use rice straw as the biomass feedstock. The same methods will be used by the Masada Resource Group in its municipal solid waste-to-ethanol facility in Orange County, New York (Mann & Bryan, 2001). BCI and the U.S. Department of Energy Office of Fuel Development have formed a cost-shared partnership to develop a 20-mgpy biomass-to-ethanol plant in Jennings, Louisiana. This plant will use dilute acid hydrolysis method to recover sugar from bagasse (sugar cane waste) and rice hulls. However, the major problem with production of cellulosic ethanol is that although there are few cellulosic ethanol pilot projects in various locations throughout the United States, there is presently no full-scale operational plant anywhere in the U.S. (Northeast Regional Biomass Program, 2001). This lack of an existing conversion plant creates a higher degree of uncertainty associated with the design for this process.

There are three basic types of ethanol-from-cellulose process designs: 1) acid hydrolysis; 2) enzymatic hydrolysis; and 3) thermochemical. The most common among these processes is acid hydrolysis (Badger, 2002). Badger (2002) argues that "virtually any acid can be used in the process; however, sulfuric acid is most commonly used since it is usually the least expensive. There are two basic types of acid processes: dilute acid and concentrated acid. Most dilute acid processes are limited to a sugar recovery efficiency of around 50%. The reason for this is that at least two reactions are part of this process. The first reaction converts the cellulosic materials to sugar and the second reaction converts the sugars to other chemicals. The biggest advantage of dilute acid process is its fast rate of reaction, which facilitates continuous processing. The biggest disadvantage is its low sugar yield. For rapid continuous processes, in order to allow adequate acid penetration, feedstocks must be reduced in size so that the maximum particle dimension is in the range of a few millimeters" (p. 18-19).

3.3 Literature review

Benefits and concerns from using biomass feedstocks for energy purposes have been discussed in many studies across the United States and abroad. Presented here is a literature review on economic, environmental, and social benefits and concerns in relation with the energies and the feedstocks examined in this study.

3.3.1 Electric power generation

Biomass can be directly fired in dedicated boilers. However, “co-firing biomass and coal has technical, economical, and environmental advantages over the other options” (Demirbas, 2003, p. 1). Hughes (2000) argues that “co-firing in existing coal-fired power plants makes it possible to achieve much better efficiency in converting biomass fuel into electric power, compared to the typical practice in the existing boilers that fire 100% wood-derived wastes as fuels” (p. 458). Biomass co-firing is applicable to most coal-fired boilers used for power generation. Typically, biomass fuels (e.g., wood wastes, short-rotation woody crops, agricultural wastes, short-rotation herbaceous crops, etc) utilized in co-firing are modest in heat content (e.g., 4000-5000 cal/g) and low in sulfur (Tillman, 2000). The woody resources are low in nitrogen and ash content while the agricultural resources can have high nitrogen and ash contents. Tillman (2000) argues that “these fuels can be co-fired at 10-25% (mass basis) without seriously impacting the heat release characteristics of most boilers” (p. 1). Because of the characteristics of biomass resources, co-firing biomass with coal helps reduce the total emissions of NO_x, SO_2 and CO_2 per unit of energy produced compared to coal fired alone (see for example, Tillman, 2000; Hughes, 2000; Mann & Spath, 2001). In addition, co-firing involves the use of existing coal-fired units to combust together a combination of biomass and coal. Boylan et al. (2000) note that “the use of existing facilities reduces the capital investment and therefore the potential cost of the resulting renewable energy. In addition, the lower investment reduces the level of economic risk" (p. 411) attracting more investors.

Some biomass co-firing cases are discussed in the following sections.

3.3.2 Feedstock availability and costs

The local availability and cost of biomass is a principal factor in determining the feasibility of co-firing at a specific site. Optimal sites for co-firing are those areas where there is enough available biomass fuel to easily support the level of co-firing and where the cost of the resource is less than that of coal. As Southeastern Regional Biomass Energy Program (SERBEP) reported in 1995, "studies by the Electric Power Research Institute (EPRI) have indicated that co-firing with biomass at levels up to 15 percent can be economical when the difference in costs between coal and wood is in the range of $0.25 to $0.40 per million BTU. However, when coal costs $1.00 to $1.50 per million BTU, it is difficult for biomass to compete" (ODOE, 2005, p. 33).

3.3.3 Co-firing

Interest in co-firing biomass with coal in existing power plants is growing largely due to the need to improve air emissions from coal-burning facilities as well as to diversify fuel supplies in attempt to reduce the dependence on foreign oil. Many cases of biomass co-firing have been tested around the nation. For example, in 1992, wood waste was successfully co-fired with coal in a 100 MW pulverized coal power plant at Georgia Power Company's Hammond Unit 1 (King et al., 1998). Tree trimmings (as wood waste) and sawdust were used in the test. The percentage of wood in the boiler fuel averaged 11.5% by weight, or 6.5% by heat input (King et al., 1998). The test results showed 14% wood loading (by weight) represented the maximum wood percentage without load reduction from the unit (King et al., 1998). Boiler efficiencies changed little during the wood co-firing process whereas NO_x emissions remained the same compared to normal coal firing. “Wood wastes were pre-ground before delivery to the plant, and the wood and coal were mixed at the plant before being delivered to the pulverizer and boiler” (King et al., 1998, p. 243).

Several short-term tests of co-firing switchgrass with coal were conducted in 1998 at the Alabama Power Company’s Plant Gadsden located in Gadsden, Alabama. Results indicated that switchgrass was successfully co-fired with coal, in some cases up to 10% of the energy input from switchgrass. Nearly 4.5 MW of renewable energy was produced by the co-firing system. Measuring the boiler efficiency indicated that it was about 0.3% to 1.0% less efficient than coal fired alone case, which was due to higher dry gas losses associated with introducing cold transport air into the furnace (Zemo et al., 2002). Emissions of sulfur dioxide and mercury were lower with switchgrass co-firing than with coal fired alone option. No change in NOx was reported compared with coal fired alone. These short-term tests raised some questions regarding long-term effects of switchgrass co-firing. One of the issues that need to be addressed is to determine the long-term effect of switchgrass co-firing on slagging and fouling. Analysis of switchgrass co-firing showed the ash to contain high percentages of alkali metal, especially potassium, which could be a problem for fouling back pass tubes.

Pennsylvania Electric Company conducted wood co-firing tests at the Shawville plant in Johnstown in 1995. Two boilers participated in the test: one 138 MWe wall-fired and one 190 MWe tangentially-fired pulverized coal boilers. The 3% biomass input was selected for co-firing test. Different fuels were involved in the test: a reference coal and biomass in the form of mill waste sawdust, utility right-of-way tree trimmings, and hybrid poplar. Although biofuels were processed before being mixed with coal grinding equipment, "tree trimmings and hybrid poplar, with longer, stringier fibers, proved to be more difficult to handle during fuel preparation and blending operations than sawdust. Only small amounts of hybrid poplar were fired because of the inability to successfully handle the fuel during operations" (King et al., 1998). The test results revealed two important issues: a) tree trimmings and hybrid poplar were more difficult to handle during fuel preparation and blending operations than sawdust, as they have longer and stringier fibers: and b) the boilers could not achieve their normal full capacity. Specifically, the 138 MW boiler lost 8 to10 MW of capacity due to feeder limitations, and the 190 MW boiler lost 15 MW of capacity due to significant reductions in mill outlet temperatures (King et al., 1998). For both units, the 3% weight biofuel blend behaved like wet coal. Penelec concluded that wood fuel should be fed separately from pulverized coal (Prinzing et al., 1996).

Madison Gas & Electric (MG&E) was the first utility in the U.S. to undertake a large-scale co-firing of herbaceous energy crops with coal. In 1996, the company co-fired switchgrass in a 50 MW wall-fired, pulverized coal boiler. A 5-day test used a 10% switchgrass/ 90% coal (on a heat basis) combination. The test showed that "sulfur dioxide emissions were largely unchanged, nitrogen dioxide emissions decreased 12%, and opacity (a measure of visible smoke) was reduced 50% compared to burning 100% coal. Post co-fire inspections of the boilers indicated no slagging or other detrimental effects" (King et al., 1998).

3.4 Economics of ethanol production

Numerous feasibility studies of ethanol production have been undertaken over the past 30 years. These studies have examined a variety of starch and sugar-based as well as cellulosic-based feedstocks. The following sections present a literature review of some of the critical issues related to feasibility of ethanol production.

3.4.1 Feedstock availability and costs

Availability, cost, and diversity of feedstock are critical economic variables for making decisions on ethanol production (Northeast Regional Biomass Program, 2001). Rahmani et al. (2000) evaluated sugarcane, elephant grass, *Leucaena,* various *Eucalyptus* species, and pines, which have higher yields than other biomass crops in Florida. They show that with Florida's weather conditions favorable for many types of crops to be grown and used as biomass feedstocks, sugarcane is the highest yielding biomass crop in the State with yields ranging from 14-22 ton per acre per year on different soil types. They report the farmgate costs ranging from $21-$32 per dry ton for sugarcane. These total costs of producing a dry ton of biomass crops up to the farmgate include all costs for rent, land preparation, crop establishment, maintenance, harvesting, chipping, and forwarding.

Kerstetter and Lyons (2001) studied the resource and economic issues of producing ethanol from wheat straw in Washington State, where there is no existing biomass to ethanol plant in commercial operation. They found that the average price for delivering straw to a 20 million gallon per year plant would increase from $32 to $54 per ton as the straw availability decreased.

In 2001, Mann and Bryan investigated the feasibility of producing ethanol from native over mature aspen, switchgrass, and other native grasses in northeastern North Dakota. They argue that “providing sufficient feedstocks to sustain a reasonably sized ethanol plant is a significant constraint for most biomass-to-ethanol plants” (p. 13) that could be built in northeastern North Dakota or northwestern Minnesota. According to their analysis, “while biomass resources are plentiful in the region, the quantities required for a plant that produces over 20 million gallons per year (mgpy) of ethanol would range from 259,000 to 459,000 bone dry tons (BDT) of biomass, depending upon its source” (p. 1). Assuming that switchgrass would be harvested twice during a growing season and that it would yield 4 to 4.5 tons/acre/year, they estimate the cost of producing switchgrass in the region to range from $27.36 to $49.27 per dry ton. A more realistic price was estimated as $39.31 per dry ton for North Dakota, based on a $48 per acre land rental value and 4-ton/acre/year yield, and $42.63 per dry ton for Minnesota, based on a land rental value of $60 per acre and 4.5-ton/acre/year yield.

The 2001 study by the Northeast Regional Biomass Program investigated the ethanol production capacity in the Northeastern states, which are poor in traditional starch and sugar ethanol feedstocks, but have abundant cellulosic feedstock resources.

The authors suggest that, given the challenges associated with developing cellulosic ethanol production capacity in the Northeast, the most feasible short-term option would be to adopt the proven, traditional technologies. As the experience in the Midwest and elsewhere has shown, even small-scale production using traditional technologies can be cost-effective. Meanwhile, over time the Northeast region could both evaluate and gain experience with ethanol production and could transition toward greater reliance upon cellulosic feedstock, as emerging cellulosic technologies prove economically more viable.

The joint project of the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) and DOE with NREL (McAloon et al., 2000) examined the lignocellulosic biomass-to-ethanol process design and economics applying the co-current dilute acid prehydrolysis and enzymatic hydrolysis process to corn stover, corn residue left in the fields after harvesting corn, for lignocellulosic ethanol process. The process was assumed for a plant producing 25 million annual gallons of fuel ethanol. The project utilized $35 per dry ton for corn stover based on results of two studies. First results were from a small stover collection program (1997-1998) performed by Iron Horse Custom Farming of Harlan, Iowa, which reported stover collection costs between $31-$36 per dry ton (Glassner et al., 1998). Second results were obtained by contractors for DOE, which had reported a range of $35-$46 per dry ton (NREL, 2000a; NREL, 1999; NREL, 2000b). Because the stover is considered a residue, it was expected that its price might not fluctuate as much as a commodity crop like corn. However, demand for stover from an established lignocellulosic ethanol industry could escalate the price.

Graf and Koehler (2000) evaluated the potential for ethanol production from cellulosic feedstocks in Oregon State. They argue that wheat straw is suitable for ethanol production with a near term yield estimated by NREL of over 60 gallons per ton. However, the cost of removing the wheat straw needs to be minimized in order to maximize the economic yield of the feedstock. The study utilized the straw collection cost which was between $25 and $35 a ton, as estimated by the Oregon Wheat League. Another feedstock examined was the forest thinning, which accumulates from the State's large forest acres. The cost of removing and delivering forest thinning to a site within 50-mile radius was estimated by Oregon private mill owners between $28 and $40 per bone dry ton and the study assumed it to be $28 for its analysis. The authors conclude that while Oregon's forest and agricultural residues have the potential to be used for ethanol production, near-term economic feasibility depends largely on what happens to the price of gasoline and the demand for ethanol. In addition, proof of economic viability of the cellulose-to-ethanol technology in a successful commercial facility would substantially improve the outlook for the development of cellulose-ethanol production in Oregon.

A standard enterprise budgeting procedure was used by Epplin (1996) to compute the base estimate of producing and transporting switchgrass an average of 64 km to an ethanol-conversion facility in Oklahoma. He shows that for a base yield of 9 dry Mg/ha the estimated cost to produce, harvest, load, and transport 1 dry Mg of switchgrass biomass to a conversion facility is $37.08. "Approximately 14% of the estimated cost is for establishment, 22% for land, 32% for annual maintenance and harvesting, and 32% for loading and transportation. The estimated delivered cost of $37 Mg $^{-1}$ is lower than most estimates computed for other regions of the country" (p. 464) . Epplin cites, for example, Lowenberg-DeBoer and Cherney (1989) who estimated that "it would cost $36 Mg^{-1} to produce switchgrass in Indiana" (p. 464). This cost did not include the cost of land, labor, or transportation. Cundiff and Harris (1995) are cited as estimating the cost of producing and delivering switchgrass to a conversion facility in Virginia between $51 and $60 Mg $^{-1}$. "They assumed that Virginia Piedmont cropland could be rented for $49 ha $^{-1}$ and would produce an average yield of 9 dry Mg/ha. The authors find higher costs because they model the system as a conventional farming operation" (Epplin, 1996, p. 465).

3.4.2 Ethanol production cost

The most significant barrier to wider use of fuel ethanol is its cost. Even with incentives for ethanol producers, the fuel tends to be more expensive than gasoline per gallon. Feedstock availability, its location, and transport to the site of treatment, pretreatment strategies, efficient hydrolytic agents, availability of robust fermentative microorganisms and process options all affect the production cost of ethanol (Ethanol Fact Book, 2003).

Shapouri, Gallagher, and Graboski (2002) note that "the total cost of producing ethanol is composed of three elements: capital-related charges, net feedstock costs, and variable operating costs" (p. 3). The authors show that variable operating expenses include "electricity, fuels, waste management, water, enzymes, yeast, chemicals, repair and maintenance, labor, management, administration, taxes and insurance, and miscellaneous expenses. Fuel includes expenses for natural gas, coal, and purchased steam ” (p. 5).

The current production costs of ethanol show a wide range. Hamelinck et al. (2005) list a number of sources that have estimated the ethanol production cost. For example, ethanol from sugar cane in Brazil costs $1.32–1.58/gal (Moreira, 2000; Larson et al., 2001), while in Europe and the U.S. ethanol derived from sugar or starch cost $2.13/gal (Reith et al., 2002) to $3.03/gal (Woods & Bauen, 2003). Projected present cellulosic ethanol production costs in Europe lie between $4.48 and 5.93/gal (Reith et al., 2002; de Boer & den Uil, 1997), and in the U.S. between $1.98 and $2.50/gal (Wyman et al., 1993; Wooley, Ruth, Glassner, et al., 1999). Future costs are projected at $0.59–$1.32/gal by Lynd et al. (1996), $0.79–$1.05/gal by de Boer and den Uil (1997), and $1.32–$1.45/gal (within 10 years) by Wooley, Ruth, Sheehan, et al. (1999). In addition, a report by the Energy Information Administration (DiPardo, 2001) estimated the current cost of producing ethanol from cellulose at $1.15-$1.43 per gallon. More recent cost estimate ranging from $1.30 to $1.50 per gallon is given by Mann and Bryan (2001). Yet another study by Kerstetter and Lyons (2001) estimated cost of making ethanol from cellulosic biomass at $1.70. Tembo et al. (2003) developed a multi-region, multi-period mixed integer model to determine the most economical source of lignocellulosic ethanol in some regions of Oklahoma along with biorefinery size, location and other important issues. The low-valued lignocellulosic biomass feedstocks such as crop residue and perennial grasses, including switchgrass, were examined for the gasification-fermentation process. The breakeven price of ethanol was determined to be about $0.758 per gallon, which was substantially less than the 1990 to 2001 average price of $1.20 per gallon. However, the authors contend that, as a gallon of gasoline contains 1.6 times as much energy (BTU) as a gallon of ethanol, “in the absence of subsidies, ethanol would not be competitive in terms of energy equivalent with gasoline when gasoline prices were less than $1.21 per gallon” (p. 625), i.e. almost twice as much as the average gasoline price of $0.63 per gallon, “as traded on the New York Board of trade from 1990 to 2001” (p. 625).

Graf & Koehler (2000) argue that “advances in feedstock processing and biotechnology could reduce cellulose-ethanol costs to $0.69-$0.98 per gallon over the next two decades” (p. 3) enabling cellulose-ethanol to compete with wholesale gasoline. Cost reductions could be achieved through improvements in individual process steps, far-reaching process integration, enzyme cost reduction, and using the remaining lignin to generate electricity (Hamelinck et al., 2005).

3.4.3 Ethanol plant size

Ethanol plant size can vary according to the type of facility and by project. “An Ethanol Production Guidebook for Northeast States” suggests that “the minimum plant size for which capital and operating costs begin to level out is about 10 million gallons per year; 20 million gallons per year is preferable. This means that a minimum of approximately 300,000 bone dry tons of feedstock per year is necessary for a 20 million gallon per year facility (Northeast Regional Biomass Program, 2001, p. 28). Since feedstock costs are a key driver of overall ethanol fuel economics, cellulosic-based ethanol facilities could become more desirable over the long-term with the low-cost cellulosic feedstocks.

In the U.S., “no new ethanol plants equal in size to today’s largest plants (200 million gallons a year (MMGY)) are being planned. Several new plants in the 70 to 100 MMGY range are planned, however, new plant sizes in the 20 to 40 MMGY range appear most common” (California Energy Commission, 2001a, p. 10).

As to cellulosic ethanol plants, at the beginning, they “will likely produce around 20 million gallons of ethanol per year; some mid-term plants may be larger, perhaps 40 to 50 million gallons per year” (Northeast Regional Biomass Program, 2001, p. 28).

In addition, “an analysis by the National Renewable Energy Laboratory (NREL) has shown that ethanol plant equipment costs do not increase linearly with plant size, and that generally, equipment costs scale with an exponent of about 0.7 (1.0 would translate to linear scaling). However, savings that may result from increased economies of scale may be offset by increased costs for feedstock collection, as the more feedstock a plant demands, the greater distance it must be transported” (Northeast Regional Biomass Program, 2001, p. 28).

3.4.4 Net energy balance of ethanol production

One of the most critical issues relating to ethanol is the question of “net energy” of ethanol production. In other words, the issue is related to whether more energy is used to grow and process the raw material into ethanol than is contained in the ethanol itself. Production of biomass requires significant amount of fossil fuel, mainly for production of fertilizers and equipment used in operations as well as to run farm operations. King et al. (1998) argue that “the energy profit ratio, i.e. the useable energy content of net biomass production divided by the direct and indirect energy required to produce it, must be greater than one and ideally many times greater, if a biomass development project is to achieve its principal objective" (p. 20).

Studies conducted since the late 1970s have estimated the net energy value (NEV) of corn ethanol. However, variations in data and assumptions used among the studies have resulted in a wide range of estimates. Shapouri, Duffield, and Wang (2002) argue that the NEV of corn ethanol has been rising over time due to technological advances in ethanol conversion processes and increased efficiency in farm production. They show that "production of corn-ethanol is energy efficient, in that it yields 34 percent more energy than it takes to produce it, including growing the corn, harvesting it, transporting it, and distilling it into ethanol" (p. iii).

Lorenz and Morris (1995) also show that "more energy is contained in the ethanol and the other by-products of corn processing than is used to grow the corn and convert it into ethanol and by-products" (p. 1). They argue that "if corn farmers use state-of-the-art, energy efficient farming techniques and ethanol plants integrate state-of-the-art production processes, then the amount of energy contained in a gallon of ethanol and the other by-products is more than twice the energy used to grow the corn and convert it into ethanol" (p. 1). They further conclude that if the ethanol industry expands utilizing more abundant and potentially lower-cost cellulosic biomass the net energy of producing ethanol will become even more attractive. In particular, their results for a hypothetical ethanol plant which uses hybrid poplar as a feedstock, suggest the net energy ratio of 2.62:1. This can be explained by the fact that "cellulosic crops, like fast growing tree plantations, use relatively little fertilizer and less energy in harvesting than annual row crops; the crop itself is burned to provide energy for the manufacture of ethanol and other co-products" (p. 8). Lignin, as a major co-product of cellulosic crops, is currently used only for fuel, however it potentially has a high chemical value.

In contrast, critics such as Pimentel *et al.* (1994) contend that ethanol produced from corn is not a renewable source of energy. In their latest study Pimentel and Patzek (2005) argue that energy outputs from ethanol produced using corn, switchgrass, and wood biomass are each less than the respective fossil energy inputs. They found that "ethanol production using corn grain requires 29% more fossil energy than the ethanol fuel produced; ethanol from switchgrass requires 50% more fossil energy than the ethanol fuel produced; and ethanol production from wood biomass requires 57% more fossil energy than the ethanol fuel produced" (p. 65). Kim and Dale (2005) argue that "this disagreement is attributable to differing data sets (including data sources and ages) and methodologies. Methodological differences include choices of the system boundaries and the allocation procedures" (p. 427). Another study by Borjesson (1996) investigated the energy yields, primary energy inputs, and net energy yields of a variety of crops, including reed canary grass and willow, concluding that the energy output to input ratios were 11 and 21, respectively.

An ethanol production guidebook for Northeast States (2001) indicates that "cellulosic biomass ethanol provides about four units of energy for every unit of fossil fuel energy used to produce it – a significantly higher ratio than for other renewable fuels, such as corn ethanol (Net energy balance is calculated by taking the energy (Btu) contained in one gallon of ethanol (76,000 Btu) minus the fossil fuel energy (petroleum, natural gas, and coal) required to produce that gallon)" (p. 19). Cellulosic ethanol has large positive net energy balance compared to corn ethanol because "relatively little fossil energy is used in the creation of cellulosic biomass and in the biomass to ethanol conversion process" (p. 19). However, there are some types of biomass that require energy while growing and later for harvesting (for example, biomass wastes such as rice hulls, and bagasse). This types of biomass waste are "often burned and do not have market value other than as feedstock for energy production" (p. 19). Delivering the biomass waste to a biorefinery for ethanol production solves this problem). In terms of energy requirement for biomass production, "biomass resources such as wood waste, and certain dedicated biomass ethanol crops (such as switch grass) are not nearly as energy intensive to produce as starch crops" (p. 19).

Overall, the net energy balance for both corn ethanol and cellulosic biomass ethanol translates into reduced reliance on fossil fuels (including imported petroleum) and reductions in greenhouse gas emissions.

3.5 Environmental benefits

Despite the cost differential, there are some advantages of using ethanol over MTBE. Yacobucci and Womach (2000) argue that ethanol contains 35% oxygen by weight, which is twice the oxygen content of MTBE. Another advantage, the authors continue, is related to the resources from which ethanol and MTBE are produced. Specifically, since ethanol is produced from agricultural products, "it has the potential to be a sustainable fuel, while MTBE is produced from natural gas and petroleum, fossil fuels. In addition, ethanol is readily biodegradable, eliminating some of the potential concerns about groundwater contamination that have surrounded MTBE" (p. 5). Furthermore, "cars designed to run on high concentrations of ethanol have the potential to emit 80% to 90% less reactive hydrocarbons than advanced-technology gasoline cars" (CFDC, 2003, p. 26). Using either E-85 (85% ethanol, 15% unleaded gasoline) or E-10 (10% ethanol, 90% unleaded gasoline) fuel greatly improves air quality and energy efficiency. A fuel-cycle analysis by Argonne National Laboratory shows a 35-46% reduction in greenhouse gas emissions and 50-60% reduction in fossil fuel energy use due to the use of ethanol as a motor fuel (CFDC, 2003). According to the Argonne National Laboratory results, in 2001, "ethanol use in the US reduced CO2-equivalent GHG emissions by approximately 3.6 million tons, the equivalent of removing more than 520,000 cars from the road" (Ethanol Industry Outlook 2002, p. 11).

CHAPTER IV

THEORETICAL BACKGROUND

4.1 Overview of the energy issues

“Energy is the lifeblood of technological and economic development” (Chow et al., p. 1528). Adequate and affordable energy supplies have been crucial to economic development and the transition from societies heavily relying on agriculture to modern industrial societies (IAEA, 2005). “All sectors of the economy – residential, commercial, transport, service and agriculture – demand modern energy services” (IAEA, 2005, p. 18), which in turn boost local economic and social development by increasing productivity and local income generation. Energy supply is key to raising living standards and it influences job creation, productivity, and local development. In other words, our overwhelming reliance on energy generated from carbon based fossil fuels such as coal, oil and natural gas is the reality of modern life.

The history of global energy supply can be divided into two eras. The first era, or the era before fossil fuels, started with the use of fire for cooking and continued up to the beginning of the industrial revolution. During this period, the main energy sources were “wood for heat and cooking, wood charcoal, wind, and water power for industry and food crops” (British BioGen, p. 7). The fossil fuel era began around the outset of the XVIII century when coal was used “as fuel for brick and glass making” (British BioGen, p. 7). By mid-XIX century, coal had become the leading fuel source for transport and power generation. Later, in the early 1900s, energy sources around the world were mostly generated from the agricultural crops while industrial products were mainly produced from plant matter (Duffield, 2006). For example, Henry Ford used corn ethanol in his original Model T engine and Rudolf Diesel used peanut oil to run his engine. By 1920, petroleum emerged as the dominant energy source for transportation fuels and industrial products. Since then, the United States and other industrialized countries have relied on petroleum as a cheap and dependable source of energy.

According to Noonan (2003), fossil fuel energy sources such as “coal, oil and gas provide around 66% of the world's electrical power, and 95% of the world's total energy demands (including heating, transport, electricity generation and other uses)” (p. 2). The author continues on noting that “coal provides around 28% of energy, oil provides 40%, and natural gases provide about 20%” (p. 2). Keith (1998) argues that 88 percent of the U.S. energy today comes from nonrenewable fossil fuels. However, regardless of how crucial energy may be for development, it is only a means to obtaining “good health, high living standards, a sustainable economy and a clean environment” (IAEA, 2005, p. 1).

Use of finite fossil fuels has provided high living standards for years; however, their consumption has come with numerous significant problems and concerns. One of the big problems is that fossil fuels are non-renewable. Fossil fuels “formed from plants and animals that lived hundreds of millions of years ago and became buried deep underneath the Earth's surface where their remains collectively transformed into the combustible materials we use for fuel” (McLamb, 2003, p. 1). Fossil fuels are limited in supply and perhaps will be depleted one day. However, at the current rate of consumption, these fuels cannot replenish fast enough to meet our future energy demands. For example, oil is not manufactured. Oil wells are drilled into the ground and oil is pumped out. As these wells grow older, they yield less oil each year. The peak global oil finding year was 1962 (See Figure 3). Since then, the global discovery rate has dropped sharply in all regions. Many experts such as petroleum geologists and the International Energy Administration think the U.S. oil production could start declining by 2010 or 2020 (IEA, 2006).

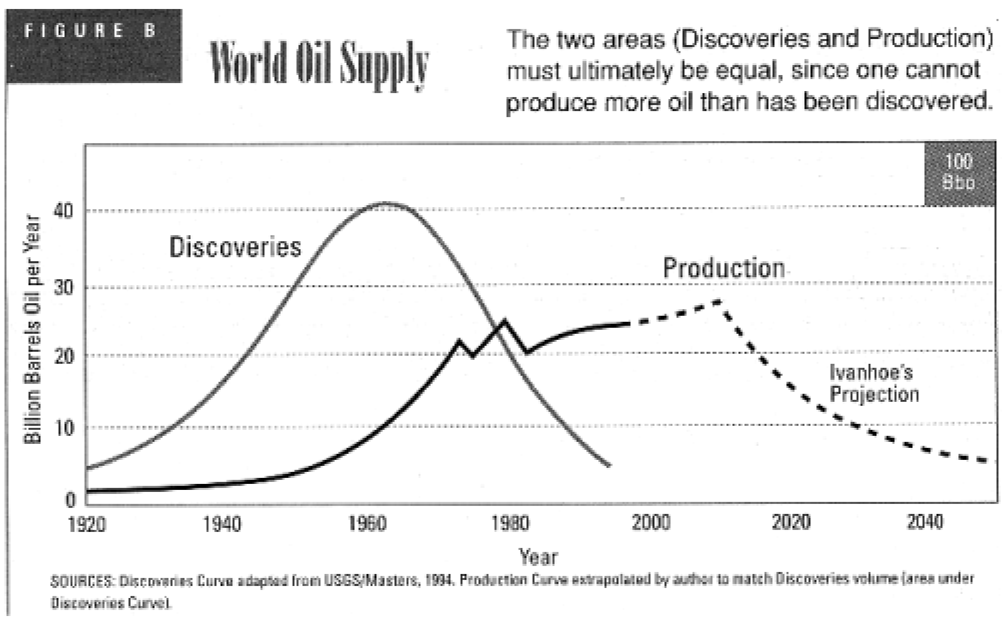

Figure 3. World oil supply

(Source: Ivahnoe LF, 1997)

Another huge problem the U.S. is facing is environmental concerns. Much of the current energy supply and use, based on limited resources of fossil fuels, is deemed to be environmentally unfriendly. The production, distribution, and use of these energy resources create irreparable damage to the environment. The environmental impacts greatly depend on the ways energy is produced and used, “the fuel mix, the structure of the energy systems and related energy regulatory actions and pricing structures” (IAEA, 2005, p. 19). Energy production or conversion processes and technologies are not without waste. Waste and various pollutants are generated throughout the entire energy chain, “often with severe health and environmental impacts” (IAEA, 2005, p. 1). In addition, “combustion of fossil fuels is chiefly responsible for urban air pollution, regional acidification and the risk of human-induced climate change (IAEA, 2005, p. 1). Water quality is another important topic of the environmental dimension, which is “affected by the discharge of contaminants in liquid effluents from energy systems, particularly from the mining of energy resources” (IAEA, 2005, p. 19). There are also the great dangers posed to natural ecosystems that result from collecting fossil fuels, particularly coal and oil. Oil spills have devastated ecosystems and coal mining has stripped lands of their vitality.

Yet another important concern is the U.S. reliance on foreign petroleum and oil products. By the early 1970s, domestic oil reserves were shrinking rapidly and the U.S. was transforming from a major oil producer to a nation dependent on foreign oil (Collins & Duffield, 2005). The first oil shock of 1973-1974 followed by the second oil shock of 1978 demonstrated that the U.S. was no longer the dominant leader in world oil (Yergin, 1991). These oil crises and fossil fuel price shocks increased an interest in energy efficiency, nuclear power, and renewable energy sources. Substantial investments were poured into research and development and numerous demonstration projects. After the oil shocks though, when petroleum shortages disappeared and prices stabilized, the U.S. stopped worrying about oil, and improving energy efficiency and developing alternative energy sources experienced declining policy interest. However, the recent security risks of importing oil from politically unstable regions of the world once again revived the interest in developing renewables and replacing petroleum products with more environmentally benign energy sources. As a result, “legislation has been passed to encourage renewable energy production and fund research on developing ethanol, biodiesel, solar and wind power, and bioproducts” (Duffield, 2006, p. 5).

Various renewable fuels are being considered, however none of them is currently able to provide even a fraction of the energy produced from fossil fuels. Despite of being the promising energy source, alternative, or also called renewable, energy sources, “collectively provide only about seven percent (7%) of the world's energy needs” (McLamb, 2003, p. 1). This means that fossil fuels as the primary source of energy for the world is going to remain the norm for a good while. For example, in 2001 only the fossil fuels – oil, natural gas, and coal – provided 86% of the energy that is consumed by all the people of the world (EIA, 2004). The International Energy Outlook 2004 (IEO, 2004) published by the United States Department of Energy (U.S. DOE) contains a projection that, in 2025, fossil fuels will provide 87% of the energy consumed globally. It is important to note that the authors of the IEO 2004 also project global energy consumption to increase by an average of 1.8% per year from 2001 to 2025. Though renewable resources offer significant environmental benefits, the cost of their development and implementation is still substantial when compared to the cost of traditional methods of handling oil, coal, and natural gas. In addition, the technology, which would make a full-scale conversion to cleaner alternative forms of fuel, is not yet available. Therefore, the combination of fossil fuels with these renewable and environmentally friendly forms of fuel could be a good first step in addressing the United State's energy demands.

Among currently available renewable energy types are solar energy, hydrogen fuel cells, wind, and biomass. These renewables differ from fossil fuels in two main respects: they are renewable and they generate less (or no) pollution. The use of renewable energy sources help reduce global carbon dioxide emissions and other air and water pollutions. In addition, they add some much-needed flexibility to the energy resource mix by decreasing the dependence on limited reserves of fossil fuels. There is much uncertainty over the future potential of renewable energy. However, it is obvious that with the world demand for oil increasing so rapidly the competition over the world's limited oil reserves will intensify. Replacing fossil fuels with alternative sources of energy is already a reality and will intensify more and more in the future. For now though "adding biofuels and other diverse sources of energy to the U.S. energy portfolio will help to significantly reduce economic and national security risks" (Duffield, 2006, p. 7).

Biofuels, the focus of the further discussion, are non-polluting and efficient sources of energy generated from plants or plant-derived materials. Many people think of renewable energy as wind and the sun energy only. However, among all renewable energy sources, biomass is the largest, most diverse and most readily exploitable resource (World Bank, 1996). Biomass currently supplies about 30 times as much energy in the U.S. as wind and solar power combined (UCS, 2004). In other words, biomass today provides about 3-4% of primary energy in the U.S. (Climate Change Technologies, 2000; ORNL, 2004). In addition, biofuels are the only renewable carbon fuels which have the potential to "readily replace fossil fuels for heat and combined heat power and as transport fuels, as well as in electricity generation" (British BioGen, p. 11).

The most common type of biomass energy worldwide comes from burning wood. However, other technologies have also been developed that can use biomass to replace carbon-emitting fuels. For example, co-firing biomass with coal and transport fuels such as ethanol from corn and lignocellulosic biomass as well as biodiesel are some of the examples. Currently, the desire to replace a substantial amount of foreign oil beyond the current capabilities of the United States has driven much interest in producing biofuels from feedstocks other than row crops (Duffield, 2006). These feedstocks include crop residues from agricultural and forestry sectors, wood waste, municipal solid waste, and dedicated energy crops. Currently biofuels cannot supply enough energy to meet the U.S. total energy demand; however, they could reduce oil imports significantly (Duffield, 2006). In addition, increases in energy efficiency and other technological breakthroughs can also contribute to gaining the U.S. energy independence.

While energy efficiency is not a primary source of energy, its potential contribution to the growing energy service needs was recognized three decades ago. In response to the oil supply crisis of the 1970s, energy efficiency experts emphasized that the same level of energy service could require significantly different amounts of energy.

For example, only about 15% of the energy from the fuel we put in our tank gets used to move our car down the road or run useful accessories, such as air conditioning and because of the weight of the automobile, even less gets used to move people from place to place. The rest of the energy is lost to engine and driveline inefficiencies and idling (U.S. DOE, 2006). Therefore, the potential to improve fuel efficiency with advanced technologies, which in this case would require less energy to move the car, is enormous.

Energy efficiency analysis usually starts with the key concepts from the theory of thermodynamics, especially its first and second laws. Put in simple language, the first law of thermodynamics says that “energy can neither be created nor destroyed” and the second law of thermodynamics says that “energy quality always degrades during the use or transformation of energy in an isolated system” (Jaccard, 2005, p. 80). “First law efficiency is measured as the “ratio of energy input to useful energy output of a device.” Many modern devices have low first law efficiencies, indicating substantial room for improvement. However, energy analysts point to second law efficiency as the best way to understand just how much efficiency improvement may be possible. Second law efficiency is defined as the “ratio of energy input of a device to the minimum amount of energy theoretically needed to perform a task” (Jaccard, 2005, p. 80). In his book Sustainable Fossil Fuels Jaccard presents a wide diversity of options and dimensions of energy efficiency supported with numerous examples of estimating the first and second law efficiencies of various energy systems. These examples first demonstrate inefficient use of fossil fuels and are followed by suggestions for their improvement. These examples show that improvements could be gained by switching to more advanced technologies, by changing the type of energy used, by using appropriate building design principles by the effectiveness of various uses of energy.

The energy efficiency avenues are examined in more detail by Amory Lovins, whose research results suggest that “about a 75% reduction in energy use for a given level of services… is achievable in a relatively short timeframe (30-50 year) via a 100% adoption of technologies that are currently available” (see, for example, Lovins et al., 1981; Fickett et al., 1990; Von Weiszacker et al., 1997) (Jaccard, 2005, p. 86). Lovins is also arguing that these improvements in energy efficiency are cost-effective. According to Lovins, the most efficient technologies already available in the market might be initially of higher capital cost, however this higher cost would be more than offset by the money saved from lower energy bills generated from operating these technologies (Jaccard, 2005). The World Energy Assessment provides another estimate of energy efficiency gains suggesting “industrialized countries could achieve cost-effective energy efficiency gains of 25-30% over the next twenty years” (Jaccard, 2005, p. 87). This estimate is based on a comprehensive survey of the energy efficiency literature comprised of 250 references. However, “the question of how much energy efficiency can be achieved and what that will mean for total energy consumption over time is complicated” (Jaccard, 2005, p. 100). Therefore, it is crucial to evaluate different levels of energy efficiency improvement and compare them with energies supplied from various alternative sources such as renewables and even clean fossil fuels before making a decision on choice of energy.

Though the use of coal, oil, and other nonrenewable resources is currently widespread, it is necessary to wean the U.S. society from these fuels in order to insure continued energy supplies into the future. Finding ways to substitute this finite and heavily polluting energy sources is vital for reducing depletion of fossil fuels, lessening the human impact on the environment and increasing the U.S. energy security while maintaining the commodities and services on which we have come to rely. Therefore, it is essential to transition away from these polluting energy sources to high efficiency and environmentally friendly renewable energy sources. This position is advocated today by many environmentalists as well as by international agencies, energy experts and corporations. As Scheer says in his 2002 book The Solar Economy: Renewable Energy for a Sustainable Global Future, "an energy supply that protects the climate and the environment must necessarily be based on renewable, not fossil or nuclear energy, which means replacing the current system with more efficient energy technology using renewable resources." The 2001 report of the Global Environmental Facility states that "a transition to renewables is inevitable, not only because fossil fuel supplies will run out – large reserves of oil, coal and gas remain in the world – but because the costs and risks of using these supplies will continue to increase relative to renewable energy." In addition, our society as a whole must change to become enormously more efficient, i.e. learn to do more with less. We must reconsider our unwise and wasteful way of using energy. This will require a major reorganization of society. The process of transition will not happen instantaneously and consumer and business behavior will not change overnight. This process will require the gradual replacement of existing fossil fuel resources with renewable fuels accompanied by gradual change in current fuel technology. Furthermore, government support in the form of various economic incentives and subsidies will be needed to ease the transition from current ways we use resources to more wise use and to reduce emissions from existing fossil fuel based technologies.

The sooner the U.S. makes this transition to renewable energy sources the better off the Nation will be in the long run. The transition would bring numerous benefits to the U.S. economy, environment and the population. It would give the U.S. the opportunity to become one of the world's leading nations in pursuing the preservation of natural resources and using the energy sources wisely. In addition, it would help the U.S. to reduce considerable risks from oil disruptions followed by sudden increases in oil prices and economic recession. Furthermore, transition to the renewable energies would reduce the U.S. contribution to the global warming problem through the significant reduction in carbon dioxide and other pollutants. One thing is clear that choices made by decision makers now regarding the renewable energies will set a road to a future less dependent on fossil fuels. This change will be crucial for our present and extremely important for our future quality of life.

4.2 Benefits from using biomass in energy generation

Potential of biomass fuels to address the problems related to fossil fuel energies has been considerably studied throughout the United States. These studies have been of national as well as of regional scale. The issues examined in these studies fall within three of the major dimensions of sustainable development: economic, environmental, and social. For example, under the *economic dimension* the factors such as biomass feedstock availability and cost, transportation cost, cost of plant construction have been investigated. *Environmental dimension* has included factors describing impacts of biofuels on soil, water, and air quality. These impacts stem from production of biomass feedstocks at the farm and forest side as well as from production and use of biomass energies such as electric power and ethanol. Finally, the *social dimension* has examined impacts on local communities which include factors such as job creation, impacts on human health, increased traffic and odor from construction and operations of biorefineries, etc.

In this study we will first evaluate some of the benefits arising from substituting biomass for fossil fuels in energy generation process. This evaluation will demonstrate whether biomass has a potential to contribute to addressing the fossil fuel related problems in the study region. Then we will discuss several critical factors that must be addressed before proceeding with a decision to build a new biorefinery in the region; however, the study will not intend to analyze a particular site selection and other related issues for a potential biorefinery. Specifically, in terms of biomass benefits our perspective will be limited to such critical arguments as: (i) saving non-renewable fossil fuel resources; (ii) securing energy resource supply through use of domestic resources; (iii) air pollution reduction; (iv) turning biomass waste stream into a revenue stream; and (v) providing jobs for local communities. The list of critical factors influencing the decision about building a new biorefinery is fairly long, however we will include the following critical factors in our discussion: (1) regional demand for energy; (2)

availability of biomass feedstocks and costs; (3) transportation and cost; (4) hazards analysis (hurricanes, tornadoes, earthquakes as examples); (5) infrastructure analysis (e.g., water, electricity, feedstock storage options, closeness to bioenergy markets); and (6) availability of local labor force. Each of these factors is important for both electric power generation and ethanol production cases examined in this study. However, it should be mentioned that the co-firing scenarios which we will be investigating for power generation analysis take place at the existing power plant meaning that the plant is adapted to accommodate the biomass input. Therefore the need to address infrastructure issues such as water, electricity and other critical factors listed may be safely assumed. In other words, the power plant analysis is the simplest, or trivial, case and therefore our discussion of critical factors will focus on ethanol plant only.

4.3 Study region – case of East Texas

The East Texas region is selected to evaluate the complexity of concerns related to use of fossil fuels and examine the role of biofuels in addressing these concerns. Specifically, the forty four Texas counties east of Interstate 45 have been chosen to investigate the feasibility of sustainable energy production (ethanol and electric power) from biomass crops such as switchgrass, sugarcane, and logging residues (The study counties are listed in Appendix A). Figure 4 presents the map of the study region comprised of the forty-four East Texas counties.

East Texas is rich with agricultural acreage and has large forest acreage. Land use in some areas is in flux. In particular, the region includes Chambers, Galveston, Hardin, Harris, Liberty, Jefferson, and Orange, counties that have substantial rice producing area. Rice farmers in these counties are facing various challenges. The 1996 Farm Bill and market environment have put an increasing economic pressure on rice farmers. Namely, as a consequence of reduced government payment rates for rice, increasing competition for water, lack of economically viable rotation crops and rising costs to comply with government programs and environmental regulations (Balas et al., 1993), there has been a tremendous drop in rice production in Texas. For example, the rice acreage in seven counties that fall into the study area has dropped from 92,779 acres in 1995 to 44,450 acres in 2002 (TASS, 2002). Figure 5 presents the historical rice acreage in East Texas capturing the period from 1980-2004.

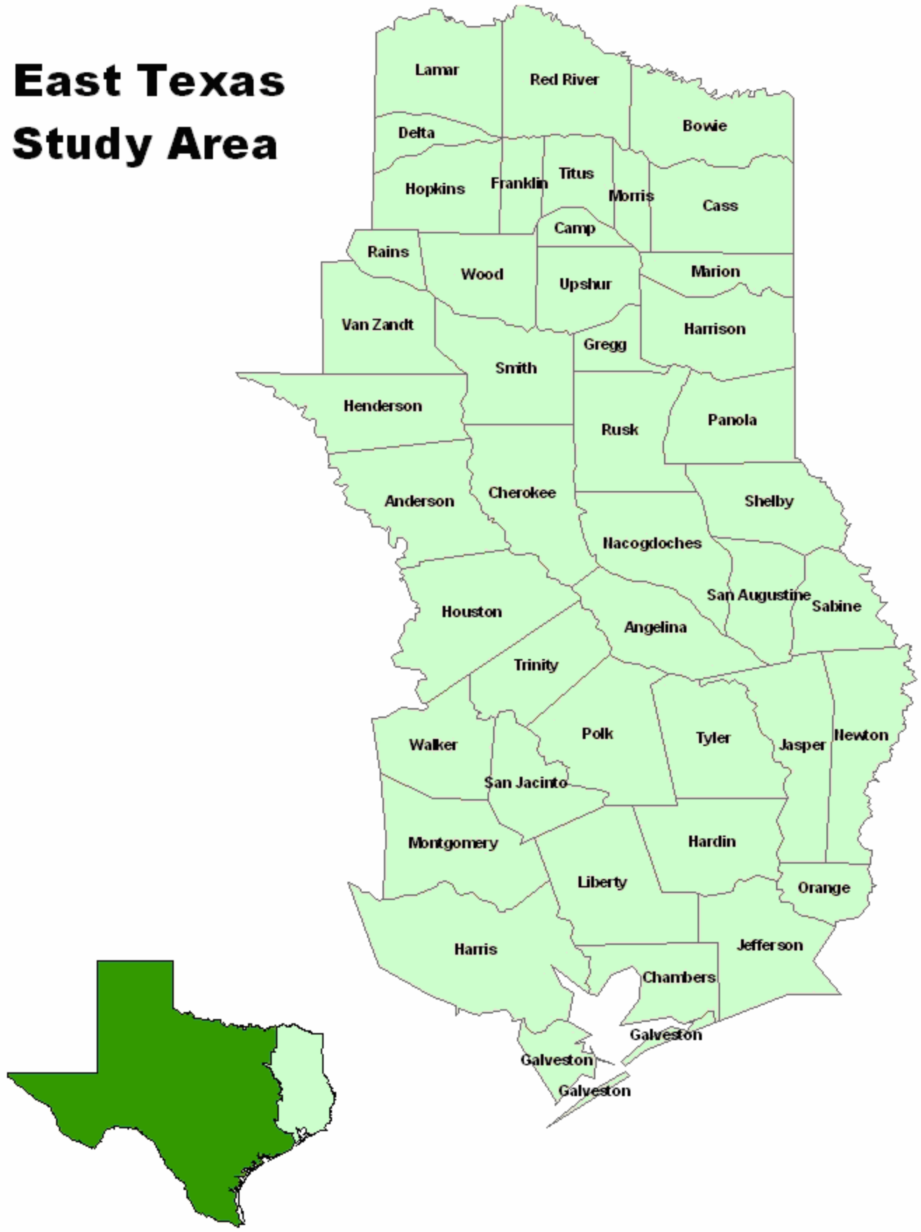

Figure 4. Map of the East Texas study region

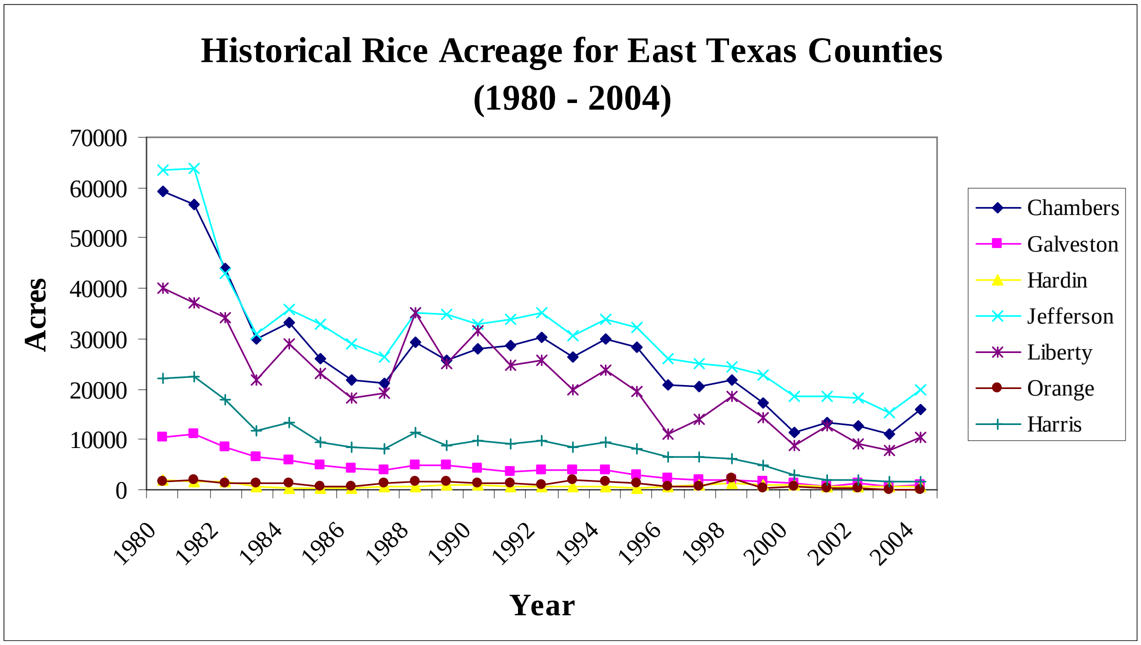

Figure 5. Historical rice acreage for East Texas counties

Furthermore, the average market price for Texas rice has dropped sharply since its peak in 1996 from $10 per hundredweight to $6 in 2000, according to the U.S. Department of Agriculture (LCRA, 2003). As a result of these challenges, farmers have indicated an interest in alternative crop production (Barta, 1998). Forest producers are facing similar challenges and are also looking for alternative production possibilities as pulp prices currently fall in rich pulp-oriented forests of East Texas. One of the options for farmers and forest producers to address their challenges would be to participate in the nation's biomass-to-energy effort selling their biomass feedstocks to energy producing facilities.

Another support for this decision could be the projected economic development and population growth in East Texas which has and will substantially increase the future electricity and transportation fuel demand in the region. According to the population projections estimated by the Texas Water Development Board, the population of Texas is expected to reach 24.5 million people by year 2010 and 28.8 million by year 2020, up from 20.86 in 2000. The population projections for the study region of forty four counties indicate that the area population will increase from 5.78 in 2000 to 6.67 millions in year 2010 and 7.73 millions in year 2020 (TWDB, 2003). Meeting the growing demand by using fossil fuels would contribute to an already serious air pollution, water contamination problems and cause various environmental and health problems in the region. Moreover, East Texas region is not in compliance on air quality with Beaumont/Port Arthur and Houston/Galveston exceeding national pollution standards (SECO Fact Sheet No. 25, 2005) and is required to use oxygenates in gasoline.

However, along with the above-mentioned challenges and concerns, East Texas offers great opportunities for bioenergy strategies. From its vast 12 million acre forest industry to its huge grain and fiber farms, the region is richly endowed with biomass (Texas Energy Planning Council, 2004). In addition, the production potential for energy crops for Texas is estimated at 9,140,000 dry tons per year (States Bioenergy, 2004). According to another source, "an estimated 30.2 billion kWh of electricity could be generated using renewable biomass fuels in Texas. This would be enough electricity to fully supply the annual needs of 3,018,000 average homes, or 30 percent of the residential electricity use in Texas" (States Bioenergy, 2004, p. 2).

In addition, the state has a varied physiography which brings a wide variety of weather to the region. "Because of its expansive and topographically diverse nature, Texas offers continental, marine and mountain-type climates" (The Handbook of Texas, 2005, p. 1). Precipitation is not evenly distributed across the state. However, East Texas is considered as one of the wettest regions with average annual rainfall of 44.2 inches (The Handbook of Texas, 2005). The average precipitation in various regions of Texas is depicted in Figure 6 showing the East Texas precipitation ranging from 38 up to over 54 inches.

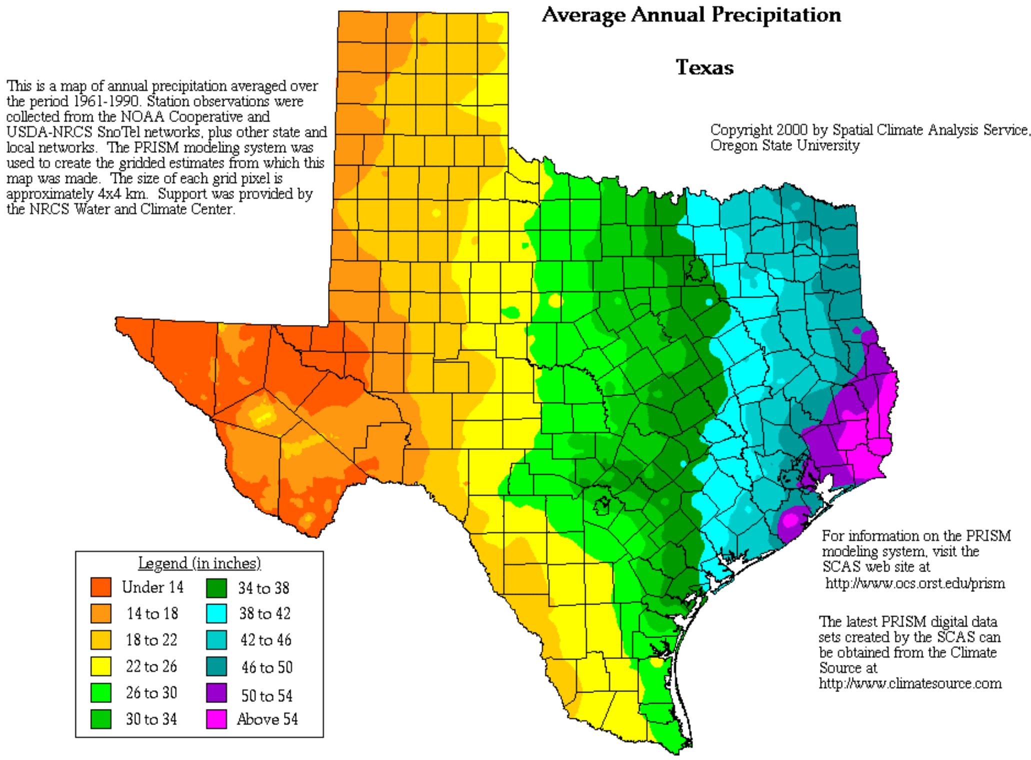

Figure 6. Average annual precipitation in Texas

Source: Texas Water Development Board, 2000

The good rainfall and the long warm growing season make the study region a satisfactory place to grow energy crops switchgrass and sugarcane along with the abundant forest species.

4.4 Regional background

Agriculture is one of the most important industries in Texas. The estimated value of agricultural production and related items in 2004 only totaled $18.2 billion. That was up sharply from $16.7 billion in 2003 and $14.4 billion in 2002 (Gleaton & Anderson, 2005). Among other crops rice, which is grown in several counties on the Coast Prairie of Texas, ranked third in value for a number of years. However, it was recently outranked by other crops such as cotton, grain sorghum, and wheat.

In East Texas, growing agricultural crops such as rice is the traditional agricultural enterprise. "The Texas rice industry contributes nearly $1 billion to the state economy every year. Roughly half of this contribution is directly related to the value of the rice crop" (Cockrell, 2004, p. 9). However, "the dependence of area rice producers on government income support to offset high production costs contributed to increasing economic stress for area farmers as the base of income support declined" (Rister et al., 1999, p. 2). Specifically, as a consequence of the 1996 FAIR Act, government payment rates for rice were scheduled to be reduced over a period of 5 years to an estimated payment of $2.03 per hundredweight (cwt) in 2002, down from an initial $2.77 per cwt in 1996 (Outlaw et al., 1996). Rice production in 2002 totaled 14.6 million cwt with the crop value of $61.4 million, which was less than the 2001 production of 14.8 million cwt. All these problems have forced rice farmers to consider switching to alternative crop production.

East Texas forest producers are another group that is in search of alternative business opportunities mainly because of falling pulp prices in the region. However, the highly productive forests of East Texas provide significant opportunities for the state's forest industry as well as serve as biomass source for energy generation. The sawdust and waste wood from saw mills and pulp mills are already being used to generate steam and electricity at many East Texas timber processing plants. Currently falling pulp prices could lend further opportunities to forest producers to improve their business conditions by providing their biomass sources for bioenergy production. In particular, the logging residues which are left in forests for decay or are burned as a result of current practices could be used for energy production becoming a profitable alternative for the forest industry.

Hence, agriculture and forestry are two industries in East Texas which could provide large sources of biomass for energy generation and help address the increasing energy demands in the state.

4.5 Energy demand

Since the discovery of the Spindletop oilfield near Beaumont in 1901, Texas has been associated with energy production through oil and natural gas production (Texas Energy Planning Council, 2004, p. 3). Texas is the largest domestic producing state for both oil and natural gas followed by Alaska. The tremendous production of the primary recovery stage of the state's oil and gas resources reached its maximum in the early 1970's. In

1972, the industry produced about 1.2 billion barrels of oil, or about 3.3 million barrels per day. In 2002, Texas operators produced about one-fifth of the domestically produced crude oil and about 30% of the natural gas produced in this country. In 2003, the state produced just under an estimated 360 million barrels, or about 0.98 million barrels per day (Texas Energy Planning Council, 2004, p. 6). Texas' annual production of oil is shown relative to that of the other top ten producing states in Figure 7 below.

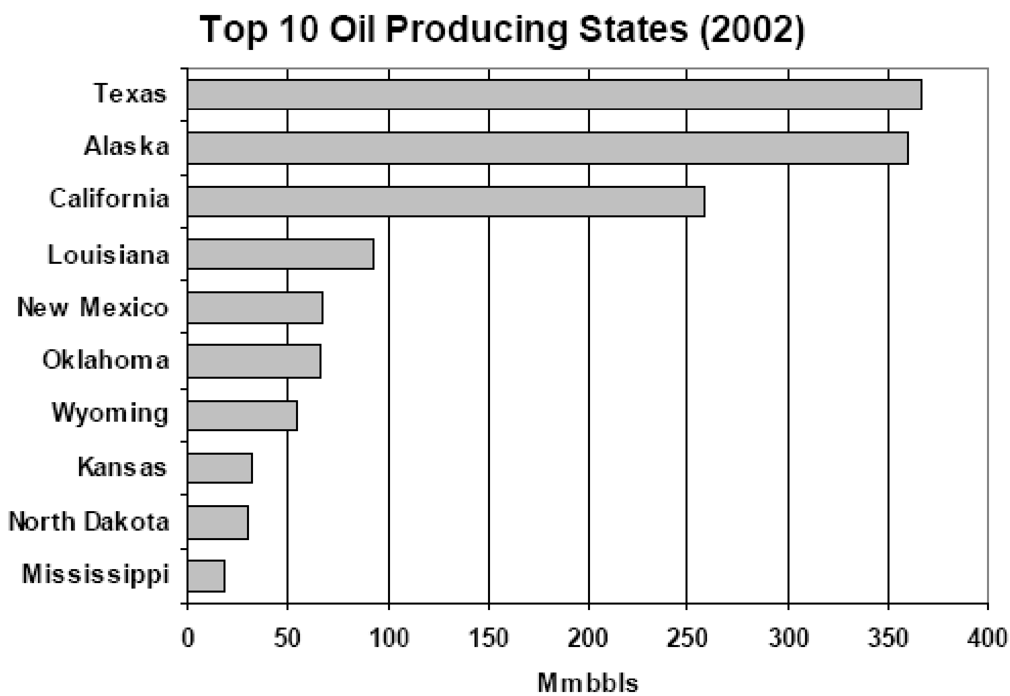

Figure 7. Top ten oil producing states (2002)

Source: Texas Energy Planning Council (2004)

Coal provides a significant portion of the state's base load electric generating capacity. "Texas consumes roughly twice as much coal as it produces, and 95% of the coal consumed is for the electric power sector" (Texas Energy Planning Council, 2004, p. 27).

However, for the first time, Texas is a net energy importer (Virtus Energy Research Associates, 1996). Oil production in the state is falling. Natural gas consumption is increasing, but reserves are shrinking. Coal use has risen. The state is now dependent on other states and foreign countries to meet energy demands. The primary reason for this demand is the fact that Texas uses huge amount of electricity. "With over 21 million residents, Texas accounts for about eight percent of the U.S. population. At the same time, it accounts for 12 percent of the nation's total energy usage. Among the states, Texas ranks first in overall consumption of petroleum, natural gas, coal, and electricity" (Texas Environmental Profiles, 2005, p. 1). This energy consumption is expected to rise further with the rising population projections. Relative BTU level consumption of these energy sources are shown in Figure 8 below:

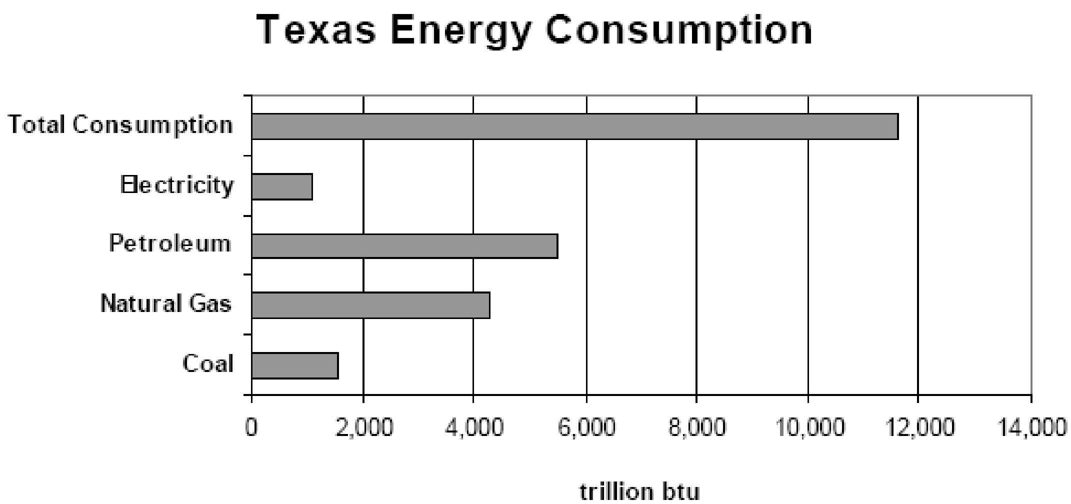

Figure 8. Texas Energy Consumption (by type of energy)

Source: Texas Energy Planning Council (2004)

Furthermore, energy sector challenges affect the state's economy. In 1981, the oil and gas industry was responsible for 25 percent of the gross state product. By 1997, it dropped to 10.4 percent and is expected to account for 8.6 percent of the gross state product by 2015 and eight percent by 2020. State tax revenues also have fallen. During the 1950s, the state received one-third of its revenue from oil and gas taxes, which dropped to 2.7 percent of the state's total revenue by 1997 (Texas Environmental Profiles, 2005).

Renewable bioenergy sources, which are abundant in Texas, could play a large role in the state's energy mix. At present, however, the state derives very little of its total energy from renewable sources.

4.6 Biomass sources

There are many types of plants in the world, and many ways they can be used for energy production. In general, there are two types of biomass: plants that are grown specifically for energy use (i.e., energy crops) and plants and residues from plants that are used for other purposes (UCS, 2004). According to the Oak Ridge National Laboratory estimations, the total world biomass resources are huge comprising 99% of biomass on land and 80% in trees. This is equivalent to about 60 years of world energy use in the year 2000 (ORNL, 2004).

The choice of plant species depends largely upon the end-use and the bio-conversion options, e.g. combustion, gasification, pyrolysis, fermentation or mechanical extraction of oils (McKendry, 2002). The plants selected by the U.S. Department of Energy for further development as energy crops are mostly perennials such as switchgrass, willow, and poplar. They were selected for their advantageous environmental qualities such as erosion control, soil organic matter build-up and reduced fertilizer and pesticide requirements (ORNL, 2004).

Perennial grasses switchgrass and sugarcane and logging residues are selected to examine the biomass feedstock potential of East Texas region. More specifically, bagasse as a byproduct of sugarcane-to-sugar process is examined for energy generation purposes in the study region. These feedstocks are discussed in the following sections.

4.6.1 Switchgrass

The U.S. Department of Energy believes that biofuel sources such as switchgrass could reduce the nation's dependence on foreign oil, reduce greenhouse gas emissions, and strengthen America's farm economy. In the U.S., the Herbaceous Energy Crops Research Program (HECP), funded by the U.S. Department of Energy, was established in 1984 (Lewandowski et al., 2003). After evaluating 35 potential herbaceous crops (18 of which were perennial grasses) Cherney et al. (1990) concluded that switchgrass was the grass that showed the greatest potential among others.

Switchgrass *(Panicum Virgatum)* is a native warm-season perennial grass widely adapted in North America. The switchgrass producing regions are depicted in Figure 9. Switchgrass is frequently used for hay, grazing, and resource conservation purposes (Moser & Vogel, 1994).

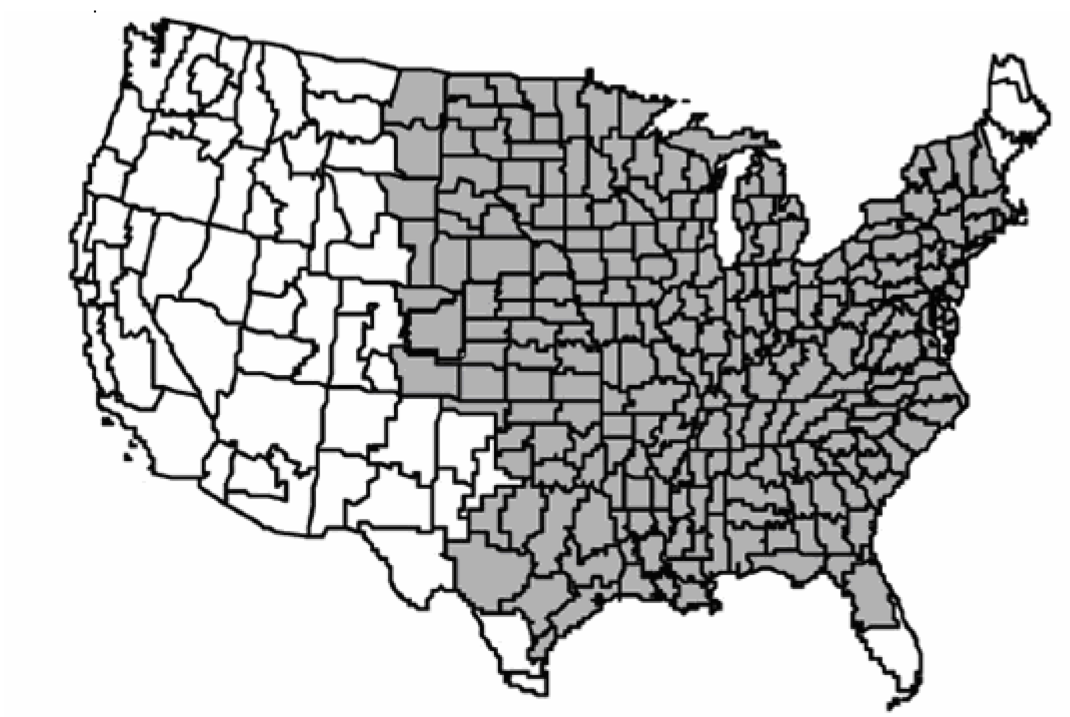

Figure 9. Switchgrass production regions (switchgrass can be grown in regions other than those included in this analysis, but yield and production practices data are lacking for these regions) (Source: Walsh et al., 2003)

Since it is a native herbaceous plant, switchgrass is resistant to many pests and plant diseases and can produce high yields with very little application of fertilizer.

Switchgrass is “very tolerant of poor soils, flooding and drought, which are widespread agricultural problems in the southeast” (Bransby, 2004, p. 1). “It grows fast, capturing lots of solar energy and turning it into lots of chemical energy – cellulose – that can be liquefied, gasified, or burned directly. Switchgrass reaches deep into the soil for water, and uses the water very efficiently” (ORNL, 1998, p. 1). It is adaptable perennial grass, which once established in a field, can be harvested as a cash crop, either annually or semiannually, for 10 years or more before replanting is needed (ORNL, 1998, p. 2). Unlike corn and other annual crops, which require annual application of herbicide, switchgrass requires herbicide use in the establishment year only (McLaughlin et al., 1998). Due to the structure of its stems and roots, switchgrass “holds onto soil … to prevent erosion” and it can help “slow runoff and anchor soil” (ORNL, 1998, p. 1). In addition, it “can also filter runoff from the fields planted with traditional row crops. Buffer strips, planted along streambanks and around wetlands, could remove soil particles, pesticides, and fertilizer residues from surface water before it reaches groundwater or streams” (ORNL, 1998, p. 1), i.e. improving water quality.

Switchgrass removes carbon dioxide (CO_2) from the air as it grows, therefore it has the potential to reduce the concentration of this greenhouse gas in the atmosphere and lower the risk of global warming. Unlike fossil fuels, which simply release more and more of the CO_2 that has been trapped underneath the earth surface for millions of years, “switchgrass "recycles" CO_2 over and over again, with each year's cycle of growth and use” (ORNL, 1998, p. 1).

Switchgrass has been researched extensively as a forage crop particularly in the Midwestern and northeastern U.S. (Moser & Vogel, 1994). However, until recently little research had been done on switchgrass as a biomass or forage crop in Texas. According to Faidley (1995), nineteen million hectares are potentially available to production of switchgrass in Texas. In 1992, the Texas Agricultural Experimental Station was chosen by the U.S. Department of Energy Biomass Feedstock Development Program as one of three regional cultivar and management testing centers to focus on switchgrass as a bioenergy feedstock (Sanderson, Reed JC & Reed RL, 1999). The five-year trial which compared commercially available switchgrass cultivars in five locations in four physiographic regions of Texas (Stephenville, Beeville, Dallas, Temple, and College Station) reported Alamo switchgrass as "the best-adapted commercially available switchgrass cultivar for biomass feedstock production in Texas in these trials" (Sanderson, Reed JC & Reed RL, 1999, p. 217). Therefore, the Alamo cultivar is assumed for analysis of switchgrass potential in East Texas.

4.6.2 Sugarcane

Sugarcane (*Saccharum Officinarum*) is a perennial crop which is common in tropical and subtropical countries across the world. "It can grow from eight to twenty feet tall, and it is generally about 2 inches thick" (Braun, 1999, p. 1). Sugarcane needs nitrogen and water for the proper growth and production of good yields. Moreover, sugarcane is the heaviest user of water. As a perennial crop, sugarcane is planted, then harvested and left alone. It re-grows the next year, can be harvested again and will continue re-growing. The crop can be left alone on average for five years followed by re-planting.

After harvest sugarcane leaves are cut off and stems are sent to the sugar factory. Sugar, the main commercial product of sugarcane, is extracted from the cane by removing the juice. The solid waste that is left after extraction of the sugar is called sugarcane bagasse, which is dried and used as a fuel (Harris & Staples, 1998). Bagasse contains the chemical energy of the sun and produces heat when burned. It is usually used by the sugar mills for steam and power generation in order to meet internal needs. However, "about 15%-25% of the bagasse is left after satisfying the mill's energy requirements, and this excess is not burned in the mill boilers" (Kadam, 2003, p. 7).

Currently, Brazil and India are the world's two largest sugarcane growers with production of 300 and 285 Mt/yr, respectively (Lower & Barros, 1999; Singh, 2000). In the U.S., there are several states growing sugarcane, namely Florida, Louisiana, Hawaii, and Texas. According to the USDA World Agricultural Outlook Board, the percent of the total U.S. sugarcane production (1988/89-1992/93 average) by state was as follows: Florida, 50%; Louisiana, 28%; Hawaii, 19%; and Texas, 4%. The U.S. sugarcane acreage rose from 823,000 acres in FY1986 to a record 954,300 acres in FY2000 (ERS, 2004).

Texas sugarcane is produced in the lower Rio Grande Valley in the southern tip of the State. Production of sugarcane in Texas resumed with the 1973 crop after years of inactivity. According to the USDA's Economic Research Service (ERS), during the 1980s, total harvested area averaged about 35,000 acres and varied little. Sugarcane production averaged about 100,000 tons per year for the same period, but varied from year to year due to changes in yields. FY2001 saw a big area expansion into sugarcane of 50 percent relative to the previous year.

Currently there is no sugarcane production in the East Texas region. However, since farmers in neighboring Louisiana are realizing sustained profits by growing sugarcane, producers, agribusinesses, financial leaders, and land owners in Southeast Texas have also indicated interest in developing this crop as a profitable alternative to rice (Rister et al., 1999, p. 1). Therefore, the capabilities of land in rice growing counties to adapt sugarcane for generation of bagasse as the region's bioenergy feedstock will be examined in this study.

4.6.3 Logging residues

Residues from the wood products and forestry industries are the largest source of biomass used today for energy. They supply about 64 percent of the total used in the United States (Climate Change Technologies, 2000). Logging residues get accumulated during wood harvesting process and are defined as "… wood biomass separated from the desired wood assortments during harvesting and usually left in the forest, including branches, tops, stumps, and even the under-sized trees left standing or felled in clearfellings" (Pulkki, 2004, p. 4).

Various industrial and consumer products can be derived from logging residues. They can be combusted, fermented, or used in bioreactors to produce energy or to produce fuels or industrial chemicals (Burden, 2003, p. 1).

The highly productive forests of Texas yield many biomass opportunities. The vast majority of the forests are located in East Texas. Forest land dominates the landscape of East Texas, where forests are 56% of the land (Dreesen et al., 2000). This part of the state is the home and heart of Texas forest industry as well. Wastes generated by the forest products industry of East Texas include logging residues left behind after harvest as well as bark, wood chips, and sawdust generated at mills (Dreesen et al., 2000).

4.6.4 Greenhouse gases (GHGs)

The GHG considered in this study are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). To calculate the total greenhouse gas impact the emissions of these three gases should be converted into common units so that they could be added together. To do this, the concept of a global warming potential (GWP) is being used to enable different GHG to be compared with each other. Since the most commonly used reference gas is CO_2, the GWP weighted emissions are measured in units of CO_2 equivalent (CO_2-Eq.). The GWP factors reflect the different extent to which gases absorb infrared radiation and the differences in the time scales on which the gases are removed from the atmosphere. The Kyoto Protocol has adopted GWPs (with 100-year time horizon) as the basis for defining equivalences between emissions of different GHG during the 2008–2012 commitment period. For example, the 100-year time horizon GWP for N_2O is 296. This means that in terms of global warming impact over 100 years, one lb of N_2O is equal to 296 lbs of CO_2. The 100-year time horizon GWP of CH_4 is 23. These GWPs are summed in Table 3 below.

Table 3. Global Warming Potentials for CO_2, CH_4, and N_2O

Greenhouse Gas	GWP
Carbon dioxide	1
Methane	23
Nitrous oxide	296

CHAPTER V

METHODOLOGY

Previous chapter discussed the benefits of using biomass feedstocks in replacing fossil fuel energies. In this chapter, we will first determine the indicators for these biomass benefits and then discuss various methods and modeling tools that will be used in estimation and evaluation of these indicators. In addition, we will discuss critical factors, which must be addressed in a biorefinery site selection process.

5.1 Determination of indicators of biomass benefits

In this section we select one indicator per each argument on benefits stemming from using biomass that we discussed in the previous section. In other words, we will have five important indicators that will present biomass benefits. The role of these indicators is to provide a better understanding of the biomass contribution to addressing the fossil fuel related problems in the study region. Each indicator expresses aspects or consequences of the production and use of bioenergy. Taken together, the indicators address address the extent to which biomass as a renewable energy is a potential solution to the fossil fuel problem in the study area. In order for biomass to have a potential to address the current energy problems each of the selected indicators must score positively. Changes in the indicator values over time will mark progress or lack of it with respect to benefits of biomass for the region's energy supply issues. Information about biomass benefits gathered through the indicators will show how useful these indicators could be to policymakers, energy analysts and the public in the study region when making energy production choices. Policymakers need tools for measuring and assessing the current and future effects of bioenergy production on human society, environment, and economy in order to shape up the energy policy for the region. The five critical indicators that we select to discuss the benefits of biomass are presented in Table 4. Some of these indicators are of quantitative character (such as replacing non-renewable resources with renewables, greenhouse gas emissions, turning waste stream into a revenue stream, and job creation) while others are of qualitative nature such as domestic resources versus imported resources. Note that some indicators can be classified in more than one dimension given the numerous interlinkages among the economic, environmental, and social dimensions.

Table 4. Critical indicators of biomass benefits

Indicator	Dimension	Characteristic	Unit of measure
1. Replacing non-renewable resources with renewables, i.e. non-renewable energy resource savings	Environmental	Quantitative	- Tons of coal - Gallons of gasoline
2. Domestic resources versus imported resources, i.e. energy resource supply security	Economic and Environmental	Qualitative	-------
3. Greenhouse Gas Emissions (GHGE)	Environmental	Quantitative	Grams of CO_2-Equivalent gases
4. Waste stream into a revenue stream	Environmental	Quantitative	Tons of biomass
5. Job creation	Economic and Social	Quantitative	Number of jobs

Following sections will determine each one of the indicators in more detail.

5.1.1 Replacing non-renewable resources with renewable resources

As it was mentioned in the earlier sections, much of our energy supply comes from coal, oil, and natural gas. They are considered non-renewable energy sources because once they are removed from the ground and used they cannot be replaced within human time scales. In fact, the world's fossil fuel deposits took millions of years to form. In contrast, renewable resources, like solar energy and trees, are materials that can be replaced through natural processes. However, renewable resources can be also depleted if drawn down more rapidly than nature can rebuild them. For example, if we harvest more timber than can grow back, the forest will die. If we catch more fish than are spawned, the stocks will die out. If we dump more carbon dioxide into the atmosphere than nature can reabsorb, the atmosphere is no longer hospitable to life (Redefining Progress, 2006).

This indicator relates to annual savings of fossil fuels coal and gasoline that have been accumulated through replacement by biomass fuels during electricity generation and ethanol production. Specifically, the savings of coal stem from substituting some portion of it with biomass feedstocks during the combustion stage. Use of biomass feedstocks in production and delivery of ethanol to the market to meet our transportation needs generate savings of gasoline. Savings of coal and gasoline from the both energy generating processes can prolong the use of these fossil fuel resources at both plants. This is a quantitative indicator by character and is measured in tons of coal and gallons of gasoline saved.

5.1.2 Domestic resources versus imported resources

Biomass is the largest domestic source of renewable energy, according to the U.S. Department of Energy (DOE). As a renewable domestic energy source, biomass fuels provide benefits over fossil fuels in various ways. For example, "these benefits can include increased domestic energy security, reduced energy imports, enhanced local energy economies, diversified energy sources, decreased emissions, waste stream reduction, and rural and agricultural economic development" (USDOE, 2005, p. 1). Biomass has several advantages with respect to other renewable resources. It is available locally throughout the year. "It is widely available, easy to transport, store, and has no environmental hazards. It can be obtained locally from plantation of land having no competitive use. Biomass-based power generation systems, linked to plantations on wasteland, simultaneously address the vital issues of wastelands development, environmental restoration, rural employment generation, and generation of power with no distribution losses" (TERI, 2000, p. 1). The primary goal of the U.S. National Energy Policy are to increase the energy supplies using a more diverse mix of domestic resources and to reduce the nation's dependence on imported oil.

This is a qualitative indicator, which relates to sources of domestic energy supply. It describes the characteristics and benefits of biomass sources selected locally and for which energy type they have been selected.

5.1.3 Greenhouse gas emissions

A key characteristic of fossil fuels is that when burned, they release carbon dioxide as well as emissions of SO_x and NO_x and other atmospheric pollutants. This happens because fossil fuels consist primarily of hydrocarbons, which are made up of hydrogen and carbon. When burned, the carbon combines with oxygen to yield carbon dioxide. The amount of carbon dioxide produced depends on the carbon content of the fuel. For example, for each unit of energy produced, natural gas emits about half, and petroleum fuels about three quarters, of the carbon dioxide produced by coal (Patin, 2004). Carbon dioxide acts like a blanket, trapping the sun energy in the atmosphere, which causes the Earth to get warmer and warmer. The amount of carbon dioxide in the atmosphere increases as people use more and more fossil fuels in their homes, factories, and automobiles. The consensus has been reached in the scientific community that if this build up continues, our planet is likely to become significantly warmer, which could cause many serious problems around the world. “These problems could include melting of arctic ice, increased forest fires, rising sea levels, loss of animal habitat, damage to coral reefs, the spreading of tropical diseases, expanding deserts, and more frequent and severe storms” (The Pembina Institute, 2006).

These environmental concerns have created many new opportunities for the use of biomass energy. Biomass can play an important role in reducing greenhouse gas emissions and air pollution. Specifically, the energy crops such as fast-growing trees and perennial grasses may reduce net greenhouse gas emissions if biomass is used in place of fossil fuels. As energy crops grow, they remove from the atmosphere through photosynthesis process a quantity of CO_2 roughly equivalent to that released when the biomass is converted to fuel and burned to release energy. On the other hand, best practices must be used while growing energy crops in order to minimize the life-cycle greenhouse gas emissions associated with planting, growing, harvesting, transporting, and converting the crops into energy. Even with emissions of CO_2 from planting, harvesting, processing and transporting the biofuel, “replacing fossil fuel energy with bioenergy will typically reduce net CO_2 emissions by over 90%” (British BioGen, p. 5).

The Greenhouse Gas emissions indicator relates to the emissions of CO_2, CH_4, and N_2O from use of fossil fuels during production of two types of energy from biomass: electricity generation and ethanol. These GHGs are covered by the United Nations Framework Convention on Climate Change (FCCC) that took place in Rio de Janeiro in 1992. This indicator is estimated separately for each type of bioenergy and represents the life-cycle emissions that include emissions generated during two stages of the bioenergy production process. The first stage takes place at the farm and includes emissions from feedstock planting, harvesting, processing, and finally hauling it to an electricity or ethanol producing plant. The second stage considers emissions generated from biomass combustion at the power plant and from ethanol processing. The indicator shows the total amount of emissions generated from both stages and is measured in grams per kWh of electricity generated and grams per gallon of ethanol, respectively. This indicator will demonstrate whether biomass utilization in the energy generation process contributes to reduction of GHG emissions to the atmosphere and by how much.

5.1.4 Waste stream into a revenue stream

One source of biomass material is waste. Human society produces enormous amounts of organic waste which includes anything from kitchen scraps, sewage, the leftovers of the food processing industries, paper, sawdust, lawn clippings, to name a few. One of the reasons why bioenergy attracts so much attention is that “it represents an opportunity to convert waste into something very valuable” (NOVA, 1999, p. 1). Everything from crops left in the field, weedy trees, animal waste to humans’ garbage, can be recycled and transformed into energy (IPT, 2004). Each year the U.S. sends more than 200 million metric tons of organic waste to landfill (ODE, 2005). Corn stover (much of it used as fodder) accounts for 100 million metric tons of this biomass waste, and newsprint biomass waste accounts for 11.2 million metric tons. Urban tree residue - leaves, Christmas trees, and broken branches - accounts for 38 million metric tons (CUNS, 2004). Recovered wood and other biomass wastes can be used to manufacture biofuel pellets to replace fossil fuels in domestic, commercial, and industrial boilers. In addition, cutting the demand for new landfill sites can reduce habitat and amenity damage to the environment. Decreasing the volume of organic material put into landfills will also reduce methane emissions, which is a powerful greenhouse gas. Other GHG emissions can also be reduced by replacing fossil fuel use with energy from biomass residues. Residues from the wood products and forestry are the largest source of biomass available today for energy, supplying about 64 percent of the total used in the United States (Climate Change Technologies, 2000). Residues from sugar cane called bagasse are used as the fuel to fire the boilers at sugar mills and to make cellulosic ethanol.

Landfill gas, which used to be known as “the dump” is another example of turning biomass waste into treasure. It has become one of America’s most cost-effective and reliable energy resources (SECO, 2006). Recovering landfill gas (LFG) offers great opportunities for increasing biomass' near-term presence in the energy mix. It gathers garbage, which is a big issue for society and environment and turns it into high-value energy products such as electricity and natural gas. “Turning hazardous LFG into marketable energy enhances landfill safety. It also reduces odors and greenhouse gases while generating revenue” (SECO, 2006, p. 1). Methane typically makes up half of all the gases emitted by a landfill (SECO, 2006). Similar to natural gas, decaying biomass materials produce greenhouse gas methane, which can be captured and burned to generate electricity at the landfill. The benefit to the environment comes from reduction of the global warming potential of methane “when it is burned under controlled conditions to create power rather than flaring it or letting it escape into the atmosphere” (SECO, 2006, p. 1). As landfill sites become scares and tipping fees increase, power generation is becoming an attractive and economic option for urban waste.

This indicator is related to residues from the forestry and sugar cane used for electricity generation and ethanol production. It will show how much residue is collected in the study area and streamed into energy generation instead of decaying on the forest sites or on the site of a sugar producing plant or at the landfill. This indicator is of quantitative character and is measured in tons of residue per year.

5.1.5 Job creation

“Bioenergy developments create new employment opportunities in manufacturing, construction, plant operation and servicing and in fuel procurement” (British BioGen, p. 5). In addition, biomass fuel production offers potential re-employment to people who lost their jobs at the fossil fuel industries such as petroleum refineries, coal mines, etc. Also, biomass fuel production provides new growing market opportunities for farmers and foresters who are currently facing substantial market challenges. Rural jobs are created for biomass production stages such as harvesting, transport and processing, and "maintaining on-farm employment during the winter when most energy crop management activities take place" (British BioGen, p. 5).

This indicator is related to jobs created by production of biomass energy such as electricity and cellulosic ethanol. Specifically, the indicator will show a total number of employees required to produce the bioenergy and this number will include employees at the power and ethanol plants as well as employees needed at a farm and forest site for biofuel procurement. This is a quantitative indicator that is measured in number of employees hired at a biorefinery and for biomass procurement.

5.2 Critical factors in the analysis of building a new biorefinery

There are a wide array of critical factors that need to be addressed before proceeding with a decision to build a new ethanol plant. We will call these factors the feasibility measures that assist in determining whether a potential ethanol project has all the required factors in place and can proceed into construction phase. For example, availability of biomass feedstocks, water and energy, transportation/ distribution network, access to local markets, site size, financial issues, community support and services, and regulatory issues are some of the feasibility measures (BBI International, 2003). Although some questions are site specific, there are basic factors that are important for all plants. For the purposes of this study, these basic feasibility measures are included to the discussion: 1) regional demand for energy; 2) availability of biomass feedstocks and cost; 3) transportation and cost; 4) hazards analysis (e.g., hurricanes, tornadoes, earthquakes, etc.); 5) infrastructure analysis (e.g. availability water, electricity, feedstock storage options, closeness to bioenergy markets); and 6) availability of local labor force. These feasibility measures influencing the decision about building a new plant will be useful for investors and businesses in the region who contemplate investing into a new plant. The selected feasibility measures are discussed next.

5.2.1 Regional demand for energy

Conducting the analysis of the regional demand for energy is very important in justifying the decision to build a new electricity generating or ethanol plant. Clearly, in regions with rapidly growing population and the expanding local economy there will be increasing demand for energy. The demand analysis can suggest how many new plants and of what size would be needed to meet the region's growing energy needs. Some other factors may also influence the demand for energy. For example, replacement of MTBE with ethanol in Northeast gasoline required 749 million gallons per year of ethanol. To meet this demand, approximately fifty ethanol plants, each supplying 15 million gallons per year of ethanol, would be required (Northeast Regional Biomass Program, 2001).

5.2.2 Biomass feedstocks availability and cost

Biomass feedstock availability is one of the most critical factors in addressing the ethanol plant construction. It is extremely important for the plant to secure a steady supply of raw biomass materials. In the U.S., providing sufficient feedstocks to sustain a reasonably sized biorefinery is a significant constraint for most biomass-to-ethanol and power generating plants. Even if a region has substantial biomass resources it is important to examine whether these quantities are sufficient for the ethanol plant of a particular size. In addition, different quantities of biomass resources will be required by the same biorefinery depending on the type of biomass selected. Also, it is a very important task for plants to secure the most attractive biomass feedstock mix at each point in time to maintain their undisrupted operations. In other words, instead of relying on a single biomass feedstock a biorefinery will be better off selecting several feedstocks that can be processed by the same technology. This diversification makes the facility less vulnerable to feedstock shortages in the future.

This factor is related to all cellulosic biomass feedstocks produced in the study area for further delivery to the ethanol plant. The biomass-to-ethanol conversion rate will be used in order to conclude whether or not the region has sufficient amount of biomass feedstocks to sustain the reasonable size (here 20 MMGY) ethanol plant.

Careful attention should be given to the cost of the feedstocks. Currently in the U.S., the estimated market price of biomass-derived energy exceeds the market price of fossil fuel-derived energy. Biomass energy costs depend on the costs of the feedstocks, transportation, conversion, and various other costs. Therefore, only feedstocks, which can produce energy competitive with the fossil fuels they replace, will be selected for bioenergy production.

5.2.3 Transportation and cost

Transportation analysis includes three important components: collection of biomass at the farm and forest site; delivery of collected biomass to the ethanol plant; and delivery of the final product, i.e. ethanol, to the local ethanol market. For all three components, it is important to examine availability of the good road network (highway system, railroads, and barges) as well as road accessibility issues. In other words, the road system, which would provide a safe and efficient connection between a farm, a forest site, and the ethanol plant as well as between ethanol plant and the markets, should be in place while choosing the ethanol plant site.

In general, the biomass hauling distance is one of the major barriers that prevent biomass from becoming an energy resource on a commercial scale. Therefore, location of the ethanol plant at close proximity from biomass sources can significantly cut the transportation costs. From the perspective of road accessibility for biomass collection purposes, obviously it is easier to collect biomass crops at a farm than to collect logging residues from a forest site with a difficult terrain. Accessibility to the biomass feedstocks from the point of view of having road system to transport biomass to the ethanol plant is rarely a technology-limiting factor, since there is equipment for almost any type of terrain (ORNL, 2005). However, significantly high transportation costs inhibit working in areas without established roads and more difficult terrain. According to FAO estimates, about 60% of the North American temperate forest is considered accessible (FAO, 2001). The cost of transportation is important to plant input costs and marketing costs. With regard to marketing costs, an initial market evaluation performed on early stage, i.e. during a pre-feasibility or feasibility phase, should identify primary markets for the plant. Ethanol from the production process is sold freight on board (FOB). Its transportation is dependent upon the purchaser and their respective location. Depending on proximity of the plant to population centers, marketing costs may be based on a variety of transportation modes. Ethanol has historically been shipped to markets by truck, rail, and barge.

The location of the plant should also consider the modes of transportation, which will be used to deliver the bulk of finished products to market. Rail access is often viewed as an essential requirement for large-scale ethanol plants. The cost of transportation varies considerably depending on mode and shipment volume. Hence, access to reliable, cost competitive transportation is an important site factor. Project developers should evaluate the modes of transportation necessary to supply materials to the plant and determine the availability and cost of these modes at prospective sites.

5.2.4 Hazards analysis

Ethanol plant site selection should be carefully studied with respect to some natural disasters. Natural hazards such as hurricanes, tornadoes, and earthquakes can be extremely dangerous to a plant. These natural disasters can cause tremendous damage to biomass feedstocks as well as to the plant site. For example, if the site is selected in the zone prone to tornadoes there is a risk that the plant could be wiped out or severely damaged by this natural event. Even if feedstocks do not get hit hard and withstand the tornado damages due to their strong root systems still the plant operations will be disrupted. On the other hand, tornado can severely damage the biomass feedstocks so that even if the plant survives there will be no sufficient amount of cost competitive biomass to continue its supply to the plant to maintain its operations. Hurricane is another natural disaster that is seasonal by nature. It is usually very damaging to the coastal areas; however, hurricane's destroying power can also reach way deep into land. Similar to tornadoes, hurricanes can cause significant damages (depending on its power) to the plant and to biomass feedstocks. Although earthquakes are rare events, they also should be included in the site analysis if the region had a previous experience with this natural disaster or if it is in the earthquake zone. Avoiding locations prone to these types of natural events could save plant investors millions of dollars. In addition, the regional energy markets would avoid experiencing the disruption in energy supply.

The analysis of hazards should include the collection of historical data on a particular disaster for each county in the study region that will give decision makers a good idea about how frequently the event occurs and how damaging it has been in the past. Usually these events are well documented and state and county level data are available for public access.

5.2.5 Infrastructure analysis

One of the most critical infrastructure issues is water availability. Available water is an especially important consideration because the steps in biomass conversion deal with dilute streams, containing relatively small quantities of material in much larger volumes of water. The long-term availability of water would need to be addressed for any plant in the study region. As an alternative to using fresh makeup water, co-siting a biomass-to-ethanol plant with an agriculture processing plant could help meet the water requirements. Many of these plants produce a relatively large amount of wastewater, which may contain starchy materials that can also be utilized as a partial feedstock for the ethanol plant. Moreover, issues such as cost, volume, quality and accessibility of water from on-site wells, existing infrastructure availability for water supply and wastewater treatment, as well as water supply issues affected by local law or regulation need to be considered.

Ethanol plant power requirements are quite high. One alternative to buying power from the grid could be the availability of power production, conversion, and transmission facilities, which would support plant operations, next to the ethanol plant. For example, in California, “the availability of an existing power plant has been the determining factor in location of some of the first facilities. This has resulted in a reduction in capital required for construction and expected reductions in fuel cost resulting from the availability of lignin from the ethanol plant for use as fuel for power generation” (Mann & Bryan, 2001, p. 33). The new plant in the study region could consider construction of a dedicated power facility to reduce the ethanol production cost and have its own source of power next to the plant.

In addition, when evaluating potential ethanol plant sites, energy cost factors such as “proximity to energy source (natural gas pipeline, coal, propane, co-generation, etc.), historic price, availability and reliability of supply, emission control costs and permit issuance time for selected energy sources need to be addressed” (CFDC, 2006, p. 13).

5.2.5.1 Feedstock storage options

Storage of biomass material is another important infrastructure issue that needs to be addressed while contemplating a construction of the ethanol plant. To prevent accumulation of moisture in feedstocks which may cause deterioration and/or spontaneous combustion, feedstocks could be stored in specially built storage facilities at the plant. Another option could be to store biomass material in barns for several months until being transported to the ethanol plant. In any case, storage requirements will ultimately affect the overall cost of the biomass and need to be factored into the purchase price for the raw material (CFDC, 2006). Overall, on-site and off-site feedstock storage options and methods of moving required feedstock volumes through the receiving system must be carefully evaluated. This is an increasingly important factor as plant size and throughput increase.

5.2.5.2 Ethanol markets

As ethanol from biomass has been shown to present a great value as a product, current and potential ethanol markets must be considered during the site location process. An ethanol market assessment is typically part of the feasibility study. The market assessment “will help provide guidance on site related issues that may potentially improve or impede ethanol marketing from specific locations” (CFDC, 2006, p. 19). Furthermore, “this assessment helps identify markets and the relative value of current and potential markets based on a variety of factors such as: regulatory, legislative or legal factors that impact target markets; an assessment of demand for specific gasoline components; transportation costs and options, including a rail service evaluation, a determination of commercial trucking service and other applicable modes including barge capability in the region; current ethanol utilization in target markets and an assessment of existing competition; ethanol price and volume utilization history in target markets" (CFDC, 2006, p. 19).

5.2.5.3 Local labor force availability

Availability of a qualified local labor force continues to be a large determining factor that companies consider when making decisions about building ethanol plants. An initial assessment of labor availability needs to be conducted to analyze the region's potential to supply adequate number of workers. If the region does not have adequate labor pool and has to mobilize workers across large distances, labor costs will increase significantly. There are some federal incentives which are structured such that they "provide a supplement to costs that are typically applicable to all projects" (CFDC, 2006, p. 31). Job training grants are examples of these incentives. Funding for these programs is provided by the federal government. These grants typically offset the cost of training new labor force at the ethanol facility. If the skills required at the new plant are not available locally, this can make training costs expensive. "Job training grants offset the direct cost to the project developer, thereby making funds otherwise spent on this activity available for other project needs" (CFDC, 2006, p. 31).

5.3 Methods and models

In this study, several methodologies and modeling techniques are employed to estimate the economic, environmental, and social impacts on the study area due to the bioenergy production related activities. The economic analysis included estimation of various costs and evaluation of regional impacts. The results for environmental analysis are based on environmental models that quantified the greenhouse gas emissions from all stages of feedstock production and use as well as changes in soil and water quality due to: (i) transfer of land under rice to grow energy crops, and (ii) collection of logging residues from the forest sites. The principal environmental model utilized here is the Soil and Water Assessment Tool (SWAT). A Life Cycle Assessment (LCA) approach was applied to GHG emissions calculation. The economic analysis utilized the economic engineering calculations to estimate yields, hauling distances and various costs. The regional economic multipliers from the INPLAN (IMpact Analysis for PLANning) input-output system were applied to assess the anticipated economic and employment effects associated with the operation of the proposed ethanol facility and co-firing at the existing power plant. Finally, some estimated parameters such as logging residue densities and densities for conventional crops (e.g., corn, wheat, rice) were adopted from the Forest and Agriculture Sector Optimization Model – Greenhouse Gas version (FASOMGHG) (Alig et al., 2005). The utilized models and tools are discussed in more detail in the following sections.

5.3.1 Soil and Water Assessment Tool (SWAT)

This study employed the SWAT modeling technique to evaluate the impacts on soil erosion and surface and groundwater quality through changes in fertilizer application and nutrient runoff created by three activities: i) transferring the rice acreage to grow switchgrass; ii) transferring the rice acreage to grow sugarcane; and iii) collecting logging residues from forest sites in forest rich counties of East Texas.

SWAT is a river basin, or watershed, scale model developed in 1998 by Arnold et al. for the USDA Agricultural Research Service (ARS).

> SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. …SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed and is a computationally efficient tool which helps to study long-term impacts (SWAT Theoretical Documentation, 2002, p. 1-2).

The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modeled by SWAT using this input data.

> SWAT allows a number of different physical processes to be simulated in a watershed. For modeling purposes, a watershed may be partitioned into a number of sub-watersheds or sub-basins. The use of sub-basins in a simulation is particularly beneficial when different areas of the watershed are dominated by land uses or soils different enough in properties to influence hydrology. By partitioning the watershed into sub-basins, the user is able to relate different areas of the watershed to one another spatially. Input information for each sub-basin is grouped or organized into the following categories: 1) climate; 2) land cover/soil/management combinations within the sub-basin (hydrologic response units or HRUs); 3) ponds/reservoirs; 4) groundwater; and 5) the main channel, or reach, draining the sub-basin. To accurately predict the movement of sediments, nutrients or pesticides, the hydrologic cycle as simulated by the model must correctly represent watershed processes. Simulation of watershed hydrology can be separated into two major divisions. The first division is the land phase of the hydrologic cycle that controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each sub-basin. The second division is the water or routing phase of the hydrologic cycle, defined as the movement of water, sediments, nutrients, etc. through the channel network of the watershed to the outlet" (Neitsch et al., 2002, p. 6-8). The more detailed SWAT model description can be found in the SWAT Theoretical Documentation by Neitsch et al. (2002).

It is assumed in this study that diverting land in rice growing counties to grow energy crops switchgrass and sugarcane may affect the soil erosion and water quality in these counties. It is also assumed that removing the logging residues from forest sites may affect the soil erosion and water quality in the counties with large forest acreage. Hence, the examination of these changes is necessary to assess the environmental impacts of these activities, which will help the decision process regarding the energy production options in the region.

5.3.2 Lifecycle Assessment (LCA) approach

Lifecycle Assessment was created as "a valuable decision-support tool for both policy makers and industry in assessing the cradle-to-grave impacts of a product or process" (GDRC, 2004, p. 1). LCA is a process that takes into account any environmental impacts associated with a product or service by identifying and quantifying energy and materials used and wastes released to the environment. More specifically, "the assessment includes the entire life cycle of the product or service, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal" (GDRC, 2004, p. 2). In addition, it assists in identifying and assessing opportunities to affect environmental improvements. "One of the key advantages of using LCA is that it allows a direct and fair comparison between two products or services concerning the environmental and energy impact" (ESRU, 2004, p. 1).

This type of analysis has been employed to research various bioenergy production processes in the U.S. and worldwide. For example, Mann and Spath (2001) applied the LCA approach to a coal-fired power system that co-fires wood residue capturing all processes necessary for the operation of the power plant, including raw material extraction, feed preparation, transportation, and waste disposal and recycling. Qin et al. (2006) used LCA approach to examine the competitiveness of switchgrass as a biomass resource for power generation through developing an understanding of the economics, engineering, energy and environmental affects of biomass in comparison with the energy sources that biomass would replace, including coal. Analysts from the U.S. National Bioenergy Center at NREL also employed the LCA approach to determine the environmental impacts of biomass conversion technologies, using a cradle-to-grave approach that includes biomass feedstock growth, harvest, conversion, and product use (NBC, 2003).

In this study, the LCA approach is utilized to examine the economic, environmental and energy implications of replacing coal with switchgrass in the electricity generating plant and co-firing coal with switchgrass at 5%-, 10%-, and 15% ratio. Specifically, LCA will help quantify the costs, energy use and other resource consumption and greenhouse gas emissions from switchgrass production processes up to the point of its combustion and disposal in the landfill.

5.3.3 IMPLAN multiplier analysis

IMPLAN (IMpact analysis for PLANning) is a widely used system which helps perform the input-output analysis for any county, multi-county region, state or group of states in the U.S. Originally IMPLAN was developed at the University of Minnesota over a period of years in conjunction with the U.S. Forest Service’s Land Management

Planning Unit in Fort Collins for community impact analysis and has been in use since 1979.

In the most general sense, an economic multiplier is a quantitative measure of economic impact that explicitly recognizes that economies (local, state, regional, national, or global) are interconnected networks of interdependent activity. When a change takes place in one part of such a network, its effects propagate throughout the system. These effects typically result in a larger total impact than the original change would have caused in isolation (Dumas, 2003). In addition to the direct effect of an economic activity, there are also indirect effects and induced effects. Indirect effects are the impacts on the chain of suppliers to the economic sector whose activity we are considering to be the direct effect; induced effects are the changes in consumer spending that are generated.

CHAPTER VI

ANALYSIS OF FEEDSTOCK PRODUCTION

Rice farmers in East Texas, being under increasing economic pressure of high production costs, lack of economically viable rotation crops, low rice prices, and diminishing government payments have been considering transferring land to alternative crops, which would improve their diminishing incomes. Forest producers have been also contemplating finding alternative business opportunities to address the problem of falling pulp prices in the region. In this chapter, we will assume that farmers in rice growing counties (Chambers, Galveston, Hardin, Harris, Jefferson, Liberty, and Orange) consider growing switchgrass or sugarcane, as alternative crops, to improve their current situation. Furthermore, we will assume that forest producers consider changing a current practice of leaving softwood and hardwood logging residues on the forest sites to collecting and delivering it to a biorefinery. In both cases, we discuss various issues related to the biomass feedstocks that are considered a potential biomass resource for electricity generation and ethanol production in East Texas region. Namely, annual feedstock availability and yields, production budgets and the hauling distances from a farm and forest to a power and ethanol plants will be estimated. Greenhouse gas emissions from the feedstock production stage will be also quantified. In addition, environmental impacts such as soil erosion and change in water quality which may be caused by transferring land under rice to grow switchgrass or sugarcane or by collecting logging residues will be assessed.

6.1 Feedstock yields, availability, and cost

Yield is an important factor in feedstock production cost "since many variable costs change little with increases in yield" (King et al., 1998, p. 14). Many factors affect yield, including the plant and soil characteristics, climate (including rainfall, frost free days, temperature extremes, and solar insulation), fertilizer, herbicide, and pesticide use, management practices, including planting and harvesting schedules, tillage practices, and harvesting methods (King et al., 1998, p. 14). In addition, for woody feedstocks the number of trees planted per acre and the number of years between harvests and the use of coppicing, i.e. regrowth from the stump instead of replanting, are the important factors affecting the yield (King et al., 1998, p. 15). The following discussion will present analysis of yields and production budgets for our biomass crops.

6.1.1 Switchgrass

Since switchgrass was announced as a perennial grass with high potential for energy production, switchgrass yield performance has been extensively researched. A number of studies have attempted to estimate the yield and cost of switchgrass in recent years. For example, King et al. (1998) mention about the switchgrass research performed by McLaughlin in 1993 at Virginia Polytechnic. The research focused on remeasuring "…switchgrass yields ranging from 2.5 – 6.5 ton per acre with a best site yield of 8.5 tons per acre. The full economic cost, including land rent of $42 per acre of producing large round switchgrass bales was estimated at $43.40 per ton for yield of 4.0 tons per acre and $28.93 per ton for yields of 10.0 tons per acre" (King et al., 1998. p. 14). In 1995, Downing and Graham (1996) of Oak Ridge National Laboratory estimated

Herbaceous Energy Crop (HEC) yields and cost for the Tennessee Valley Authority (TVA) region covering portions of 11 southeastern states. HEC yields ranged from 5.8 – 8.9 dry tons per acre with costs ranging from $28–$64 per dry ton. The wide range of estimated cost was primarily a result of yield variation resulting from differences in soil quality. Walsh et al. (2003) assumed their regional average switchgrass yields to vary between 3.48 tons per acre for North Plain states (Montana, North Dakota, South Dakota, Wyoming) and 5.98 tons per acre for Corn Belt states (Iowa, Illinois, Indiana, Missouri, Ohio) with South Plain states (Texas included) yielding 4.33 tons per acre. These estimates were based on a wide variety of assumptions regarding yield, production cost, land rents, land access, and business structure.

The research by McLaughlin and Kszos (2005), as cited in “A billion-ton feedstock supply for a bioenergy and bioproducts industry” report, indicates that “current average annual yields from switchgrass clones tested in small plots over multiple years at 23 locations in the United States range from a low of 4.2 dry tons per acre to a high of 10.2 dry tons per acre, with most locations having an average between 5.5 and 8 dry tons per acre. Yields from the best clones were generally 8 dry tons per acre or higher. The highest observed yield at any location or year was 15.4 dry tons per acre. The best-performing clones were often the same at a majority of the 23 sites spread over the Great Plains, the Midwest, and the South, where none of the test plots were irrigated” (ORNL, 2005, p. 32).

Switchgrass production trials established in various locations in Texas during 1992 to 1996 have revealed that Alamo cultivar was the best switchgrass adapted with the yields of 3.6 to 8 dry tons per acre (Sanderson, Reed, Ocumpaugh, et al., 1999). Since there have not been extensive tests on growing switchgrass in the study area to have an accurate estimate of the expected yield, we assume that switchgrass will be harvested once during a growing season (in the Fall season), will have the stand life of 10 years and yield 4.33 tons/acre/year (9.7 Mg/ha/yr), as in Walsh et al. (2003) estimates for the South Plains states.

Switchgrass production costs were adapted from Qin et al. (2006). We kept the assumptions from this study regarding the production process modifying the yield to 4.33 tons per acre per year. Qin et al. (2006) assumed that switchgrass was established on recrop fields, harvested loose for hauling and chopping, and transported by compression into modules. With these assumptions their overall cost of establishment, growth, and harvest of switchgrass with 10 ton/ac yield was estimated at $32.53/ton. Although in general, establishment of switchgrass requires a two-year period, it was assumed that approximately 25% of the fields were not successfully established during the first year and reseeding was carried out for these fields (Ney et al., 2002). Establishment included seeding of the fields, application of herbicides and lime, and soil preparation, and it was assumed that the field equipment such as herbicide applicator and no till-drill were used. Further maintenance of switchgrass fields was a relatively low cost process which mainly included the fertilizer application and mechanical weed control. These operations required another set of field equipment such as fertilizer spreader and a sickle mower. Mower-conditioner and silage chopper with a wagon were utilized for harvesting switchgrass for loose hauling and chopping.

Overall, the switchgrass cost budget for our yield of 4.33 tons per acre reflecting the establishment, maintenance, and harvesting processes amounts to $124.64 per acre, or $28.78 per ton. Using the 2004 rice acreage data from Texas Agricultural Statistics Service (TASS, 2002 and 2004) and the yield of 4.33 tons/acre we calculate the annual availability of switchgrass which is presented in Table 5.

Table 5. Annual switchgrass availability in East Texas rice counties

County name	County Rice Acreage	Switchgrass (tons/year)
Chambers	16,024	69,383.9
Galveston	847	3,667.5
Hardin	762	3,299.5
Harris	1,522	6,590.3
Jefferson	19,954	86,400.8
Liberty	10,475	45,356.8
Orange	90	389.7
Total	49,674	215,088.5

6.1.2 Sugarcane

Texas sugarcane production is mainly concentrated in the Southeast of the State in the Rio Grande Valley. East Texas does not have any sugarcane acreage. The Southeast Texas sugarcane budgets though cannot be adapted here because of the big differences in the soils, irrigation, climate, and other production conditions of two regions. In 1999, studying the farming economics of sugarcane in Southeast Texas, Rister et al. adapted the published research results from Louisiana as the basis for their farm level analysis because there was no sufficient information available to develop local enterprise budgets. Taking the same approach, we adopt the 2005 Louisiana sugarcane budget to develop the East Texas sugarcane scenario.

In their study, Rister et al. (1999) cautioned that there were many important questions that had to be answered when Southeast Texas sugarcane farmers decide to transition land from rice into sugarcane and adapt the Louisiana budgets. These questions are similarly important for rice farmers in East Texas. For example, clay soils and above average annual precipitation, infrequent droughts requiring irrigation water, disease outbreaks and high machinery costs were some of the concern issues. Another most uncertain issue was the sugarcane yield, which can vary greatly due to weather and such adverse factors as “freezes, drought, salt accumulation in the soil, heavy rains at harvest, diseases, and weed and insect problems” (Smith, 2003, p. 1). Furthermore, the authors argued that on average Texas producers could experience lower and more variable yields than the ones in Louisiana that range between 29-33 tons per acre. However, irrigation may reduce some of the variability requiring increased attention to land farming.

The USDA’s National Agricultural Statistics Service (NASS) reports the Texas sugarcane yields as 37.3 tons per acre in year 2004 and 34.7 tons per acre in year 2005 (USDA/ NASS, 2004). In this study we assume the sugarcane yield to be 35.6 tons per acre, as it is projected for 2005 Louisiana sugarcane. Further, we assume that the East Texas region sugarcane production is similar to Louisiana's 2005 sugarcane production projections and present the Louisiana projected costs and returns on a representative 1,000-acre sugarcane farm with a four-year rotation schedule. The projected costs and returns are given on per acre dollar value. According to 2005 Louisiana sugarcane budgets (Breaux & Salassi, 2005), the projected net economic returns to management and risk, taking into account all fixed and variable costs as well as the opportunity costs to land, labor and operating capital is negative $10.50 per acre of sugarcane produced. This bottom-line estimate of returns to management and risk is calculated taking into account the following items. The farm has a standard land rotation, with four approximate equal acreage components of the total 1,000 acres in plant cane, which includes first stubble, second stubble, and fallow. Average yield across harvested acreage for plant cane, first stubble and second stubble is 35.6 tons per acre. Raw sugar is valued at 20.5 cents per pound and molasses yield is valued at 35.0 per gallon. Gross value of production is $1,077.83 per acre. From this gross value, a milling charge (i.e. payment in kind) deduction per acre amounts to $430.63. Total land charge (i.e. payment in kind) is $129.44 per acre. Fixed and variable production expenses, including costs for labor, capital asset depreciation, and interest opportunity, total $441.23. Overhead expenses amount another $84.53.

Earlier we had argued that the rice farmers have indicated the desire to consider sugarcane as an alternative crop to currently grown rice. However, the projected negative net economic returns of $10.50 per acre would not be attractive for sugarcane farmers in East Texas. Moreover, the yield uncertainty and other concerns mentioned above could make this cost go up even further (see Rister et al. (1999) for detailed discussion). Therefore, it is doubtful that farmers would decide to switch their rice land to grow sugarcane without making profits. In addition, lack of existing sugar mill in the region reduces the sugarcane potential as an alternative crop as building a new mill or purchasing it will need additional cost considerations.

However, assuming that there is a sugar mill in the region and the farmers would decide to switch land to grow sugarcane, sugarcane bagasse could be considered as an additional cellulosic feedstock for energy generation in the region. Bagasse is a fibrous biomass remaining after sugarcane stalks are crushed to extract their juice. Kadam (2000) reports bagasse as comprising 30.8 percent of sugarcane. According to the United Nations Development Program's (UNDP) Bioenergy Primer (Sivan Kartha & Larson, 2000), bagasse accounts for about 30 percent of the weight of fresh cane. Using this result and assuming the sugarcane yield at 35.6 tons per acre, we derive the bagasse yield of 10.68 tons per acre.

Similar to switchgrass, Table 6 summarizes the annual availability of sugarcane and bagasse for the rice counties in East Texas based on the discussion of feedstock yields and rice acreage data for year 2004.

Table 6. Annual availability of sugarcane and bagasse in East Texas rice counties

County	Rice Acreage	Sugarcane (tons/year)	Bagasse (tons/year)
Chambers	16,024	570,454.4	171,136.3
Galveston	847	30,153.2	9,046.0
Hardin	762	27,127.2	8,046.7
Harris	1,522	54,183.2	16,072.3
Jefferson	19,954	710,362.4	210,714.2
Liberty	10,475	372,910.0	110,616.0
Orange	90	3,204.0	950.4
Total	49,674	1,768,394.4	526,581.9

6.1.3 Case of potential acreage expansion

Tables 5 and 6 show the amounts of switchgrass and sugarcane bagasse that can be available annually if grown on the rice acreage of 49,674 ac in the rice counties. Further in the analysis we will use the conversion rates for power generation (Chapter VII) and ethanol production (Chapter VIII) to examine whether these amounts of biomass feedstocks would be sufficient to support the 100 MW power plant and the 20 MMGY ethanol plant. If the rice counties cannot provide enough biomass individually or jointly as a rice region then additional acreage from various agricultural crops in these counties will be considered. The agricultural crops that could be suggested for conversion to grow energy biomass will include corn, soybean, wheat, and sorghum. If the decision is made to convert land under these crops the additional acreage could come as 7,700 acres from corn (5,600 acres in Harris County and 2,100 acres in Liberty County); 16,400 acres from soybeans (2,800 acres in Chambers County and 13,600 acres in Liberty County); 7,300 acres from wheat (2,800 acres in Chambers County and 4,500 acres in Liberty County); and about 4,600 acres of sorghum (1,000 acres in Galveston County, 2,700 acres in Liberty County and less than 1,000 acres in each Chambers and Harris counties) (TASS, 2004). This would add another 36,000 acres to the initial 49,674 acres bringing the total land acreage for switchgrass and sugarcane to 85,574 acres.

6.1.4 Logging residues

The 2003 county level volumes of softwood and hardwood logging residues for the study area were available from the Texas Forest Service (Xu & Carraway, 2005). Residue availability estimates are based on a mill survey conducted by the Texas Forest Service (Xu, 2004) and a wood utilization study published by the U.S. Department of Agriculture Forest Service (Bentley & Johnson, 2004). The Texas Forest Service includes stumps, tops, limbs, and unutilized cull trees in defining the logging residues types. Among the Northeast Texas counties Cass, Harrison, Nacogdoches, Panola, and Cherokee have been identified as the top five producers of logging residue. Tyler, Polk, Jasper, Angelina, and Newton counties were the top five producers of logging residue in Southeast Texas (Xu & Carraway, 2005). In 2003, a total 3.38 million logging residues were produced in East Texas, 68.8 percent from softwood and 31.2 percent from hardwood (Xu & Carraway, 2005). The results are summarized in Table 7 and present a sum of both softwood and hardwood residues for each county in 2003.

Table 7. Average annual recoverable logging residues in East Texas counties

County	Recoverable Logging Residue (tons)	County	Recoverable Logging Residue (tons)
Anderson	53,993	Nacogdoches	139,210
Angelina	168,107	Newton	154,996
Bowie	89,018	Orange	24,202
Camp	18,056	Panola	125,525
Cass	191,250	Polk	228,443
Chambers	6,672	Red River	57,526
Cherokee	123,558	Rusk	113,314
Franklin	3,954	Sabine	81,825
Gregg	27,510	San Augustine	120,066
Hardin	129,780	San Jacinto	58,308
Harris	34,190	Shelby	101,969
Harrison	140,493	Smith	61,013
Henderson	16,967	Titus	16,775
Houston	94,972	Trinity	118,393
Jasper	227,954	Tyler	252,882
Jefferson	26,607	Upshur	36,604
Liberty	78,016	Van Zandt	7,324
Marion	88,836	Walker	59,486
Montgomery	64,506	Wood	19,647
Morris	21,953	Total	3,383,900

To calculate the approximate yield of logging residue we divided the volumes of residue from the above table by the private forestland acreage in each county, which was available from the 2003 Forest Inventory and Analysis (FIA), USDA Forest Service website. The softwood residue yields range from 0.01 ton/ac in Franklin County to 0.52

ton/ac in San Augustine County, whereas hardwood residue yields had less variation ranging from 0.02 ton/ac in Walker County to 0.27 in Jefferson County. Yields for both residue types by county are summarized in Appendix B. Logging residue harvest cost of $8.71 per ton was derived from the Forest Residues Transportation Costing Model (FRTCM) (Rummer, 2005). This cost accounts for all fixed, variable and labor costs involved in the harvest process and does not consider costs involved during forest establishment, maintenance and tree harvest stages. In further analysis, we assume that only two thirds of the residue is harvested for energy production leaving one-third of residue to provide the long-term nutrient balance in soils (Helynen & Hakkila, 1999-2003).

6.2 Biomass feedstock seasonality

"Because energy systems must be carefully designed to operate reliably, efficiently, and at low-cost" (Robles-Gil, 2001, p. 44), the planning and design stages have a larger need to assess the availability of resources and feedstocks. Specifically, availability of required amount of biomass on continuous basis is a critical issue to secure a biorefineries undisrupted operations. However, the seasonality of biomass feedstocks creates a serious obstacle to their extensive use in energy generation. Currently, large power stations firing fossil fuels generally use more than one base fuel and one co-fuel, because of regular changes in availability and price. Similar to the fossil fuel burning plants, it is a very important task for biorefineries to secure the most attractive biomass feedstock mix at each point in time. In other words, instead of relying on a single biomass feedstock a biorefinery should select several feedstocks that can be processed by the same technology. In addition, intermediate fuel storage systems to level out seasonal fluctuation in availability and procurement logistics for the needs of large-scale consumption could help avoid the seasonality problem.

With respect to feedstocks considered in this study, all three of them are cellulosic biomass resources and can be processed by the same technology that power and ethanol plants choose to install. In East Texas, logging residues have no seasonality problem, as they are available all year round in the forest sites. The seasonal nature of the availability of the bagasse may cause a major problem. Bagasse is produced during and after the cane harvest for about six months of the year. The two options for exporting electricity from a sugar mill or producing ethanol all year round would be to either store and manage the bagasse so that fuel is available for the full year or use a second fuel for the six months that bagasse is not available. The second fuel here could be logging residues, which are available in large amounts. The seasonal availability of switchgrass could be as many as four cuts. However as reported by Sanderson et al. (1999) Alamo switchgrass yields decreased greatly as harvest frequency increased from one to four harvests per year. This is mainly because switchgrass is slow to regrow after cutting. Therefore, for maximum biomass yields a single harvest in the fall would be best (Sanderson, Reed JC & Reed RL, 1999). If one harvest per season supplies sufficient amount of switchgrass to a biorefinery then switchgrass bales could be stored at the plant and support biorefineries undisrupted operations. Similar to bagasse, if switchgrass cannot supply the required amount of fuel, a biorefinery could consider a mixture of switchgrass with logging residues.

6.3 Hauling distance

Hauling distance is one of the major barriers that prevent biomass from becoming an energy resource on a commercial scale. The economically acceptable transport distance for forest fuel, due to its low energy density, is a fraction of that for oil and is typically less than 100 km (Richardson et al., 2002).

McCarl et al. (2000) computed the average hauling distances for the South Central region of the U.S., which includes East Texas, using the formula derived by French (French, 1960). Namely, given a rectangular road system, a per square mile density of biomass production (BD), a plant requirement of M tons of biomass, and a biomass yield Y per acre in BTUs, the average hauling distance (D) formula is:

$$D = .4714 * (M / (640 * BD * Y)) \wedge 0.5 \qquad (2)$$

We utilize this formula to calculate the average hauling distances for switchgrass and logging residues for counties in the study region. Clearly, the average hauling distance for the same feedstock changes depending on the energy type, as the amount of feedstock required by a power plant differs from the amount required by an ethanol plant. Average hauling distances for power generation and ethanol production will be calculated in Chapters VII and VIII, respectively.

6.4 GHG emissions

Biomass feedstocks require fossil fuel inputs for various stages of their production processes. The major fossil fuel energy inputs include fertilizers, mostly nitrogen which is made from natural gas, and fuel used in operating equipment during the planting, maintenance, and harvesting stages and transporting feedstock to a biorefinery (Cook &

Beyea, 2000). These fossil-based energies are one of the main sources of anthropogenic CO_2 emissions.

This section provides the analysis of greenhouse gas emissions associated with the switchgrass production process and harvesting logging residues. As sugarcane is not specifically grown for use in energy production process, we do not include analysis of emissions related to the sugarcane production as part of bagasse emission analysis. However, we will quantify the greenhouse gas emissions from using bagasse at the energy producing stage in the ethanol and power generating plants. We take a similar approach with regard to logging residues. Specifically, we do not consider emissions related to the forest production process. We only account for emissions that accumulate during the logging residue collection stage. Emissions related to transporting the feedstocks to a power generating and an ethanol plant as well as emissions from the plant processing stage will be discussed in Chapters VII and VIII, respectively.

The analysis of GHG emissions associated with the preparation of switchgrass is adopted from Qin et al. (2006). Their switchgrass preparation process takes into account the total mix of activities required for growing switchgrass and transporting it to a bioenergy plant. The authors analyzed the various pathways for switchgrass production for the lowest GHG emissions and concluded that the optimal combination of activities was establishing switchgrass after existing cropping, harvesting switchgrass loose for hauling and chopping, then transporting after compression into modules. All these activities require inputs such as fossil fuels, chemicals, fertilizers, and herbicides that produce GHG emissions when they are manufactured. Table 8 summarizes the energy consumption and the greenhouse gas emissions accumulated from machinery operations, except transportation, for switchgrass production process.

Table 8. GHG emissions and energy consumption from preparation of switchgrass

Switchgrass preparation stage	Operations	Energy Consumption (Btu/kg switchgrass)	CO_2 emissions (grams/ kg switchgrass)	N_2O emissions (grams/ kg switchgrass)	CH_4 emissions (grams/ kg switchgrass)	CO_2-eq emissions (grams/ kg switchgrass)
Establishment	Recrop fields	5	0.4	0.9E-5	0.5E-3	0.4
Growth	Growth	24	1.9	4.5E-5	2.4E-3	2.0
Harvest	Loose, hauling & chopping	59	4.7	1.1E-4	0.5E-2	4.8

Source: Qin et al. (2006)

Energy consumption for above listed activities sums up to 88 BTU/kg of switchgrass. Adding to this the energy consumption of 447 Btu/kg of switchgrass derived from use of lime and chemicals (Table 9) totals to 535 Btu/kg of switchgrass.

Table 9. GHG emissions and energy consumption from use of lime and chemicals

Emission species	Energy	CO_2	N_2O	CH_4	CO_2-Eq
Emissions and energy consumption from fertilizer and Atrazine (g or Btu/kg switchgrass)	441	28.2	2.03E-1	6.5E-02	89.9
Emissions and energy consumption from agriculture lime (g or Btu/kg switchgrass)	6	9.2	1E-05	5E-04	9.2
Emissions and energy consumption from all chemicals (g or Btu/kg switchgrass)	447	37.4	2.03E-01	6.5E-02	99.1

Source: Qin et al. (2006)

Adding up the emissions from switchgrass production activities and usage of lime and chemicals and applying these estimates to the amount of switchgrass that can be produced annually by East Texas rice counties we receive the annual emission results presented in Table 10.

Table 10. Annual energy consumption and GHG emissions from switchgrass preparation in East Texas rice counties

County	Switchgrass (tons/year)	Total Energy consumption (MMBtu/year)	Total CO_2 Emissions (tons/year)	Total N_2O Emissions (tons/year)	Total CH_4 Emissions (tons/year)	Total CO_2-eq. Emissions (tons/year)
Chambers	69,383.92	33,675.06	2,794.72	12.79	4.59	6,690.95
Galveston	3,667.51	1,780.00	147.72	0.68	0.24	353.67
Hardin	3,299.46	1,601.37	132.90	0.61	0.22	318.18
Harris	6,590.26	3,198.54	265.45	1.21	0.44	635.52
Jefferson	86,400.82	41,934.10	3,480.14	15.92	5.71	8,331.95
Liberty	45,356.75	22,013.62	1,826.92	8.36	3.00	4,373.92
Orange	389.70	189.14	15.70	0.07	0.03	37.58
Total	215,088.42	104,391.83	8,663.55	39.64	14.22	20,741.78

A different procedure was employed to quantify the greenhouse gas emissions related to the harvest of logging residues. The Forest Residues Transportation Costing Model (FRTCM) by Rummer (2005) was utilized to evaluate the logging residue harvest scenario. This spreadsheet calculator is designed to help users create their scenarios by comparing alternative methods of moving biomass from the forests sites to a bioenergy facility and allows estimation of loading and hauling costs for different combinations of equipment as well as consideration of several other forest site operations. It is available from the USDA Forest Service website at http://www.srs.fs.usda.gov/forestops/downloads/FoRTSv5.xls. Using the model we assumed that logging residue was loaded by a knucleboom loader into a container truck and hauled 2.5 miles to a disk chipper for chipping. Then, the disk chipper was directly loading chipped residue to a 120 cubic yard van-type truck, which was then transported to bioenergy producing facility. The gallons of diesel required per ton of harvested residue were then determined from the model at 0.99 gal/ton. In order to express the emissions from logging residue harvest in grams per kilogram of logging residue, additional adjustments were made to the FRTCM. Specifically, we made adjustments to a load size (25 tons per truckload), the weight of diesel (3.2432 kg), and biomass moisture content (50% moisture level). Finally, the diesel amount was multiplied by the diesel emission factors estimated in the GREET model (Wang & Santini, 2000) to arrive at the logging residue emissions from the harvest stage. The diesel emission factors used in calculations were carbon dioxide (CO_2) - 3188.07 g/kg of diesel, methane (CH_4) -

0.08 g/kg of diesel, and nitrous oxide (N_2O) - 0.11 g/kg of diesel. Table 11 presents the logging residue emissions from the collection stage.

Table 11. GHG emissions from collection of logging residues (grams/kg of LR)

	Energy consumption (BTU/kg LR)	CO_2	N_2O	CH_4	CO_2-Eq.
Logging residue (LR) collection stage	137.5	11.28	0.00038	0.00028	11.403

Applying the energy and emission estimates from above table to East Texas region, we receive the following results shown in Table 12.

Table 12. Annual fuel consumption and GHG emissions from logging residue (LR) collection

County	Recoverable logging residue (wet tons)	Energy consumption (MMBTU/kg LR)	Total CO_2 emissions (g/kg LR)	Total N_2O emissions (g/kg LR)	Total CH_4 emissions (g/kg LR)	Total CO_2- Eq. emissions (g/kg LR)
Anderson	35,995.33	4,948.83	1,437,461.93	48.66	36.07	1,452,694.69
Angelina	112,071.33	15,408.17	4,475,532.26	151.50	112.31	4,522,959.39
Bowie	59,345.33	8,159.12	2,369,936.59	80.22	59.47	2,395,050.76
Camp	12,037.33	1,654.96	480,706.99	16.27	12.06	485,801.04
Cass	127,500.00	17,529.39	5,091,671.04	172.36	127.77	5,145,627.39
Chambers	4,448.00	611.54	177,629.43	6.01	4.46	179,511.77
Cherokee	82,372.00	11,324.95	3,289,499.04	111.35	82.55	3,324,357.80
Franklin	2,636.00	362.41	105,267.80	3.56	2.64	106,383.32
Gregg	18,340.00	2,521.48	732,401.94	24.79	18.38	740,163.19
Hardin	86,520.00	11,895.24	3,455,148.07	116.96	86.70	3,491,762.21
Harris	22,793.33	3,133.75	910,244.36	30.81	22.84	919,890.20
Harrison	93,662.00	12,877.16	3,740,361.51	126.61	93.86	3,779,998.06
Henderson	11,311.33	1,555.14	451,714.42	15.29	11.34	456,501.23
Houston	63,314.67	8,704.84	2,528,450.63	85.59	63.45	2,555,244.57
Jasper	151,969.33	20,893.57	6,068,845.91	205.44	152.29	6,133,157.36

Table 12. Continued

County	Recoverable logging residue (wet tons)	Energy consumption (MMBTU/kg LR)	Total CO_2 emissions (g/kg LR)	Total N_2O emissions (g/kg LR)	Total CH_4 emissions (g/kg LR)	Total CO_2- Eq. emissions (g/kg LR)
Liberty	52,010.67	7,150.71	2,077,029.06	70.31	52.12	2,099,039.30
Marion	59,224.00	8,142.44	2,365,091.18	80.06	59.35	2,390,154.01
Montgomery	43,004.00	5,912.42	1,717,350.76	58.13	43.09	1,735,549.49
Morris	14,635.33	2,012.14	584,457.28	19.78	14.67	590,650.76
Nacogdoches	92,806.67	12,759.56	3,706,204.06	125.46	93.00	3,745,478.63
Newton	103,330.67	14,206.46	4,126,476.57	139.68	103.55	4,170,204.77
Orange	16,134.67	2,218.28	644,332.67	21.81	16.17	651,160.65
Panola	83,683.33	11,505.24	3,341,866.71	113.12	83.86	3,377,280.41
Polk	152,295.33	20,938.39	6,081,864.62	205.88	152.62	6,146,314.02
San Augustine	80,044.00	11,004.88	3,196,531.11	108.21	80.21	3,230,404.69
San Jacinto	38,872.00	5,344.33	1,552,340.68	52.55	38.95	1,568,790.81
Shelby	67,979.33	9,346.17	2,714,732.57	91.9	68.12	2,743,500.54
Smith	40,675.33	5,592.26	1,624,356.21	54.99	40.76	1,641,569.48
Titus	11,183.33	1,537.55	446,602.78	15.12	11.21	451,335.42

Table 12. Continued

County	Recoverable logging residue (wet tons)	Energy consumption (MMBTU/kg LR)	Total CO_2 emissions (g/kg LR)	Total N_2O emissions (g/kg LR)	Total CH_4 emissions (g/kg LR)	Total CO_2- Eq. emissions (g/kg LR)
Trinity	78,928.67	10,851.54	3,151,990.64	106.7	79.09	3,185,392.23
Tyler	168,588.00	23,178.39	6,732,506.96	227.9	168.94	6,803,851.21
Upshur	24,402.67	3,355.01	974,512.56	32.99	24.45	984,839.45
Van Zandt	4,882.67	671.3	194,987.71	6.6	4.89	197,053.99
Walker	39,657.33	5,452.31	1,583,702.71	53.61	39.74	1,600,485.18
Wood	13,098.00	1,800.78	523,064.37	17.71	13.13	528,607.27

6.5 Environmental issues

Shifting large areas of land from traditional row crops to grow perennial grasses switchgrass and sugarcane or removing logging residues from the forest sites can have significant environmental impacts. In this section, we will first discuss environmental impacts related to our scenarios of converting rice land to production of switchgrass and sugarcane, and removal of logging residues from the forest floor in the East Texas region. Next, we will provide the results of environmental impacts assessed by the SWAT model. Specifically, we will present the SWAT results on change in surface and groundwater quality and soil erosion in the study area.

6.5.1 Environmental impacts from feedstock production

6.5.1.1 Switchgrass

Taking into account the switchgrass characteristics mentioned earlier, conversion of land from rice region into switchgrass could result in following benefits: reduced soil erosion; reduced surface and subsurface fertilizer and herbicide/pesticide migration; improved surface and ground water quality; increased wildlife habitat; reduced emissions of global warming gases and carbon sequestering in root systems that are more extensive than annual crops; restoration of degraded soils, and improve regional air quality by reducing SOx and NOx emissions (King et al., 1998). Several studies demonstrate environmental benefits of switchgrass production. For example, McLaughlin and Walsh (1998) show that environmental benefits of utilizing switchgrass as a renewable energy crop include improved soil conservation, improved energy gain and improved reductions in emissions of carbon dioxide. The erosion limiting capacity of perennial grasses contributes into addressing the soil erosion problem, which influences soil and water quality in agricultural areas around the world and is considered a major threat to a long-term crop production in the U.S. (Larson et al., 1983). In addition, perennial grasses increase the soil organic matter through their well-developed rooting systems (McLaughlin et al., 1994). Environmental and economic analyses of switchgrass production by Nelson (2001) demonstrates the significant reduction in sediment yield (99%), edge-of-field erosion (98%), and surface runoff (55%) as a result of planting switchgrass on cropland in the Delaware Basin in northeast Kansas.

6.5.1.2 Sugarcane

Unlike switchgrass, “sugarcane is a biomass-producing crop that requires substantial input of both water and nitrogen to achieve maximum yields” (Wiedenfeld, 1995, p. 101). “Lysimeter studies (Thompson, 1976) carried out in the 1960s determined an empirical sugarcane yield/water use relationship, which roughly equates to 10 mm of water producing a yield of 1.0 ton of cane per hectare. A crop of sugarcane will require in the region of 1100-2000 mm of water depending on the local climatic factors and crop age” (James, 2004, p. 122). This water demand can be met through rainfall, irrigation, or combination of both. “The ideal environment for sugarcane is one in which rainfall (or irrigation) is well distributed during the growing season, but where the preharvest ripening period is relatively dry, and the sunshine hours are plentiful throughout the whole season” (James, 2004, p. 16). East Texas, where average annual rainfall is 44.2 inches could be a favorable region for sugarcane production, however, sugarcane does not perform well under continued wet conditions and together with clay soils in the region would require a superior drainage system (Rister et al., 1999). In addition, about 140,600 pounds of herbicide is used in Texas in sugarcane production which averages around 3.3 pounds per acre per year (Smith, 2003). The sugarcane farm chemicals such as pesticides and herbicides, fertilizers and soil particles, which are carried by storm and irrigation runoff to the natural water courses and coastal zones, can have negative impacts on the surrounding natural habitat.

6.5.1.3 Logging residues

"The connection between forests and water is complex and varies with topography, geology, climate and vegetation" (Moore, 1999, p. 1). Some forest management practices can significantly affect water quality and hydrology through runoff, erosion, stream flow, etc. In particular, logging activities and further removal of logging residues from the site can potentially affect stream ecosystems through altered inputs of organic matter such as leaf and needle fragments and debris as well as large woody debris (Moore, 1999). In addition, the most problematic aspect of complete biomass removal is the risk of excessive nutrient loss and the effect this has on future stand growth (see for example, Anderson, 1985; Hakkila, 1989; Hendrickson, 1988; Stuart et al., 1981; Van Hook et al., 1982). Existing literature provides different views on this issue. For example, Tiarks et al. (2004) argue that it is important to retain logging residue on the site for supporting long-term productivity. They show that retaining all aboveground biomass positively impact the tree growth increasing the volume of the pines in Central Louisiana forest by about 10 m^3. Findings vary for the influence of residue retention on soil nutrient dynamics. Some studies show little or no impact of residue retention on the soil nutrients (Proe & Dutch, 1994; Smith et al., 1994). Other studies report some positive effects from residue retention (see for more information O'Connell et al., 2004; Jurgensen et al., 1992; Smethurst & Nambiar, 1990). In many parts of the world, the current management policy is to leave a higher percentage of residues on site to recycle nutrients, reduce site disturbance, and eliminate accumulations of residues at roadside.

For example, new guidelines, commissioned by the new energy technology program "Wood Energy 1999-2003" launched in Finland, suggest that one third of harvesting residues should be left on site in final cuttings to provide the long-term nutrient balance in soil if ash is not recycled. In addition, several studies have reported that harvest residue retention has resulted in increased soil moisture (Smethurst & Nambiar, 1990; Blumfield & Xu, 2003; O'Connell et al., 2004; Roberts et al., 2005). Still another study by Roberts et al. (2005) found that residue retention results in cooler soil temperatures (see also Valentine, 1975; Smethurst & Nambiar, 1990; Powers, 2002) whereas residue removal exposes soils to greater soil temperature extremes (O'Connell, 2004). Overall, successful residue management can benefit the plantation through increased growth (Jones et al., 1999) reducing the need for fertilizer inputs, and benefiting the environment by reducing off-site effects.

In East Texas, 39 counties of the study region contain 11.5 million acres of forest with most forest acreage being classified as timberland. Current forest management is such that logging residues are left on the forest site for decay or are burned. Removing logging residues for the regional biomass energy purposes can have some environmental effects on the water quality, soil erosion, and soil nutrients. Hence, SWAT modeling tool was employed to evaluate these impacts and results are presented in the following section.

6.6 SWAT application to East Texas

The SWAT simulation model (Arnold et al., 1998; Neitsch et al., 2002) was adapted to simulate our scenarios of converting rice land to grow switchgrass and sugarcane, and remove logging residues from the forest site. The study region includes nine out of twenty-three major river basins in Texas, which spill into the Gulf of Mexico. These are the Sulphur, Red, Sabine, Neches, Neches-Trinity, Trinity, Trinity-San Jacinto, San Jacinto, and San Jacinto-Brazos River basins. The major Texas river basins are shown in the map created by the Texas Water Development Board (see Figure 10).

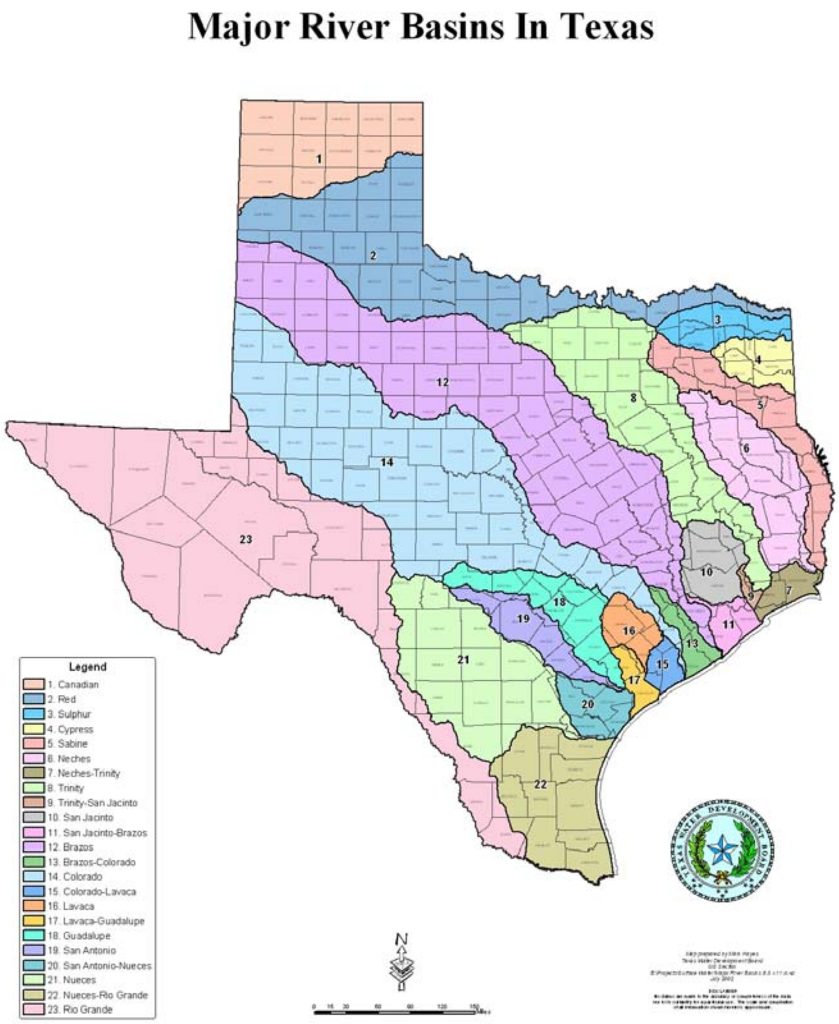

Figure 10. The major Texas river basins

(Source: Texas Water Development Board, 2005)

In SWAT, these river basins are delineated into smaller sub-basins which are further delineated into individual HRUs. We used the “Surf Your Watershed” option available at the U.S. EPA website (http://www.epa.gov/surf/) to determine the watersheds that our rice and forest counties cross. We then matched our county watersheds with the HRUs determined for watersheds in the SWAT model. In the model, each HRU carries individual crop acreage. There were 14 HRUs corresponding to the rice counties and 34 HRUs corresponding to the forest counties. This allowed us to select the input files for the crop management by each HRU. We modified the crop and the management files to fit our scenarios. In particular, we added the Alamo switchgrass with the necessary physical parameters as a new crop into the crop file. In addition, we changed the rice parameters and management operation schedule once to run the switchgrass scenario and again for the sugarcane scenario. We also changed the forest management files to incorporate the scenario of removing two-third of logging residues from the forest site. To do this, we used the forest management files written for pine trees, as reference files, since the predominant forest-type group in East Texas is the loblolly-shortleaf pine type (Rosson, 1992). Historical climate data were available from 1962-2001, 40-year period. The list of parameters from the output.hru file that were of our interest to conduct the environmental analysis is given in Table 13.

Table 13. Annual SWAT parameters from comparative runs

SWAT-Variable	Description and Unit
1. PRECIP	Precipitation (mm H_2O)
2. PET	Potential evapotranspiration (mm H_2O)
3. ET	Actual evapotranspiration (mm H_2O)
4. SNOFALL	Precipitation falling as snow (mm H_2O)
5. SNOMELT	Snow or ice melting (mm H_2O)
6. IRR	Irrigation (mm H_2O)
7. WYLD	Water yield (mm H_2O)
8. SURQ	Surface runoff to stream flow (mm H_2O)
9. SYLD	Sediment yield (mtons/ha)
10. ORGN	Organic nitrogen transported out of the HRU (kg N/ha)
11. ORGP	Organic phosphorus transported with sediment (kg P/ha)
12. SEDP	Sediment P yield (kg P/ha)
13. NSURQ	NO_3 surface runoff (kg N/ha)
14. NO_3GW	NO_3 transported in the groundwater loading from the HRU (kg N/ha)
15. SOLP	Soluble P yield, transported by surface runoff (kg P/ha)

6.6.1 Case of switchgrass and sugarcane

The main goal of this analysis was to determine the impacts on sediment yield, surface runoff, and nitrogen and phosphorus in surface and groundwater runoff as a result of growing switchgrass and sugarcane on land previously used to grow rice (Chambers, Galveston, Hardin, Harris, Jefferson, Liberty, and Orange counties). The rice counties reside within the Neches-Trinity, Trinity, Trinity-San Jacinto, San Jacinto, and San Jacinto-Brazos River Basins. The analysis was based on the 1962-2001 40-year modeling period. We first ran the SWAT model to establish a "baseline" scenario for all 14 HRUs that comprise the rice region. Then we ran modified SWAT scenarios for switchgrass and sugarcane on the same acreage. Annual averages were simulated and calculated over the 40-year period for the eight environmental variables listed in the table above (variables 8-15). Further, each of the environmental variables was multiplied by the number of acres within each particular HRU to calculate the “acreage-weighted” values. We kept the watershed names for selected HRUs to keep the “county-watershed” link. Table C-1 in Appendix C presents the simulation model results for all HRUs in the study area.

As can be seen from the data presented in Table C-1, switchgrass production on rice land provides significant reduction in all eight environmental variables in almost all HRUs. Reduction in average surface runoff ranged from 20.7% (East Fork San Jacinto watershed) to 79.6% (Sabine Lake watershed) with slight increase in few HRUs. The average surface runoff increase was estimated for HRUs in Lower Sabine (1.2%), Lower Trinity-Kickapoo (1.6%), and West Fork San Jacinto (1.7%) watersheds. The decrease in average surface runoff is due to strong switchgrass stem and root systems, which hold onto soil and prevent erosion, slow runoff, and stabilize soil. The increase in runoff in Lower Sabine, Lower Trinity-Kickapoo, and West Fork San Jacinto watersheds could be a result of the first year establishment of switchgrass and the quality of soil in these HRUs. However, the results for these HRUs may improve over the years of switchgrass stand and growth. The superior qualities of switchgrass also explain a decrease in sediment yield, which ranges from 69.4% to 93.4% in comparison with the base-line scenario. The decrease of 69.4% was estimated for the West Galveston Bay watershed HRU, whereas the highest decrease of 93.4% was estimated for the HRU in the San

Jacinto watershed. As switchgrass requires a very low fertilizer application, it substantially reduces the amount of nitrogen and phosphorus content of surface and ground water contributing to the water quality improvement. For example, reduction in average amount of nitrate (NO_3) surface runoff ranges between 46.7% (San Jacinto watershed) and 83.3% (Sabine Lake watershed). NO_3 transported in the groundwater loading from the HRU decreases substantially in comparison with the rice case and is in the range of 79.4% (Pine Island Bayou watershed) to 97% (San Jacinto watershed). The highest reduction in average annual amount of organic nitrogen transported out of the HRUs is in the HRU within the Lower Neches watershed, 98.8% less than the base-line scenario. The amount of organic nitrogen transported out of the HRUs is 87.6% less than the rice case. Reduction in organic phosphorus transported outside the HRU with sediment falls into a high range of 86.9% for the HRU in North Galveston Bay and 99% for the HRU in Lower Neches watershed.

Sugarcane results show that it also contributes to the reduction of soil erosion and water contamination in the study region, although it does not perform as well as switchgrass for some of the variables. For example, reduction in surface runoff ranges from 0.5% in North Galveston Bay to 48.0% in Sabine Lake watershed. However, surface runoff increased significantly in Lower Sabine watershed (59.5%) and slightly in Pine Island Bayou (2.1%), Lower Trinity Kickapoo (0.6), West Fork San Jacinto (1.0%), and Spring (3.15) watersheds. The simulation results indicate that growing sugarcane on rice land presents benefits in terms of decreased sediment yield and amount of organic nitrogen and phosphorus transported by surface runoff out of the HRUs. Average sediment yield decreases in all HRUs ranging from 47.7% (North Galveston Bay watershed) to 95.7% (East Fork San Jacinto). This reduction is sediment yield can be explained by the characteristics of sugarcane root growth as a perennial crop. For some sugarcane varieties, roots can grow 3-6 m deep holding onto soil and providing stability (James, 2004). Average organic nitrogen transported out of HRUs decreased significantly ranging from 87.2% (Sabine Lake watershed) to 98.1% (West Fork San Jacinto watershed). However, since sugarcane, unlike switchgrass, requires substantial phosphorus application soluble mineral forms of phosphorus transported by surface runoff increase significantly in nearly all HRUs ranging from 6.2% in Lower Sabine to 215.5 % in Lower Trinity-Kickapoo watershed. The wide range of the increase could be due to factors such as soil mineral content, cultivation, crop type, and moisture content.

Overall, the results reveal that production of biomass crops switchgrass and sugarcane on rice land in East Texas would provide significant reduction in almost all water quality and other environmental variables considered in this analysis. In turn, this would improve the surface and ground water quality in the region along with reducing the soil erosion, which is detrimental for agricultural land and creates significant problems for farmers. Finally, it should be mentioned here that the potential net effect of these energy crops on overall fertilizer use and nutrient runoff is difficult to assess until commercial production begins.

6.6.2 Logging residues

As was discussed in earlier sections, existing literature offers different views regarding the impacts of removing logging residues on erosion, sediment yield, surface runoff, and water quality. In this study, in order to reduce the potential adverse effects caused by removal of residues, we assumed that only two thirds of the residues was collected from the forest sites leaving one third of it on the fields to provide soil nutrition for future increase in production.

Further analysis is performed similar to switchgrass and sugarcane cases discussed above. The same environmental variables as above were of interest under the scenario of removing logging residues. The thirty nine forest rich counties (Anderson, Angelina, Bowie, Camp, Cass, Chambers, Cherokee, Franklin, Gregg, Hardin, Harris, Harrison, Henderson, Houston, Jasper, Jefferson, Liberty, Marion, Montgomery, Morris, Nacogdoches, Newton, Orange, Panola, Polk, Red River, Rusk, Sabine, San Augustine, San Jacinto, Shelby, Smith, Titus, Trinity, Tyler, Upshur, Van Zandt, Wood, Walker) reside in nine river basins including the Sulphur, Cypress, Sabine, Neches, Neches-Trinity, Trinity, Trinity-San Jacinto, San Jacinto, and San Jacinto-Brazos river basins. Thirty-four HRUs capturing our region were selected from the model. The simulation was based on the 1962-2001 40-year modeling period. We first ran the SWAT model to establish a “baseline” scenario of leaving logging residue on forest floor for all 34 HRUs. Then we ran the modified SWAT scenario of removing two-third of logging residues from the forest sites. Annual averages were simulated and calculated over the 40-year period for the eight environmental variables listed in Table 13 (variables 8-15). Further, each of the environmental variables was multiplied by the number of acres within each particular HRU to calculate the “acreage-weighted” values (Appendix D presents the simulation model results for all 34 HRUs in the study area).

SWAT model simulations delivered mixed results partially supporting our anticipation of the impacts of removing the residues from forest sites on soil and water quality. Specifically, we anticipated that removing residues would increase the surface water runoff, as there would be less biomass blocking the water flow. Increase in this variable ranged from one to over ten percent with the highest of 10.3% in HRU within the Bois D'arc-Island watershed (Red River County). Further, we anticipated that erosion and sediment yield would increase, as soils washed away from the forest site would flow without obstacles on their way. Increase in these variables ranged from over 3% in Upper Sabine watershed to over 18% in White Oak Bayou and Lower Neches watersheds. Moreover, surface runoff was expected to carry away some amount of nitrogen and phosphorus that was applied to the area to increase the forest production. As a result, the amount of nitrogen and nitrates that percolates to the ground water would decrease. Expected decrease ranged between 3% (East Galveston Bay watershed) and 28% in HRU within the Upper Sabine watershed. In addition, since one-third of the residues was assumed to be left on the site, not a significant amount of these chemicals was expected to be transported away meaning that soils would contain some nutrients to support the future forest production. This assumption, however, did not hold for several HRUs where the amount of nitrogen runoff from the HRUs was almost twice the amount of the baseline condition. This was the case for the HRUs within Lower Neches, Lower Angelina, Village, Pine Island Bayou, Lower Trinity-Kickapoo, and the East Fork San Jacinto watersheds. This could be explained by the total amount of fertilizers applied to the area, by greater concentration of these nutrients in the tree species growing in the forests and quality of soils. This assumption did not hold also for HRUs in few other watersheds (Mckinney-Posten Bayous, Bayou Pierre, Lower Sulphur, and Caddo Lake watersheds) where amount of chemical runoff slightly decreased in comparison with the baseline scenario, which again could be due to soil type, the initial application of these fertilizers, the amount of rainfall, and other climate conditions in these watersheds.

Overall, the results reveal that removing logging residues from the forest site in East Texas would increase the surface runoff, sediment yield and the amount of nitrogen and phosphorus transported outside the HRUs, but would decrease the level of nitrate in ground water. However, since the scenario considers leaving one-third of residues on the forest site the increase in these variables is not significant for most of the HRUs. This analysis allows the conclusion that removing two-third of logging residues from the forest sites for use in energy production may not have a significant negative environmental impact on the study region except for several HRUs. As there is no consensus reached in the field regarding the effects of removing logging residues on erosion, nutrients, and water quality, additional research into this issue could provide stronger scientific results.

6.7 Conclusions

Our analysis of feedstock production indicates that based on the assumptions made for switchgrass production, the Alamo switchgrass cost budget amounts to $124.64 per acre, or $28.78 per ton. This estimated cost includes the establishment, maintenance, and harvesting processes and does not include transportation related costs. The projected negative net economic returns of $10.50 per acre of sugarcane appear not to be an attractive alternative for rice farmers. In addition, the yield uncertainty and other concerns (soil types, irrigation, weather conditions, yield variability, disease outbreaks, high machinery costs, etc.) could further increase the cost. Therefore, it is doubtful that farmers would decide to switch their rice land to grow sugarcane without making profits. Also, lack of an existing sugar mill in the region reduces the sugarcane potential as an alternative crop since building a new mill or purchasing it would bring additional cost considerations. However, assuming that the region has a sugar mill and the market conditions are favorable for farmers to switch land to grow sugarcane, sugarcane bagasse could be considered as another source of cellulosic feedstock for bioenergy generation in the region. The analysis of logging residue availability indicates that the study region has a potential to supply significant amount of logging residues for biofuels generating purposes. In fact, the estimated amount of logging residues could potentially support up to three 100 MW power plants.

The GHG emissions associated with the switchgrass preparation and collection of logging residues were quantified. The GHG emissions related to switchgrass production amounted to 106.3 grams/kg, and for logging residues, they yield 11 grams/kg. Environmental impacts from shifting large rice lands to grow perennial grasses switchgrass and sugarcane or removing logging residues from the forest sites were evaluated applying the SWAT model. The model results demonstrate that switchgrass production on rice land provides significant reduction in all selected environmental variables nearly in all HRUs. Reduction in average surface runoff and in the amount of nitrogen and phosphorus content of surface and ground water is due to superior characteristics of switchgrass as a herbaceous crop which has strong stem and root systems and requires a very low fertilizer application. Sugarcane results show that growing it on the rice land also presents benefits in terms of decreased sediment yield and amount of organic nitrogen and phosphorus transported by surface runoff out of the HRUs. However, since sugarcane, unlike switchgrass, requires substantial phosphorus application soluble mineral forms of phosphorus transported by surface runoff increase significantly in every HRU. Finally, our results indicate that removing logging residues from the forest site would increase the surface runoff, sediment yield and the amount of nitrogen and phosphorus transported outside the HRUs, but would decrease the level of nitrate in ground water. However, since the scenario considers leaving one-third of residues on the forest site the increase in these variables is not significant for most of the HRUs. Therefore, that removing two-third of logging residues for use in energy production may not have a significant negative environmental impact except for few HRUs.

CHAPTER VII

ELECTRIC POWER GENERATION

7.1 Introduction

This chapter analyzes various biomass power generating scenarios for a 100 MW power plant in East Texas. We will consider two combustion alternatives here: direct combustion and various co-firing cases. Specifically, we will investigate the biomass potential of East Texas to support a 100 MW power plant and its economic, environmental, and social implications for the region. Co-firing scenarios will include co-firing coal with switchgrass, sugarcane bagasse, and logging residues at 5% -, 10% -, and 15% ratios.

Previous chapters discussed the feedstock availability, yields, and costs. We now turn to hauling the required amounts of feedstocks from a farm and forest site to a power generating plant and will derive the hauling distance and costs, greenhouse gases emitted during biomass transportation and combustion, and discuss environmental issues related to power generation such as resource savings. Construction of a new power plant versus retrofitting existing plant to add biomass to the process will be also discussed. East Texas feedstock potential will be examined for biomass fired alone and all co-firing cases. Finally, social impacts, which include health risks related to fossil fuel emissions from power plants and local job creation, are evaluated.

7.2 Feedstock requirements

Annual feedstock requirements are estimated for a 100 MW power generating plant for all feedstocks. We utilize the assumption made in McCarl et al. (2000) that a 100 MW power plant's annual energy requirement is seven trillion BTUs (TBTUs). In addition, the following Higher Heating Values (HHV) and moisture levels (see Table 14) were applied to calculate the amounts of feedstocks that would provide seven TBTUs to the 100 MW power plant annually:

Table 14. Higher Heating Values (HHV) and moisture levels for switchgrass, sugarcane bagasse and the logging residues

Biomass	HHV	HHV units	Moisture Percent	Source
Switchgrass	15,991	kJ/kg wet	11.99%	Sami et al. 2001
Bagasse	18,950	kJ/kg dry	45.0%	Kadam. 2000
Softwood Logging Residues	9,000	BTU/lb dry	50.0%	Black & Veatch Coporation. 2004 Asikainen and Pulkkinen. 1998
Hardwood Logging Residues	8,000	BTU/lb dry	50.0%	Black & Veatch Coporation. 2004 Asikainen and Pulkkinen. 1998

We also applied the conversion factors of 0.9478171 BTU per kJ (kiloJoules), 907.18474 kg per ton (short, US), and 1.1023113 ton (short, US) per tonne to the information given in the table above to adjust the quantities of required biomass to the biomass moisture levels and to receive the final feedstock amounts in wet tons. Table 15 summarizes the feedstock requirements of the plant.

Table 15: Feedstock requirement for a 100 MW power plant (biomass fired alone case)

Feedstock	BTU/ton	Wet Tons
Switchgrass	13,749,785	509,099
Bagasse	14,901,117	854,115
Logging Residues	9,000,000	777,778

Subsequently, the amount of feedstocks required for 5%-, 10%-, and 15% co-firing scenarios is as given in Table 16:

Table 16: Annual amount of feedstocks required for co-firing scenarios

Feedstock (wet tons)	5% co-firing	10% co-firing	15% co-firing
Switchgrass	25,455.0	50,909.9	76,364.9
Bagasse	42,705.9	85,411.5	128,117.3
Logging Residues	38,888.9	77,777.8	116,666.7

7.3 Feedstock hauling distance

As was mentioned in the previous chapter, the hauling distances are derived using the formula (2) from Chapter VI. Switchgrass average hauling distance was calculated using the feedstock required mass of 509,099 tons, yield of 4.33 tons/acre and the 10% density. The density of 10% is an assumption since in Texas growing switchgrass is still in an experimental stage, therefore no actual density data exists. This assumption is reasonable because in order for farmer to participate in the bioenergy program and intensively supply biomass to a biorefinery the density of the energy crop should be higher than the density of most of the conventional crops in the region. Currently, in Texas the density of conventional crops is relatively low, such as, for example, 1.6 % for corn, 1.1% for wheat and 2.2% for rice, as estimated by Forest and Agricultural Sector Optimization Model Greenhouse Gas version (FASOMGHG) (Alig et al., 2005). On the other hand, conventional crops (corn and grain) in the MidWest region, which is heavily involved in testing the potential of biomass feedstocks, the crop densities range from 12 to 20 %. Furthermore, because of the lack of actual yield data, we assume that all counties, which may grow switchgrass, have the same yield of 4.33 tons/acre and therefore the average hauling distance is same for all counties. Switchgrass average hauling distances for fired alone and all co-firing cases are presented in Table 17:

Table 17. Switchgrass average hauling distances

Firing scenarios	Average hauling distance (miles)
100% Switchgrass	20.20
5% - mass input	4.52
10% - mass input	6.39
15% - mass input	7.82

Bagasse as a byproduct of the sugar producing process is used at the sugar mill to generate electricity and therefore does not have any hauling distance attached.

For logging residues, the yields and feedstock requirements were derived in earlier sections. The biomass densities of 3.5% and 1.2% for softwood and hardwood residues, respectively, that we adopt here, were estimated by FASOMGHG (Alig et al., 2005) for the U.S. South Central region which includes Texas. In estimating these densities, FASOMGHG calculated a weighted average stand rotation from the model rotation data weighted by FASOM forest inventory. One was divided by the average stand rotation and the result was multiplied by 0.8 yielding the logging residue densities. The 0.8 is the practical forest density for forestlands as determined from the map, Forest Density in the Conterminous U.S., U.S. Environmental Protection Agency (Figure 11).

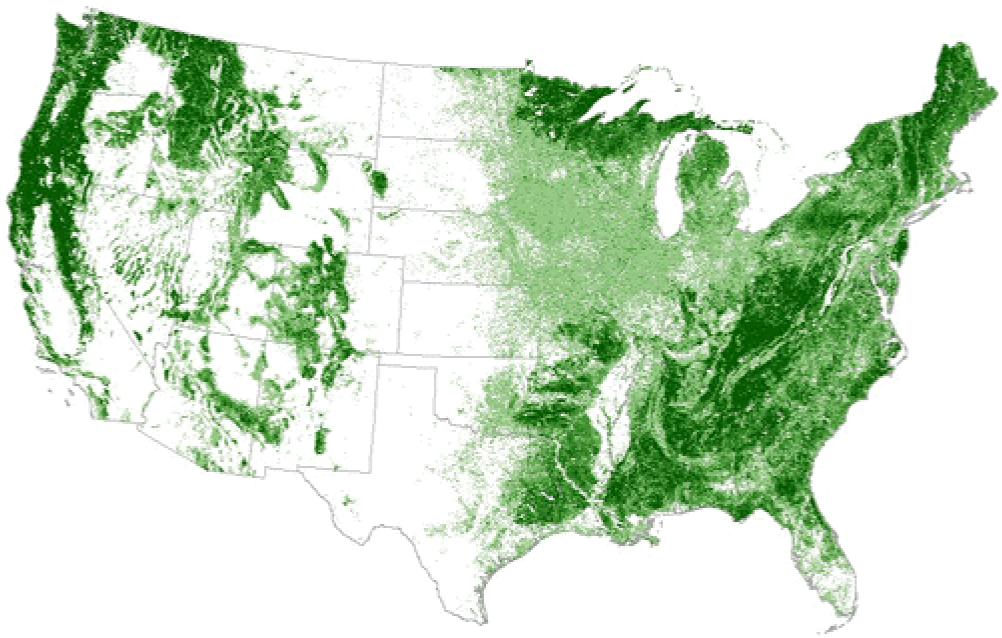

Figure 11. Forest Density in the Conterminous U.S. (Source: U.S. EPA, 1991)

As logging residue yields were derived individually for each county, the hauling distances calculated here vary from county to county. Table 18 summarizes the average hauling distances for logging residues, which we grouped into distance ranges. The complete list of the estimated hauling distances for logging residues, softwood and hardwood, by county are presented in Appendix E.

The county-by-county comparison of hauling distances reveals a very wide range of results. For example, the shortest distance for softwood residues was obtained for San Augustine County (122 miles) and the longest was the distance for Van Zandt County (982 miles). For hardwood residues, the shortest distance was calculated for Jefferson County (291 miles) with the longest one being for Walker County (1092 miles).

Table 18. Average hauling distance for softwood and hardwood logging residues

Softwood residue		Hardwood residue	
Group range (miles)	Number of counties	Group range (miles)	Number of counties
100-200	19	300-500	19
200-300	12	500-700	12
300-500	4	700-900	5
Above 500	2	Above 900	1

Some of the estimated hauling distances are quite large and would require traveling outside the state boundaries to collect the biomass material. In addition, these distances would cause the transportation costs go up significantly. Therefore, we will assume that only average hauling distances up to 200 miles will be accepted in the analysis. Based on the results presented in Table 18, this means that only 19 counties (see Appendix E) can be considered as providing biomass from softwood residues and none of the counties could supply hardwood residues.

As co-firing biomass with coal at 5-, 10- and 15% mass input requires significantly less amount of feedstocks the average hauling distances are relatively shorter, more so for softwood than hardwood residues. Table 19 presents the hauling distance ranges for both residue species (Appendix E contains the calculated distances for all counties). As it was mentioned above, we will assume that only counties with hauling distances up to 200 miles will be considered for biomass collection for each co-firing case.

Table 19. Range of the average hauling distances for softwood and hardwood residues (miles)

Logging residue distance	5% co-firing	10% co-firing	15% co-firing
Softwood			
Min	27	38	47
Max	220	310	380
Hardwood			
Min	65	92	112
Max	244	345	423

Note that for softwood residues, at 5% co-firing all counties except Van Zandt (220 miles) have hauling distances less than 200 miles. At 10% co-firing, Franklin (282 miles) and Van Zandt (311 miles) counties fall beyond 200-mile limit. Finally, at 15% co-firing, there are three counties with the distance above 200 miles. These are Franklin (346 miles), Titus (201 miles), and Van Zandt (380 miles) counties. For hardwood residues, the number of counties with the hauling distances larger than 200 miles is even bigger. For example, at 5% co-firing only Chambers (226 miles) and Walker (244 miles) counties have hauling distances greater than 200 miles. At 10% co-firing, there are seven counties and at 15% co-firing there are 16 counties, which meet the 200-mile limit and therefore are included in the analysis (see Table E-2 in Appendix E for these counties).

7.4 Feedstock hauling costs

Transportation from a farm to a plant gate represents a significant cost of the energy generating process. The larger the plant and the more spreadout the resource, the greater the impact on transportation cost (King et al., 1998). The cost of hauling biomass from a farm to a power plant is largely a function of the hauling distance, and it increases as the hauling distance increases. In the case of co-firing coal with biomass, increasing the co-firing ratio will also increase the hauling cost, as it will require collecting biomass within a larger radius from the power plant.

Several studies have investigated the hauling cost for various feedstocks. For instance, Noon et al. (1996) estimated the average switchgrass transportation cost in Alabama to be $8.00/dry tonne for 25 miles hauling distance. Graham and others at Oak Ridge National Laboratory evaluated the cost of delivering wood chips to different size plants in Tennessee. Their hauling cost estimates ranged from $7 to $16 per dry ton, accounting for 18 to 29% of plant gate cost (Graham et al., 1997). Switchgrass transportation costs were estimated for soil parcels within 50 miles of the plant (in Kansas), based on a fixed $4.00/ton load/unload fee plus ten cents per ton-mile (King et al., 1998). Still another study by Kerstetter et al. (2001) showed that transportation costs for the rice straw feedstock were computed as a fixed cost of $5.50 plus a cost of $0.088 per mile. With these costs, a 50-mile haul cost would be about $10/ton, which was typical of what is found in the Pacific Northwest.

Three different feedstocks examined in this study have different hauling distance and transportation considerations. Hence, the hauling costs are estimated differently for each case. Note, as we discussed earlier, that bagasse as a byproduct of sugar production process is not transported to a power plant but is burned at sugar mill to generate electricity for further support of the sugar production processes. Therefore, bagasse has no hauling distance and cost parameters attached. Further discussion is related only to switchgrass and logging residue hauling costs.

Hauling costs per ton of biomass were calculated utilizing the formula derived in McCarl et al. (2000)**:**

$$HC = (FC + 2 * AD * CM) / LS \qquad (3)$$

where

HC is a hauling cost

FC is a fixed load cost

AD is an average distance

CM is a per mile cost

LS is a load size.

We derived the average hauling distances for switchgrass and logging residues in the previous section. Here, we assume the truckload size to be 14 and 25 tons for switchgrass and logging residues, respectively.

Switchgrass per mile cost was calculated at $1.87/mile using the hauling scenario parameters assumed in Qin et al. (2006). Based on these parameters, per mile cost calculation included all fixed, variable and labor costs associated with the hauling process. Thus, it would cost $5.40/ton to haul switchgrass to a power plant, or $75.55 per truckload.

The hauling cost parameters (fixed load cost and cost per mile) for logging residues were taken from the Forest Residues Transportation Costing Model (FRTCM), which we used to estimate logging residue GHG emissions in Chapter VI. We assumed that residue was loaded by a knucleboom loader into a container truck and hauled 2.5 miles to a disk chipper for chipping. Then, the disk chipper was directly loading chipped residue to a 120 cubic yard van-type truck, which was then transported to a bioenergy producing facility. This model was amended to produce costs per mile from its standard model results. Similar to switchgrass, the per mile cost calculations included fixed, variable and labor costs. Calculated per mile costs for forest counties ranged from $1.14 to $1.26 per mile with smaller costs corresponding to distances of 200 miles and longer. The hauling costs obtained using these per mile costs show a wide range mainly because of the hauling distances that we derived earlier. For example, in biomass fired alone case the hauling cost ranges between $12.30 (hauling distance 122 miles) and $18.24 (hauling distance 200 miles) per ton for softwood residues. This translates to $307.50 - $456.0 per truckload. The hauling distances for co-firing cases were relatively shorter as co-firing cases require less biomass input, therefore the hauling costs fall into a smaller range. Table 20 contains the hauling cost ranges for co-firing cases for soft- and hardwood residues, which were derived using average hauling distances presented in Table 18.

Table 20. Hauling costs for co-firing cases ($/ton)

Logging Residues	5% co-firing	10% co-firing	15% co-firing
Softwoods	11.43 – 26.95	12.54 – 26.95	13.45 – 26.95
Hardwoods	15.26 – 26.95	17.98 – 26.95	20.00 – 26.95

The cost of $26.95 corresponds to the maximum distance of 200 miles that is being set for all power plant scenarios. The hauling costs per ton were then multiplied by the required biomass quantity to determine the annual hauling cost for supplying logging residue biomass to the 100 MW power plant. The annual hauling costs for biomass fired alone scenario were in the range of $9.57 - $14.19 millions. Co-firing cases were calculated in a similar way. Note that the wide range of annual hauling costs for all scenarios is due to a large variation in the hauling distances calculated in the earlier section. Results are presented in Table 21.

Table 21. Annual biomass hauling costs (millions of U.S. dollars)

Electricity Production Scenarios	Annual Hauling Costs		
	Switchgrass	Logging Residues	
		Softwood	Hardwood
Biomass fired alone	2.75	9.56 – 14.19	-
5% co-firing	0.61	0.44 - 1.04	0.59 - 1.04
10% co-firing	0.87	0.98 - 2.09	1.4 – 2.09
15% co-firing	1.06	1.57 - 3.14	2.3 - 3.14

7.5 Biomass fired alone

Currently application of biomass as the sole source of fuel for power plants with large capacity is not common or economical (Qin et al., 2006). In addition, biomass feedstocks have higher volatility, lower sulfur, and ash content, and a lower heating value compared to coal. Some biomass can have a relatively high alkaline metal content, and are rich in chlorine and silica (King et al., 1998). This nature of biomass brings other problems to power generation such as slagging and fouling which make the biomass-only case a less attractive investment alternative.

7.5.1 Annual feedstock costs at the power plant gate

As was mentioned earlier, a 100 MW power plant requires about seven trillion BTUs and this in turn would require burning 509,099 tons of switchgrass, 875,000 tons of bagasse, or 777,778 tons of logging residues. Based on our estimations of biomass production and hauling costs, the cost of a ton of biomass feedstocks delivered to the power plant would be: $34.18 for switchgrass; a range between $21.01- $26.95 for a ton of softwood residues. We multiplied these per ton feedstock costs by the tons of required amount of biomass to derive the annual biomass costs at the power plant gate. The results are $17.4 millions for switchgrass; a range of $16.34 - $20.96 millions for softwood logging residues.

7.5.2 Switchgrass and logging residue costs versus coal cost

Switchgrass and logging residues will be used for electricity generation only if they are competitive with coal. Currently switchgrass is not cost competitive with coal. Figure 12 shows the breakeven cost of switchgrass and coal at 5% and 15% co-firing. Taking the average coal cost of $27.30/ton (EIA, 2005), the breakeven switchgrass cost must be about $19.61/ton and $21.58/ton at the two co-firing ratios, respectively, which is much lower than the real cost of $34.18/ton estimated in this study. Switchgrass only matches up when the cost of coal reaches $48-$50 for these cases, which is almost two times the current average coal cost.

In this analysis, logging residue costs were estimated between $21.01- $26.95 per ton. Costs increase with the increase in the co-firing ratio which is explained by increase in required amount of biomass and therefore in the biomass hauling distance. These costs are competitive with coal cost of $27.30/ton since we assumed that average hauling distances are up to 200 miles. For all distances greater than 200 miles, logging residue costs will be more expensive than coal.

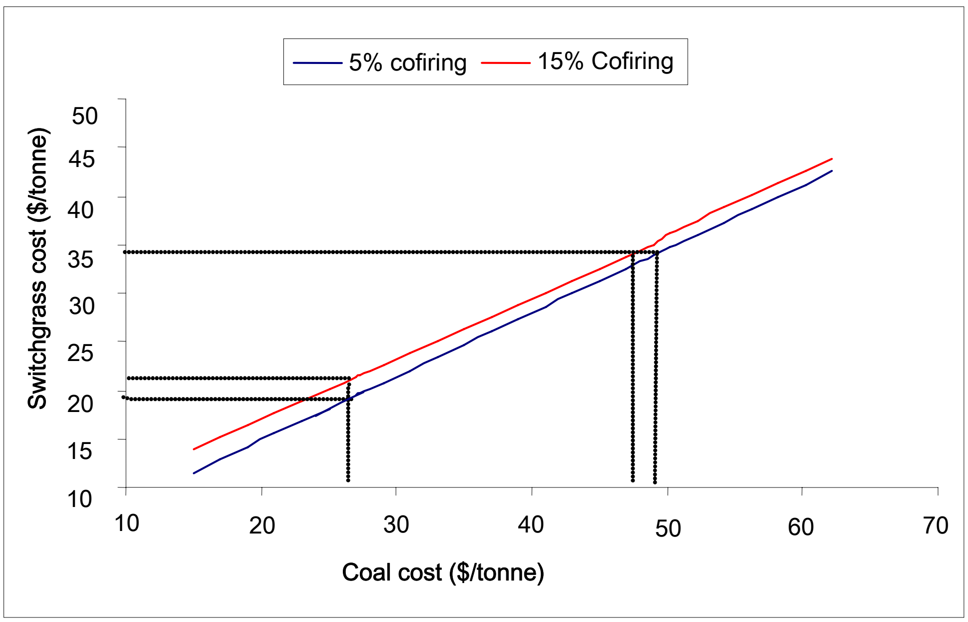

Figure 12. Switchgrass and coal cost breakeven.

7.5.3 East Texas feedstock potential for power generation

Comparison of the biomass availability in East Texas counties with the biomass requirements of the 100 MW power plant reveals that if rice growing counties decided to switch land to switchgrass, individually they would not be able to supply the required amount of biomass to keep the plant running. Furthermore, these counties would not be able to support the power plant even if they jointly supplied their annual switchgrass production. The total amount of joint annual switchgrass production tops 215,088.42 tons from 49,674 acres, which is almost 2.4 times less than the plant requirement of 509,099 tons. The total amount of joint annual bagasse production that could be available in these counties is 526,582 tons, which also falls short of 875,000 required tons. If we consider adding the acreage from other agricultural crops discussed earlier, which will bring the total acreage to 85,574 acres, the annual switchgrass production will rise to 370,535.42 tons, which is still 1.4 times less than the annual biomass required by the power plant. However, the extended acreage could provide about 909,652 tons of bagasse, which is slightly over the power plant requirement.

This analysis indicates that East Texas rice producing counties currently cannot supply sufficient amount of switchgrass to support the 100 MW biomass-alone power plant. This is true for switchgrass even when other crop acreage is added. The initial acreage cannot provide enough bagasse either. However, the acreage expansion improves the situation for bagasse supplying more than required biomass for the power plant operations. Hence, if rice is replaced by sugarcane the biomass capacity of the rice counties could support only one power plant based on a single biomass source, i.e. bagasse.

In contrast, our estimates of logging residues indicate that although the 39 counties rich in forest land would not be able to individually supply the required amount of logging residues (777,778 tons), they could jointly generate about 2.3 million tons of residue biomass which could potentially support up to three 100 MW plants in the region. However, significantly large average hauling distances estimated for some of the counties in Chapter VII show that transportation cost could be a main obstacle in delivering feedstock to the power plant in these counties. In addition, choosing a location for a power plant, which would minimize the feedstock hauling costs and be economically feasible, may be a significant challenge. In the long run, the technological improvements and/or possible increase in biomass availability, which would reduce the biomass feedstock and transportation costs, could make this alternative viable for all counties. In this case, construction of a biomass-alone power plant in East Texas will require several important considerations. For example, the feedstock availability analysis showed that among counties with large annual amount of logging residues (over 100,000 tons) are Tyler (168,588 tons), Polk (152,295 tons), Jasper (151,969 tons), Cass (127,500 tons), Angelina (112,071 tons), and Newton (103,331 tons). All these counties, except for Cass, are located around Tyler County. In addition, Tyler County is surrounded by several other counties (e.g. Hardin, Harrison, Nacogdoches, San Augustine, and Trinity) which could be considered as the second large suppliers of logging residues. Assuming that the biomass feedstock is uniformly spread over the forest acreage of these counties, a potential location for the power plant could be proposed in the Tyler County. Moreover, the advantage of locating the plant in the Tyler County is that the plant could consider receiving a mix of biomass feedstocks, the second biomass feedstock being switchgrass or sugarcane bagasse from the closely located counties (Liberty, Jefferson, and Orange). These three counties could also add to the pool of logging residues, although their amounts are smaller than the rest of the selected counties and the hauling distances are larger than 200 miles. Specifically, Liberty County could supply 52,011 tons, Jefferson County 17,738 tons, and Orange County 16,135 tons of logging residues. Transportation distances for Tyler, Polk, Jasper, Newton, Hardin, Harrison, Nacogdoches, San Augustine, and Trinity are all less than 200 miles therefore this case assumes a potential for a biomass only power plant. In contrast, the Cass County, which is located in the northern part of the region, can provide 127,500 tons of logging residues. However, it is surrounded by counties that can supply relatively small amounts of logging residues. Assuming that the plant is located in Cass County, the following counties could be selected to supply the logging residues: Bowie (59,345 tons), Red River (38,351 tons), Morris (14,635 tons), Marion (59,224 tons), Harrison (93,662 tons); Upshur (24,403 tons), Gregg (18,340 tons), Camp (12,037 tons), Titus (11,183 tons), Franklin (2,636 tons), Wood (13,098 tons), Smith (40,675 tons), Rusk (75,543 tons), and Panola (83,683 tons). Together these counties could provide 674,315 tons of logging residue, which falls short of required amount by 103,463 tons. Biomass shortage along with significantly large hauling distances and high hauling costs would make this case not a viable option for a plant location in Cass County.

In summary, from the point of view of biomass availability, the biomass-alone power plant alternative appears viable only for logging residues and not an attractive alternative if switchgrass or sugarcane bagasse is selected as the plant feedstocks. Since biomass-alone power plants are not common and economical, as it was mentioned earlier, this presents co-firing as a more attractive alternative. Moreover, some recent studies proved that co-firing could also overcome the problems stemming from the biomass nature (e.g. slagging, fouling) and perhaps be environmentally beneficial (Boylan *et al*., 2000). Therefore, the co-firing case is discussed next.

7.6 Co-firing

King et al. (1998) note that co-firing of biomass in “retrofitted coal-fired power plants generally have higher efficiencies, lower capital requirements, and lower electricity costs than combusting the same fuels in dedicated biomass… plants” (p. 235). However, the local availability and cost of biomass feedstocks is the most important factor in determining the feasibility of co-firing at a specific location. In addition, the potential for co-firing biomass with an existing coal plant is highly dependent on the cost of transportation from the areas of lowest cost biomass production to coal plants selected for co-firing.

The following analysis is based on the retrofit of an existing coal fired boiler to allow the introduction of switchgrass, bagasse and logging residue biomass feed stream. We adjusted the biomass required, greenhouse gas emissions, and feedstock costs by the co-firing ratios. Co-firing budgets were created for all three biomass feedstocks at 5%, 10%, and 15% co-firing cases.

7.6.1 Annual feedstock costs at the power plant gate

The feedstock costs at the power plant gate are calculated based on the feedstock production and hauling costs that were estimated for our feedstocks in earlier sections.

For example, switchgrass per ton costs at the plant gate are $29.99 for 5%-, $30.49 for 10%- to $30.87 for 15% co-firing cases. Same costs for a ton of logging residues are between $20.14 - $35.66 for a ton of softwood residues and range between $23.97- $35.66 for a ton of hardwood residues. Note that the cost goes up as the co-firing ratio increases. This is mainly because of increasing hauling distance from the farm or forest site to the power plant gate related to increase in the required amount of biomass. Based on these costs the total cost of delivering the annual required amount of feedstock to the power plant is: $0.76 millions for 5%-, $1.55 millions for 10%- and $2.36 millions for 15% co-firing of switchgrass with coal and range between $0.78 – $4.16 for softwood and $0.9 – $4.16 millions hardwood logging residues.

7.6.2 Feedstock potential for co-firing cases

Analysis of feedstock potential for co-firing cases in the study region shows that the counties ranged differently in this respect. In the rice region, only Chambers, Jefferson, and Liberty counties demonstrate the adequate potential with regard to co-firing coal with 5% of switchgrass. At 10% co-firing, only Chambers and Jefferson counties, and only Jefferson County at 15% co-firing have a potential to support the power plant operations. In case of bagasse, again Chambers, Jefferson and Liberty counties show the potential for both 5% and 10% co-firing cases, whereas only Chambers and Jefferson counties can accommodate the 15% co-firing case. If the acreage from other agricultural crops is added in these counties, then Chambers, Harris and Liberty counties will have a feedstock potential to support the power plant operations for all three co-firing cases. The Liberty County especially stands out as its additional acreage could raise the switchgrass production up to 144,514 tons a year and production of bagasse up to 356,445 tons a year, which is significantly larger than the required biomass for co-firing cases.

Logging residue potential analysis indicate that only Cass, Jasper, Polk, and Tyler counties can supply sufficient amount of biomass for all three co-firing cases. Angelina, Cherokee, Hardin, Harrison, Nacogdoches, Newton, Panola, San Augustine, and Trinity counties present a potential for only 5% and 10% co-firing cases, and Houston, Liberty, Marion, Rusk, Sabine, Shelby, Smith, and Walker counties can supply biomass for only 5% co-firing case. In addition, Liberty and Jefferson counties could consider a mixed feedstock cases with switchgrass – logging residue or bagasse – logging residue combinations. The rest of the counties can provide biomass in very small amounts that cannot support any co-firing case.

Based on these results, existing power plants in these counties can consider switching to co-firing coal with biomass by modifying the plant to accommodate the biomass flow.

7.6.3 Switchgrass yield considerations

Discussion in the previous section showed that among feedstocks switchgrass cannot provide sufficient amount of biomass input to support the 100 MW power plant. Several things could change this situation: increase in switchgrass yield or available land. Another thing would be to consider the smaller size power plant, which would require less switchgrass input. The increase of available land demonstrated that extended acreage could not supply the required amount of switchgrass. The switchgrass production in this case yields 370,535.42 tons. We can now assume that switchgrass yield increases and is eight dry tons per acre. This is a reasonable assumption since this yield has been achieved at various experimental locations, including some regions in Texas for Alamo switchgrass. The yield of eight dry tons per acre translates to 9.09 wet tons per acre. Multiplying this yield by the initial acreage of 49,674 acres, we receive 451,537 tons per year of switchgrass production, which is still not enough for the power plant. This means that changing only yield while keeping all other factors constant does not increase the switchgrass supply in the region. Then trying the extended acreage of 85,572 acres gives an annual switchgrass production of 777,945 tons, which is now 1.5 times greater than the plant requirement of 509,099 tons. Therefore, we can conclude that agronomic research is needed to examine the potential to increase the switchgrass yield, which together with the extended acreage would provide larger amounts of this feedstock.

7.6.4 Cost of power plant modification

The modification cost for co-firing capability is $50-100/kW for blending feed and $175 200/kW for separate feed (kW of biomass power capacity) (Hughes et al., 2000). Qin et al. (2006) investigated the modification cost for a 100 MW boiler co-fired at 5%, 10% and 15%. Their results are considered directly appropriate for our analysis. The authors show that for a 100 MW boiler co-fired at 5%, which has a $200/kW, cost of capital modifications would amount $943,764.94. With a salvage value of 10% of initial value and a 10-year useful life, the straight-line depreciation cost per year per unit would be $0.85/kW/year, or $0.12/MWh (assuming 300 days of operation per year, and 24 hours operation per day). At 10% co-firing, the depreciation expense becomes \$0.24/MWh and at 15%, \$0.36/MWh.

7.7 GHG emissions from hauling biomass feedstocks

Greenhouse gases are emitted during the biomass feedstock establishment, maintenance, harvest, hauling, and combustion stages. Here we present estimates for emissions from hauling the feedstocks to a power plant. Switchgrass hauling emissions were adapted from Qin et al. (2006). In order to estimate the emissions from hauling logging residues we first determined the gallons of diesel required to haul a ton of harvested residues. This was done by dividing twice the average hauling distances that we estimated in earlier section by truck fuel efficiency, which was assumed at 5 miles per gallon, and the truckload size (25 tons). Results were then adjusted for the weight of diesel (3.2432 kg per gallon), converted into kilograms of diesel per kilogram of logging residues and multiplied by the following diesel emissions in grams per kilogram of diesel to arrive at emissions in grams per kilogram of feedstock: carbon dioxide, 3188.068; methane, 0.08; and nitrous oxide, 0.108 (Wang et al., 1999). Although the hauling distances for logging residues were calculated and grouped into approximately 100-mile range, we present emissions only for minimum and maximum hauling distances, as examples. Table 22 summarizes the emissions from hauling the biomass feedstocks to the power plant.

Table 22. GHG emissions from hauling switchgrass and logging residue to the power plant (grams/kg)

Co-firing ratio and distance	CO_2	CH_4	N_2O	CO_2-Eq.
5% co-firing				
Switchgrass	24.4	0.030	0.0014	25.49
Logging Residues				
Softwood				
27 miles (min)	4.92	0.0001	0.0002	4.98
220 miles (max)	40.12	0.0010	0.0014	40.54
Hardwood				
65 miles (min)	11.85	0.0003	0.0004	11.98
244 miles (max)	44.50	0.0011	0.0015	44.97
10% co-firing				
Switchgrass	25.01	0.031	0.0014	26.14
Logging Residues				
Softwood				
38 miles (min)	6.93	0.0002	0.0002	7.00
310 miles (max)	56.53	0.0014	0.0019	57.13
Hardwood				
92 miles (min)	16.78	0.0004	0.0006	16.95
345 miles (max)	62.91	0.0016	0.0021	63.58
15% co-firing				
Switchgrass	25.48	0.031	0.0014	26.63
Logging Residues				
Softwood				
47 miles (min)	8.57	0.0002	0.0003	8.66
380 miles (max)	69.30	0.0017	0.0023	70.02
Hardwood				
112 miles (min)	20.42	0.0005	0.0007	20.64
423 miles (max)	77.14	0.0019	0.0026	77.95

7.8 GHG emissions from combustion of biomass feedstocks

A large number of studies indicate that biomass fuels provide substantial environmental benefits absorbing carbon dioxide during growth and emitting it during combustion (McCarl et al., 2000; Gold & Tillman, 1996; Demirbas, 2004). This way biomass fuels assist the atmospheric carbon dioxide recycling and do not contribute to the pool of greenhouse gas emissions. In essence, biomass consumes the same amount of CO_2 from the atmosphere during growth as is released during combustion (Demirbas, 2004). Therefore, biomass is considered a zero net carbon dioxide emission fuel source. For example, the switchgrass carbon content is 42.04 percent by weight, or 420.4 g of carbon per kilogram of switchgrass. Assuming that all the carbon in switchgrass is converted from CO_2 through the photosynthesis process, the CO_2 used by switchgrass can be calculated from the carbon content of switchgrass. This calculation by Qin et al. (2006) is equal to 1540.5 g CO_2/kg of switchgrass. We further assume that this carbon will be released during combustion. However, since combustion emissions match the photosynthetic uptake, overall there will be net zero emissions from burning biomass as the sole feedstock at the power plant (Qin et al., 2006). Similarly, in the case of logging residues, carbon absorbed while tree is growing can compensate for carbon released when residues are burned at the plant. For bagasse, the carbon absorbed by the sugar cane as it grows compensates for the carbon released when bagasse is used at the power plant (Kadam, 2000). Table 23 presents GHG emissions for all feedstocks fired alone cases.

Table 23. Emissions from feedstocks fired alone (grams/kWh)

Emission Species	CO_2	N_2O	CH_4	CO_2-Eq.
Grams/kWh switchgrass	1,660	0.10	0.16	1,693.3
Grams/kWh bagasse	1,690	0.11	0.18	1,726.7
Grams/kWh logging residues	1,255	0.08	0.14	1,281.9

Overall, we assume that all three biomass feedstocks contribute zero CO_2 emissions from the combustion stage. In contrast, combustion of coal generates significant emissions, even though coal-fired steam power boilers in the utility power industry in the U.S. have much better heat rates than biomass-fired boilers. For example, coal-fired steam power boilers have heat rates ranging from 9.5 to 13.7 MJ/kWh equating to HHV efficiency 25% to over 37%, on a net station heat rate (NSHR) basis, whereas existing biomass power plants have heat rates from 13.7 to 21.1 MJ/kWh or even higher, which correspond to HHV efficiencies from 25% to 17% or lower (Hughes, 2000). Life Cycle CO_2 emissions from coal presented here are from Qin et al. (2006) and were derived using the US EPA report on GHG sinks and sources (Hockstad & Hanle, 2002). Results for emissions from coal burned alone case are summarized in Table 24.

Table 24. GHG emissions from coal burned alone case

Emission species	CO_2	N_2O	CH_4	SO_x	CO
Emission factors (g/kg coal)	2,085	0.031	0.022	17.16	0.25
Emissions (g/kWh)	935	0.014	0.010	7.69	0.11

7.9 Post-combustion GHG emissions

The post-combustion treatment considers transporting the process waste to a landfill. Similar to Qin et al. (2006), we assume that post-combustion waste, which mainly consists of ash, will be hauled to a landfill 5 miles away from the plant by a heavy-duty truck with the load capacity of 25 tons. As GHG emissions from waste transportation are not of significant amount their calculation for biomass-alone and co-firing cases is ignored here. In addition, since biomass feedstocks in this study contain SOx that is well below the EPA emission standards the post-combustion SOx treatment is also ignored in this analysis.

7.10 GHG emissions from co-firing cases

Most co-firing studies, including this study, have been conducted with biomass percentages below 20% by mass. Within this range, the slagging and fouling problems brought by firing biomass are not very significant, but the synergetic effects of co-firing on emission reduction can be significant (Qin et al., 2006). For further analysis, we use the thermal efficiency of 20.7 % for switchgrass, as assumed in Qin et al. (2006), as well as for bagasse and logging residues.

Table 25 below shows the GHG emissions per kilowatt-hour of total electricity generated estimated for co-firing cases for all three feedstocks. Note that as the co-firing ratio goes up, emissions from all feedstocks also go up. However, the coal portion of emissions decreases and emissions from biomass go up. Biomass emissions increase because the biomass input increases with the increasing co-firing ratio. However, as was mentioned in the previous section, CO_2 emissions from biomass combustion will be absorbed during the plant growth process and hence the net CO_2 emissions from co-firing cases will decrease by this amount demonstrating the contribution of biomass into the reduction of CO_2 emissions. The amounts of N_2O and CH_4 emissions also go up with the increase in the co-firing ratio, however this increase is insignificant.

Table 25. Life-Cycle Emissions from co-firing scenarios for switchgrass, sugarcane bagasse and logging residues

Co-firing ratio (mass input)	Emission Species (grams/KWh)			
	CO_2	N_2O	CH_4	CO_2-Eq.
5% mass input				
Switchgrass	941.43	0.016	0.013	943.25
- switchgrass	34.89	0.002	0.003	
- coal	906.53	0.014	0.010	910.90
Bagasse	935.16	0.015	0.012	939.88
- bagasse	25.98	0.002	0.002	
- coal	909.18	0.014	0.010	913.55
Logging Residue	933.51	0.016	0.014	938.57
- logging residue	38.40	0.003	0.004	
- coal	895.11	0.013	0.010	899.19
10% mass input				
Switchgrass	944.01	0.017	0.016	949.41
- switchgrass	70.94	0.004	0.007	
- coal	873.07	0.013	0.009	877.13
Bagasse	937.76	0.016	0.015	942.84
- bagasse	53.36	0.003	0.005	
- coal	884.40	0.013	0.010	888.48
Logging Residue	934.43	0.018	0.017	940.15
- logging residue	77.59	0.005	0.008	
- coal	856.84	0.013	0.009	860.89
15% mass input				
Switchgrass	946.68	0.019	0.019	958.14
- switchgrass	108.21	0.006	0.010	
- coal	838.47	0.013	0.009	842.53
Bagasse	942.48	0.018	0.018	948.22
- bagasse	82.41	0.005	0.009	
- coal	860.07	0.013	0.009	864.13
Logging Residue	937.46	0.020	0.021	943.86
- logging residue	117.87	0.008	0.013	
- coal	819.58	0.012	0.009	823.34

Comparing CO_2-Eq. result for 5% co-firing of switchgrass with coal presented in the above table with overall life cycle CO_2 emissions of 997.5 g/kWh from coal burned alone (Qin et al., 2006) we calculated the 5.4% reduction in emissions. Carrying this calculation for all co-firing ratios and feedstocks we obtain the emissions reduction which are presented in Table 26.

Table 26. CO_2-Eq. emissions reductions for all co-firing ratios

Co-firing ratios	Switchgrass	Bagasse	Logging residues
5%	5.4%	5.8%	5.9%
10%	4.8%	5.5%	5.7%
15%	3.9%	4.9%	5.4%

7.11 Greenhouse gas emission reduction trading

It is difficult to assign direct economic value to reductions of CO_2-Eq. emissions from our biomass feedstocks given that there is no formally operating marketplace for these emissions (Ney, 2002). In his study, Ney utilizes the 2010 forecast price that was derived for compliance with the Kyoto Protocol (KP), \$4.96 per ton CO_2-Eq. (Yellen, 1998). He also notes that some estimates of GHG emission reduction values have been as high as \$95 per ton CO_2-Eq. This study will use two prices to estimate the annual GHG emission reduction for our co-firing cases. Specifically, one set of annual values will be obtained if the price forecast of \$4.96 per ton CO_2-Eq. is achieved. A second set of annual values will be obtained utilizing the current emission reduction price from the European (EU) markets, which is \$13.47 per ton CO_2-Eq. (Point Carbon, 2006). Results for both sets of values are shown in Table 27.

Table 27. Economic values of CO_2-Eq. emission reductions (\$/year)

Co-firing ratios	Switchgrass		Bagasse		Logging residues	
	KP price	EU price	KP price	EU price	KP price	EU price
5%	232,485.12	526,138.20	246,927.05	558,821.81	252,540.98	571,526.71
10%	206,086.81	466,396.06	234,242.15	530,114.54	245,769.98	556,203.24
15%	168,674.92	381,729.02	211,186.48	477,937.15	229,871.00	520,222.18

7.12 Environmental issues

7.12.1 Resource savings

Co-firing coal with biomass results in reduced use of coal, i.e. savings of the fossil fuel resource. We assume that a 100 MW power plant would require 250 thousand tons of coal annually. This assumption is based on a power plant's annual coal requirements which we calculated using Pittsburg Seam Coal and Utah Coal HHV values of 31.7 MJ/kg and 32.9 MJ/kg, respectively (OPT Journals, 2004), and which amounted to 256.8 thousand tons and 247.4 thousand tons of coal, respectively. Using our assumption, co-firing coal with switchgrass at 5% would result in reducing coal input by 5%, or savings of 12,500 tons of coal. Instead, as we calculated earlier, it would take 25,455 tons of switchgrass, 42,706 tons of bagasse and about 38,889 tons of logging residues to substitute for this amount of coal savings. The amount of substituted biomass is different for each feedstock because different biomass feedstocks have different burning characteristics. Similar analysis is performed for 10 and 15 percent co-firing cases. Table 28 summarizes the results of coal savings for all co-firing ratios.

Table 28. Coal savings from biomass substitution in co-firing cases (tons)

Fuel resources	5% co-firing	10% co-firing	15% co-firing
Coal savings	12,500	25,000	37,500
Biomass substitution:			
Switchgrass	25,455	50,910	76,365
Bagasse	42,706	85,412	128,117
Logging Residues	38,889	77,778	116,667

Above calculated coal savings could provide electricity to additional customers in the region. For example, according to the U.S. EPA, the average home in the U.S. consumes approximately 900 kWh/month or 10.8 MWh/year of electricity (US EPA, 2006). On the other hand, it takes, on the average, 0.47 tons of coal (940 pounds) to produce 1000 KWh of electricity, so one ton of coal can produce 2,100 KWh of electricity (IDA, 1997). Based on these estimations, the average home consumes approximately 5.14 tons of coal annually. Dividing our coal savings by this figure shows that coal savings at 5% co-firing would provide electricity to 2,432 average homes; at 10% co-firing it would provide electricity to 4,864 average homes, and at 15% co-firing – to 7,296 average homes in the region.

7.13 Social impacts

Power plants co-firing coal with biomass can benefit the study region in several ways. For example, reduction in GHG emissions contributes to the improvement of the air quality and therefore reduces the health risks that the population residing nearby the power plants may face. In addition, coal-burning plants, which decide to co-fire coal with biomass, can benefit the local community providing new jobs. These issues are discussed in more detail in the following sections.

7.13.1 Health

Texas has nineteen coal-burning power plants and is highly dependent on coal for its energy supplies. Sixteen of the nineteen plants have been exempted or grandfathered from the Clean Air Act's newer emission standards (Musil et al., 2003). These plants release into the air pollutants such as mercury, sulfur dioxide, nitrogen oxide, and CO_2, which in high concentrations can have serious adverse effects on health. Four such plants are located in East Texas region in Harrison, Rusk and Titus counties (Clear the Air, 2006).

This study did not have an objective to perform a detailed health impact analysis related to power plant emissions in East Texas counties, selecting a study group to observe nearby power plants and determine the types and different levels of pollution to which they were exposed. Rather, the study intended to recognize the health risks related to fossil fuel emissions from power plants that communities in East Texas region may face and demonstrate the contribution of biomass to addressing these health problems. The detailed analysis would require collection of data on individuals or population exposure to fine particulate matter and other combustion-related air pollutants from a plant, over time. In addition, county level data on morbidity and mortality related to respiratory and cardiovascular diseases caused by fossil fuel emissions would be required. Unfortunately, lack of the data made it impossible to present some health impact analysis for the study region. Contacting the Texas State Department of Health Services/Center for Health Statistics in Austin failed to obtain any data, as this type of detailed data is not currently gathered by the State agency. However, numerous time-series, cross-sectional, and prospective cohort studies have observed associations between mortality and particulate air pollution (see for example, studies by Dockery et al., 1993; Pope et al., 1995; Abbey et al., 1995, 1999). In addition, results from both short-term and long-term studies which have been undertaken in Europe and the United States have demonstrated that air pollution caused by fossil fuel burning has an effect on cardiac deaths and hospital admissions in addition to respiratory effects (see review by Brunekreef & Holgate (2002) for detailed discussion of recent studies).

Some steps undertaken to slow atmospheric greenhouse gas accumulation from fossil fuel burning could reduce accumulation of various dangerous air pollutants (for example, carbon monoxide, nitrogen oxides, sulfur oxides, particulate matter) and, hence, contribute to the reduction of adverse health effects. Therefore, shifting to clean sources of energy such as biomass could be one way of improving public health in East Texas counties as less air polluting substances would be emitted from the power plants. Our analysis of greenhouse gas emissions from power generation in East Texas demonstrates that, unlike fossil fuels, biomass feedstocks possess several characteristics that contribute to the reduction of these dangerous pollutants and can decrease the population health risks. We showed that biomass reduces the net CO_2-equivalent emissions per unit of electricity generated. In addition, biomass has lower sulfur content compared to coal and therefore reduces the SO_2 emissions from the power plant. Also, because biomass is more volatile than coal and contains less amounts of fuel-bound nitrogen, co-firing it with coal may result in lower NO_x emissions. Furthermore, burning biomass can reduce the emissions produced during mining of coal and decrease the amount of particulates that are accumulated during limestone production for flue gas scrubbing (Mann & Spath, 2001). In the short-run, the substitution of biomass for coal would yield immediate benefits for the local community, especially for population located in close vicinity from the power plant. In the long run, this action could have a local as well as global benefits reducing particulate air pollution and slowing the build-up of greenhouse gases.

7.13.2 Job creation

Biomass benefits include creation and retention of local jobs in a rural economy. For biomass power systems, it is estimated that six full time jobs are created for each MW of installed capacity (California Biomass Energy Alliance, 2005). According to the report by the Oregon Department of Energy, depending on the capacity of a power plant, this employment figure includes 15 to 20 or more personnel at the power plant, and the balance of people who are involved in fuel processing and delivery stages. In addition, for fuel procurement employment, the Oregon DOE report assumes that a six-person crew could produce approximately six full chip vans per day, which would include felling, skidding, chipping, and three daily round trips per driver. They further assume that a chip van will hold 23 green tons of biomass, and a 25-MW plant that consumes 430,000 green tons per year will require nine crews, for 54 employees in fuel procurement. Based on these assumptions, we assumed that the 100 MW power plant, which requires approximately 777,778 tons of logging residue, and 509,099 tons of switchgrass would require about 36 people at the power plant. Moreover, taking into account the plant feedstock requirements, the 100 MW plant would require approximately 10 crews for switchgrass (60 employees) and 16 crews for logging residues (96 employees) in fuel procurement. Thus, the total local employment impact of the 100 MW biomass power plant would top approximately 96 employees for a plant using switchgrass and 132 employees for a plant using logging residues as biomass feedstocks. Applying employment multipliers for indirect and induced effects estimated for the East Texas region using the IMPLAN model, the secondary employment effects are estimated to be 401 jobs for switchgrass and 552 jobs for logging residues. Adding up direct and secondary employment effects, the total regional employment effects amount to 497 jobs for a plant using switchgrass and 684 jobs for a plant using logging residues.

7.14 Discussion

The switchgrass production cost estimate, excluding hauling cost, was $28.78. With the hauling cost estimated here at $5.40/ton the switchgrass total production cost arrives at $34.18 per ton, which is within the range discussed in the literature. This is the cost at which switchgrass can be delivered to the power plant. The logging residue costs at the power plant gate were estimated at $21.01- $26.95 per ton. At these costs, the logging residues can compete with the coal cost of $27.30, however estimated switchgrass costs are relatively higher. For switchgrass to become competitive with coal, either switchgrass production costs should decrease or coal price should increase. In order to reduce production costs, “agronomic research is needed to improve switchgrass yields, develop lower cost establishment and growing practices, or determine lower cost harvest and transportation processes” (Qin et al., 2006, p. 31).

Currently using biomass as the sole source of fuel for power plants with large capacity is not common or economical. Our analysis of biomass feedstock availability reveals that if biomass-alone power plant was economical, currently East Texas rice growing counties would not be able to supply sufficient amount of switchgrass to support the 100 MW biomass-alone plant operations. They would not be able to do it neither individually, nor jointly. The total annual switchgrass production in these counties falls short of the plant requirement about 2.4 times. The total amount of joint annual bagasse production in these counties is also less than the plant requirement. Adding acreage from other conventional crops does not improve the switchgrass potential; however, bagasse availability increases slightly beyond the plant requirement. Another option to increase the annual biomass production would be achieving higher yields. For example, we assumed 4.33 tons/year yield for the Alamo switchgrass. If a yield of eight dry tons per acre is achieved as in various other experimental sites, then together with the additional acreage an annual production of 777,945 tons could be reached. This amount of switchgrass would be sufficient to support the 100 MW power plant. In contrast, estimates of logging residues indicate that although counties rich in forest land would not be able to individually supply the required amount of logging residues, they could jointly generate about 2.3 million tons of residue biomass which could potentially support three 100 MW plants in the region. However, significantly large estimated average hauling distances show that transportation cost could be a main obstacle in delivering feedstock to the power plant. In the long run, the technological improvements and/or possible increase in biomass availability, which would reduce the biomass feedstock and transportation costs, could make the biomass-only case a viable alternative. In contrast, the regional biomass feedstock potential presents co-firing coal with the selected feedstocks at all three co-firing ratios as a feasible alternative. Existing power plants in the counties that have sufficient biomass potential could modify the plant to accommodate the biomass, which would be delivered to a boiler together with coal.

Unlike coal combustion that generates significant emissions, biomass feedstocks substituted for coal contribute zero CO_2 emissions from the combustion stage. Although total GHG emissions from co-firing cases go up, CO_2 emissions from coal decrease and CO_2 emissions from biomass combustion will be absorbed during the plant growth process. Therefore, the net CO_2 emissions from co-firing cases will decrease by the amount of biomass CO_2 emissions demonstrating the contribution of biomass to the reduction of CO_2 emissions. Our estimates of lifecycle CO_2-Eq. emissions generated from the co-firing cases show that at 5% co-firing of switchgrass with coal CO_2-Eq. emissions decrease by 8.7% in comparison with coal fired alone case. Five percent co-firing with bagasse reduces emissions by 8.4% and co-firing with logging residues reduces emissions by 9.9%. Similarly, the 10% co-firing reduces emissions by 12.1% for switchgrass, 10.9% for bagasse and 13.7% for logging residues. Finally, 15% co-firing reduces the emissions by 15.5% for switchgrass, 13.4% for bagasse and 17.5% for logging residues demonstrating the biomass contribution to the reduction of GHG emissions. Furthermore, substituting coal with biomass reduces use of coal extending the use of this fossil fuel resource; hence, more consumers in the region will receive electricity in their homes. Coal savings from 5% co-firing would provide electricity to 2,432 average homes; from 10% co-firing it would provide electricity to 4,864 average homes, and from 15% co-firing – to 7,296 average homes in the region. Finally, coal-burning plants that decide to co-fire coal with biomass can benefit the local community providing new jobs. Our estimations show that the direct local employment effect of the 100 MW biomass power plant would top approximately 96 employees for a plant using switchgrass and 132 employees for a plant using logging residues as biomass feedstocks. Together with the secondary employment effects, the total regional employment effects amount to 497 jobs for a plant using switchgrass and 684 jobs for a plant using logging residues. These jobs include employment at the plant as well as biomass fuel procurement positions.

7.15 Conclusions

Our analysis of feedstock potential for power generation in East Texas indicates that currently the region cannot support a 100 MW power plant using switchgrass or sugarcane bagasse. With the addition of acreage from other agricultural crops, bagasse gains the potential to support the power plant, however switchgrass is still short of the amount required by the power plant. Only increase in acreage together with the high yield gives switchgrass the production that could be sufficient to support the plant.

Agronomic research to improve the switchgrass yield could assist in obtaining high yields. On the other hand, the region can provide sufficient amount of logging residues to support up to three power plants in the region. The analysis shows that switchgrass cost at the power plant gate yields $34.18 per ton. The logging residue costs at the power plant gate were estimated at $21.01- $26.95 per ton. At the cost estimated in this study, switchgrass cannot compete with the coal cost of $27.30, but logging residues do. For switchgrass to become competitive with coal, either switchgrass production cost should decrease or coal price should increase. In order to reduce switchgrass production cost, "agronomic research is needed to improve switchgrass yields, develop lower cost establishment and growing practices, or determine lower cost harvest and transportation processes" (Qin et al., 2006, p. 31).

The study results shows that co-firing biomass reduces CO_2-Eq. emissions more than biomass fired alone. This is another advantage of co-firing over biomass-alone power plants which are not currently economical. In addition, co-firing assists in coal savings which can generate power to additional homes in the region. Finally, if brought to the region, a biomass plant can create new jobs at the plant as well as in industries supporting the power plant such as manufacturing, construction, biomass fuel procurement and many others through the local ecomony. The study estimates the total regional employment effects to amount at 497 jobs for a plant using switchgrass and at 684 jobs for a plant using logging residues. These jobs include employment at the plant as well as biomass fuel procurement positions.

CHAPTER VIII

ETHANOL PRODUCTION

8.1 Introduction

The feasibility of ethanol production depends on several factors. The availability of required amount of biomass feedstock on a continuous basis, cost of feedstock, hauling costs, cost and the price of ethanol relative to other, non-renewable sources of energy are critical to determining the feasibility of ethanol production.

To have an ethanol industry that provides substantial economic and environmental benefits to the region, the production base of biomass feedstocks needs to be large enough to support a plant. In this chapter, we will analyze the potential of East Texas region to sustain a 20 MMGY lignocellulosic ethanol plant. We will estimate various costs, greenhouse gas emissions and discuss the emerging technology for a lignocellulosic ethanol in the study region. Specifically, we will estimate the annual feedstock cost at the ethanol plant gate, feedstock hauling distances and costs, ethanol processing cost and the cost of ethanol plant construction. Furthermore, we will quantify the greenhouse gas emissions related to hauling the feedstocks from a farm and forest site to the ethanol plant and ethanol processing stages, which will be added to the emissions from feedstock production stage to estimate the life-cycle emissions from all stages of ethanol production. Environmental and infrastructure issues along with the socio-economic impacts from ethanol production in the region will be also evaluated.

8.2 Feedstock requirements

Amounts of switchgrass, bagasse, and logging residues required to sustain a 20 MMGY cellulosic biomass-to-ethanol plant were calculated based on estimated conversion rates for a commercial ethanol plant provided in Table 29. This Table also contains the biomass moisture levels that allowed us to calculate the required feedstock amounts in wet tons.

Table 29. Ethanol conversion rates and moisture levels for switchgrass, bagasse, and softwood and hardwood logging residues

Ethanol Feedstock	Ethanol Production	Production Units	Moisture Percent	Source
Switchgrass	50.00	gal/dry ton	11.99%	Greene, 2004
Bagasse	71.88	gal/dry ton	45.00%	Northeast States, Northeast Regional Biomass Program, 2001
Softwood Logging Residues	66.50	gal/dry ton	50.00%	Mann & Spath, 2001
Hardwood Logging Residues	66.50	gal/dry ton	50.00%	Mann & Bryan, 2001

Table 30 presents the summary of required feedstock supply for a 20 MMGY ethanol plant for all feedstocks.

Table 30. Annual feedstock requirements for a 20 MMGY ethanol plant

Feedstock	Annual requirements (wet tons)
Switchgrass	454,494
Bagasse	505,929
Softwood logging residues	601,504
Hardwood logging residues	601,504

8.3 Feedstock hauling distance

Similar to the power generation case, we utilize the average hauling distance formula (3) from Chapter VI to calculate the feedstock hauling distance from a farm to the cellulosic ethanol plant. Switchgrass average hauling distance was calculated using the annual required feedstock mass of 454,494 tons, yield of 4.33 tons/acre /year, and the 10% density. The result shows that on average it takes 19 miles to haul switchgrass from a farm to the ethanol plant. This distance is assumed for all rice counties in East Texas. The annual feedstock requirements of 601,504 tons along with yields and densities estimated in Chapter VI were used for calculations of hauling distances for softwood and hardwood residues. We grouped the hauling distances for East Texas forest counties in 100-mile increments and present results in Table 31. Detailed hauling distance results for each county are presented in Table F-1, Appendix F.

Table 31. Average hauling distance for ethanol production

Softwood residue		Hardwood residue	
Group range (miles)	Number of counties	Group range (miles)	Number of counties
100-200	25	200-300	2
200-300	8	300-400	12
300-400	2	400-500	12
Above 400	4	Above 500	13

The softwood logging residue average distances ranged between 100 and over 800 miles with most of the counties being within 200-mile distance from the hypothetical plant. The hardwood residues are spread with the average distances ranging from 200 to above 600 miles for most of the counties. For example, softwood residues in the San Augustine County need to be hauled for 107 miles whereas in Van Zandt County it would take 864 miles to haul the required amount of biomass to the ethanol plant. The hardwood residues require relatively longer hauling distance with the minimum of 256 miles for the Jefferson County and maximum of 960 miles for the Walker County. All these distances, especially the distances for the hardwood residues, are significantly larger than hauling distances assumed in the literature and indicate that it would require going way outside the state boundaries in order to collect the required amount of biomass. In addition, these long hauling distances mean high transportation costs, which would drive up the cost of delivering logging residues to the ethanol plant. This could be a significant barrier for the region's bioenergy production. Similar to the electricity generation case, we will assume that only counties with the hauling distance up to 200 miles are considered in the analysis, which leaves out 14 counties with softwood residues and all counties with hardwood residues. Therefore, the further analysis will focus only on softwood residues. Next section presents the hauling costs for the estimated hauling distances.

8.4 Feedstock hauling costs

Feedstock hauling costs per ton were calculated using the formula (3) from Chapter VI. Above calculated average hauling distances and the truckload sizes of 14 and 25 tons for switchgrass and logging residues, respectively, were assumed in deriving the costs. With the per-mile cost of $1.87 for switchgrass derived earlier, the switchgrass hauling cost is $5.08 per ton, or $71.06 per truckload. For calculation of the logging residue hauling costs, we first calculated the per mile costs using the Forest Residues Transportation Costing Model which was introduced in earlier chapters. The per mile costs were estimated within a range of $1.15–$1.37. The higher costs correspond to the shorter distances. Note that as the distance increases the costs decrease because a fixed cost is distributed over a larger distance. With these per mile costs, the hauling costs ranged from $11.73 to $18.4 per ton of residues, or $293.18–$460.0 per truckload. Note that since hauling cost is mainly a function of a distance, the costs increase, as the hauling distances get larger.

8.5 Annual feedstock costs at the ethanol plant gate

The cost of delivering biomass to the plant consists of two components: production cost and hauling cost. The cost of delivering switchgrass and logging residues is calculated adding up the feedstock production cost with the hauling cost. In the case of switchgrass, production cost includes costs associated with all production stages (establishment, maintenance, and harvest). Logging residue cost includes only collection and processing of biomass at the forest site. For switchgrass, it will cost $33.86 to deliver a ton of this feedstock to the ethanol plant. In turn, the cost of delivering to the plant the annual amount of required biomass is equal to $15.4 million. Taking into account the range of per ton hauling costs derived for softwood residues in the previous section and the collection cost of $8.71 calculated in Chapter VI, the cost of delivering a ton of logging residues to the plant ranges from $20.44 to $27.11, which yields the annual cost in the range of $12.29–$16.31millions.

8.6 East Texas ethanol feedstock potential

Providing sufficient feedstocks to produce ethanol is a significant constraint for an ethanol plant that could be built in the East Texas region. Although the region is rich in biomass, the quantities required for a 20 MMGY ethanol plant exceed 300,000 wet tons per year (Mann & Bryan, 2001). Constraints on supply and hauling distances become significant when the combination of availability of feedstocks, transportation costs, seasonal availability, and competing uses for feedstocks are taken into consideration (Mann & Bryan, 2001). In this study, we compare the annual feedstock requirements of the 20 MMGY ethanol plant with the availability of biomass feedstocks in the East Texas rice growing counties assuming that rice farmers are willing to switch land from rice to switchgrass or sugarcane, and with logging residues from the forest rich counties. This comparison reveals that annual availability of switchgrass in these counties is not sufficient to support a 20 MMGY cellulosic ethanol plant that would use switchgrass as a sole feedstock. Furthermore, these counties would not be able to support the ethanol plant even if they jointly supplied their annual switchgrass production. The total amount of joint annual switchgrass production is equal to 215,088.4 tons, which is less than the plant requirement of 454,494 tons. The total amount of bagasse availability in these counties is 526,582 tons, which is slightly over the required amount of 505,929 tons meaning that potentially the region could supply the ethanol plant with the annually required amount of bagasse. Similar to the power generation analysis, if we consider adding the acreage from other agricultural crops the annual switchgrass production will rise to 370,535.42 tons, which is still short of the ethanol plant biomass requirement by 1.2 times. The extended acreage could increase the bagasse availability providing about 909,652 tons of bagasse. This is 1.8 times more than the plant requirement. However, since there is no sugar mill in the region, currently this is not a viable option. Besides, before switching land to grow sugarcane, rice farmers would have to consider many issues related to construction of a sugar mill and identify issues related to locating an ethanol plant (e.g., capital investment, co-location with existing electricity generating plant, various infrastructure considerations, logistics, environmental issues, etc). For logging residues, forest rich counties also cannot individually support this size ethanol plant. However, jointly these counties can supply about 2.3 million tons of biomass, which is about 4 times the plant-required amount. Large estimated average hauling distances and their costs though may become a big hurdle in choosing this option. Assuming that this option was chosen, identifying a location for the ethanol plant construction could be another significant challenge. With the same idea as in the power plant case, we could argue that ethanol plant could be located in the Tyler County. In addition, we could also suggest selection of different county combinations that would provide required biomass. However, in reality this approach would require consideration of many issues such as availability of land, infrastructure needs, modes of transportation, water availability and wastewater treatment, waste handling, and distribution of a final product, to name a few, with cost considerations of each one of them.

In summary, no county in East Texas region can individually sustain a 20 MMGY ethanol plant providing sufficient amounts of switchgrass, bagasse, or logging residues as a sole biomass resource. Therefore, the decision about choosing a location for the cellulosic plant, types and sources of biomass it will be utilizing along with various environmental and infrastructure issues should be made on the regional level.

8.7 Switchgrass yield considerations

Discussion in the previous section showed that among feedstocks switchgrass cannot provide sufficient amount of biomass input to support the 20 MMGY ethanol plant. Several things could change this situation: increase in switchgrass yield or available land. Another thing would be to consider the smaller size plant, which would require less switchgrass input. The increase of available land demonstrated that extended acreage could not supply the required amount of switchgrass. The switchgrass production in this case yields 370,535.42 tons. We can now assume that switchgrass yield increases and is eight dry tons per acre. This is a reasonable assumption since this yield has been achieved at various experimental locations, including some regions in Texas for Alamo switchgrass. The yield of eight dry tons per acre translates to 9.09 wet tons per acre. Multiplying this yield by the initial acreage of 49,674 acres, we receive 451,537 tons per year of switchgrass production, which is still not enough for the ethanol plant. This means that changing only yield while keeping all other factors constant does not increase the switchgrass supply in the region. Then trying the extended acreage of 85,572 acres gives an annual switchgrass production of 777,945 tons, which is now 1.7 times greater than the plant requirement of 454,494 tons. Therefore, we can conclude that agronomic research is needed to examine the potential to increase the switchgrass yield, which together with the extended acreage would provide larger amounts of this feedstock.

8.8 Ethanol plant size considerations

Since switchgrass cannot support the 20 MMGY ethanol plant, the question arises as to what plant size can the region's switchgrass production support? "The minimum plant size for which capital and operating costs begin to level out is about 10 million gallons per year" (Northeast Regional Biomass Program, 2001, p. 28). Therefore, cutting the 20 MMGY plant size by half and examining the switchgrass requirements for the 10 MMGY ethanol plant, which is 227,247 tons a year, we can conclude that still the region's 215,089 tons received from the initial acreage would not be sufficient. Examining the extended acreage reveals that it will yield 370,535.42 tons of switchgrass a year, which is 1.6 times greater than the new plant size requirement. Unlike switchgrass, the region can supply sufficient amounts of sugarcane bagasse and logging residues for a smaller size plant, although large logging residue hauling distances and costs still remain a barrier in choosing this alternative.

8.9 Lignocellulosic ethanol production process and technology

Cellulose-ethanol technology used for each feedstock was two-stage dilute acid hydrolysis. This is by far the oldest technology for converting biomass to ethanol. The hydrolysis occurs in two stages to accommodate the differences between hemicellulose and cellulose. The first stage can be operated under milder conditions to maximize yield from the more readily hydrolyzed hemicellulose. The second stage is optimized to hydrolyze the more resistant cellulose fraction. The liquid hydrolyzates are recovered from each stage and fermented to ethanol. Residual cellulose and lignin left over in the solids from the hydrolysis reactors can be used as boiler fuel to produce steam or electricity. However, these processes are not considered in this study.

8.10 Energy use

Energy used by processes at the ethanol plant was calculated in terms of gallons of diesel equivalent energy. This was done using the estimates from Wang et al. (1999). The authors assumed, based on recent simulations of cellulosic ethanol production by National Renewable Energy Laboratory (NREL) that such ethanol plants consume 2,719 BTU of diesel fuel, and generate 1.73-kilowatt hours (kWh) of electricity per gallon of ethanol produced. Taking into account the conversion factors of 10,043.24 BTU per kWh and 128,450 BTU per gallon of diesel, the diesel equivalent energy use is estimated at 0.16 gallons of diesel per gallon of ethanol produced from logging residues and 0.09 gallons of diesel per gallon of ethanol produced from switchgrass and bagasse. Thus, the annual energy use by the 20 million gallon ethanol plant is estimated at 1,776,006 gallons of diesel for switchgrass and bagasse, and 3,128,657 gallons for logging residues. These energy use estimates will be used in the following section for calculation of GHG emissions from the ethanol production process.

8.11 GHG emissions from hauling biomass to ethanol plant

GHG emissions from hauling biomass feedstocks to the ethanol plant are calculated similar to the electricity generation case. Again, switchgrass hauling emissions were adapted from Qin et al. (2006). To estimate the emissions from hauling logging residues we first determined the gallons of diesel required to haul a ton of harvested residues. This was done by dividing twice the average hauling distances that we estimated in earlier section by truck fuel efficiency, which was assumed at 5 miles per gallon, and the truckload size. Results were then adjusted for the weight of diesel (3.2432 kg/gal), converted into kilograms of diesel per kilogram of logging residue and multiplied by the following diesel emissions in grams per kilogram of diesel to arrive at emissions in grams per kilogram of feedstock: Carbon Dioxide, 3188.068, Methane, 0.08, and, Nitrous Oxide, 0.108 (Wang & Santini, 2000). Although the hauling distances for logging residues were calculated and grouped into 100-mile ranges, here we present emissions for selected hauling distances as examples. Table 32 summarizes the emissions from hauling these biomass feedstocks to the ethanol plant.

Table 32. GHG emissions from hauling switchgrass and logging residues to the ethanol plant (grams/kg)

Biomass	CO_2	N_2O	CH_4	CO_2-Eq.
Switchgrass	29.18	0.0017	0.036	30.51
Logging Residues				
100 miles	18.24	0.0006	0.0006	18.43
200 miles	36.47	0.0012	0.0006	36.86
300 miles	54.71	0.0019	0.0014	55.29
400 miles	72.94	0.0025	0.0018	73.72
500 miles	91.18	0.0031	0.0023	92.14
600 miles	109.41	0.0037	0.0027	110.57

8.12 GHG emissions from ethanol processing

We calculate the GHG emissions from the ethanol plant processing stage using the energy use estimates in gallons of diesel derived in the earlier section and emission factors per gallon of diesel used in Chapter VI. Adjusting these emission factors, which are in grams per kg of diesel, for the diesel weight of 3.24 kg /gal of diesel, we bring the GHG emission factors to "grams per gallon of diesel" units. We then apply these factors to the gallons of diesel used per gallon of ethanol. Table 33 presents the emission factors used in the calculation.

Table 33. GHG emission factors for diesel

Emissions	grams/kg of diesel	grams/gal of diesel
Carbon dioxide (CO_2)	3188.06	10,339.5
Methane (CH_4)	0.08	0.26
Nitrous oxide (N_2O)	0.11	0.35

Using these emission factors, the GHG emissions from ethanol processing stage are calculated in grams per gallon of ethanol and are summarized in Table 34.

Table 34. GHG emissions from processing of one gallon of ethanol (grams/gal)

Biomass feedstock	CO_2	CH_4	N_2O	CO_2-Eq.
Switchgrass & Bagasse	918.15	0.02	0.03	927.88
Logging Residues	1617.44	0.04	0.05	1634.58

8.13 Total GHG emissions from ethanol production

Relevant harvest and hauling GHG emissions were determined in earlier sections in “grams per kilogram of feedstock” units. However, emissions from the ethanol plant processing stage in the previous section are calculated in grams per gallon. To calculate the total emissions from biomass harvest, hauling and processing stages we converted the emissions from harvest and hauling stages into “grams per gallon” units adjusting ethanol conversion rates for feedstock moisture levels. Table 35 shows the ethanol conversion rates in both units.

Table 35. Ethanol conversion rates

Biomass	Ethanol conversion rate (gal/ton)	Ethanol conversion rate (gal/kg)
Switchgrass	50.00	0.049
Bagasse	71.88	0.044
Softwood Logging Residues	66.50	0.037
Hardwood Logging Residues	66.50	0.037

Using the conversion rates from the above table, the total GHG emissions from ethanol production were calculated in grams per gallon of ethanol and results are presented in Table 36.

Table 36. Total GHG emissions from production of one gallon of ethanol (grams/gal)

Biomass	CO_2	CH_4	N_2O	CO_2-Eq.
Switchgrass	2419.78	4.2109	2.2424	3718.15
Bagasse	918.15	0.02	0.03	927.88
Logging Residues				
100 miles	2415.28	0.0638	0.0765	2440.88
200 miles	2907.98	0.0719	0.0927	2938.99
300 miles	3400.95	0.0854	0.1116	3437.09
400 miles	3893.66	0.0962	0.1278	3935.20
500 miles	4386.63	0.1097	0.1441	4433.04
600 miles	4879.33	0.1205	0.1603	4931.15

To compare the total GHG effects from ethanol production with the gasoline emissions we have to take into account that a gallon of ethanol contains less energy than a gallon of gasoline. For example, Tembo et al. (2003) show that, "in terms of energy, 1.6 gallons of ethanol would be required to replace one gallon of unleaded gasoline" (pp. 1-2). Therefore, we multiply the ethanol emissions by 1.6 and subtract from per gallon life cycle emissions for gasoline. The CO_2 life cycle emissions for gasoline were calculated as an average of three estimates discussed in Contadini et al. (2000) and are about 10,708.67 g/gal-Eq. The CO_2 estimates were from various models such as Acurex (1996), Wang (2000), and DeLucchi (1997). Our emissions for N_2O and CH_4 are based on a conservative assumption that they are same as the emissions from the gasoline burning stage only, although in reality they can be higher than our numbers. Our assumption is justified, as there are no accurate life cycle estimates for these emission species. Our estimates were calculated using conversion factors from Dautremont-Smith (2002) (0.0020 Lbs N_2O and 0.0019 Lbs CH_4 per gallon of gasoline) and are 0.8618 g/gal for CH_4 and 0.9072 g/gal for N_2O. The gasoline CO_2-Eq. emissions arrive at 10,997.02 g/gal, which is significantly higher than emissions from our biomass feedstocks. The per gallon CO_2-Eq. emissions from switchgrass are 5949.04 g, which is 1.8 times less than gasoline CO_2-Eq. emissions. Similarly, the per gallon CO_2-Eq. emissions from bagasse are 1,484.61 g, over seven times less than gasoline CO_2-Eq. emissions, and per gallon CO_2-Eq. emissions from logging residue range from 3,905.41 g to 7,889.84 g, 2.8 to 1.4 times less than the same emissions from gasoline. This is mainly because the larger fraction of gasoline emissions comes from its combustion in vehicles whereas biomass emissions are recaptured by plant growth, as it was discussed in earlier sections. In addition, the CO_2-Eq. emissions from bagasse and logging residues are smaller in comparison with CO_2-Eq. emissions from switchgrass because we did not account for the emissions arising from the production of sugarcane and trees at the farm and forest site, respectively.

8.14 GHG emission reduction trading

Similar to our analysis for the power plant emission reductions, we will follow Ney (2002) approach to put economic value on GHG emission reductions. Ney utilized the 2010 forecast price that was derived for compliance with the Kyoto Protocol, \$4.96 per ton of CO_2-Eq. (Yellen, 1998). If this price forecast is achieved, annual GHG emission reductions from the 20 MMGY ethanol plant calculated based on the results from the previous section could provide a value of \$500,760 annually to switchgrass, \$9,436,311 annually to bagasse, and a range of \$3,082,323 to \$7,034,877 annually to logging residues.

8.15 Ethanol processing cost

The ethanol processing cost for cellulosic biomass feedstocks was calculated adapting the estimates from Wallace et al. (2005). The processing cost included fixed costs, costs for enzymes, other raw materials (feedstock excluded), denaturant, capital depreciation, and waste disposal and was calculated at \$1.39 per gallon of ethanol. This cost was multiplied by the annual ethanol plant production of 20 MMGY to quantify the annual plant processing cost, which arrived at \$27.8 millions.

Earlier we estimated the harvest and hauling costs for our feedstocks, which were in “dollars per ton of feedstock” units. These costs were converted into “dollars per gallon of ethanol" units and summed up with the annual processing cost to yield the total cost of operating a cellulosic ethanol plant for one year. This cost totaled at $43.2 million for switchgrass and ranged from $39.4 to $44.0 millions for logging residues. Based on these costs, the cost of the gallon of ethanol produced from switchgrass equals $2.16, which falls between $1.97 and $2.20 for gallon of ethanol from logging residues.

For sugarcane bagasse, since we assume that the ethanol plant is located next to a sugar mill, bagasse has no hauling costs. In addition, we do not account for harvest costs for sugarcane here. Therefore, the processing costs for ethanol produced from bagasse are $1.39 per gallon of ethanol with $27.8 millions of annual plant processing cost for a 20 MMGY plant, as it was derived above.

8.16 Cost of ethanol plant construction

Construction costs for ethanol plants are directly related to the plant size. Coltrain (2001) argues that "new plants will cost about $1.50 per gallon of ethanol capacity" (p. 15). Furthermore, when compared to a 40 MMGY plant, a 30 MMGY plant will probably cost about 10 cents a gallon more to construct and a 20 MMGY will cost about 20 cents more. Based on these estimates, the cost of building a 20 MMGY cellulosic ethanol in East Texas would yield approximately $34 million assuming a $1.70 cost per gallon of ethanol capacity. With the costs of the gallon of ethanol we derived in the preceeding section, the cost of the plant construction would be even higher ranging between $39 - $44 million.

8.17 Infrastructure issues

A review and assessment of possible sites for the ethanol plant in East Texas region should include the water and electricity availability and the feedstock storage place among other infrastructure issues. We discuss these critical factors next.

8.17.1 Water

Water quality, quantity, and infrastructure for handling water treatment are the most important site considerations for developers. “The water requirements factor into capital cost of the plant, operating costs and permit issues that will become important when the plant is constructed” (CFDC & The Nebraska Ethanol Board, 2006, p. 14). During the past decade, new process technology has reduced the volume of process water required in ethanol plants and has minimized the water discharge volume.

Available water is an especially important consideration because the steps in biomass conversion deal with dilute streams, containing relatively small quantities of material in much larger volumes of water. It is estimated that approximately 500,000,000 gallons of water per year would be required to support a 20-MGPY ethanol plant (Mann & Bryan, 2001). The long-term availability of this amount of water would need to be addressed for the 20 MMGY plant in the study region. In addition, the quality of the source water for the ethanol facility should be sufficient to protect fermenting bacteria from toxic water contaminants and to avoid the fouling of heat exchangers by dissolved solids. Water treatment will likely be necessary to ensure this quality is attained. Treatment consists of anaerobic and aerobic treatment that converts organic wastes to biogas that can be burned in the boiler. Solids are separated out and disposed.

Wastewater disposal can take place through discharge to surface water, land, or an evaporation pond. Of these three options, evaporation ponds are the most costly (Northeast Regional Biomass Program, 2001).

8.17.2 Electricity

An ethanol plant has high electricity demands. Co-location with a biomass power plant can positively affect the economics of ethanol production in a variety of different applications. The synergies associated with co-location can lead to a reduction in capital costs for the ethanol facility, decreased operating costs for both facilities, and the creation of new revenue streams.

8.17.3 Feedstock storage options

Storage of biomass material is very critical in maintaining the ethanol plant in the study region. To prevent accumulation of moisture in switchgrass and logging residues, which may cause deterioration and/or spontaneous combustion, these raw materials, could be stored in specially built storage places at the plant or stored in barns for several months until being transported to the ethanol plant. In any case, storage requirements will ultimately affect the overall cost of the biomass and need to be factored into the purchase price for the raw material.

8.18 Environmental issues

Ethanol is finding support as a result of producing less GHG emissions and water pollutants than traditional transportation fuels. Because the CO_2 released during combustion comes primarily from carbon dioxide taken up during photosynthesis, a net emission reduction of carbon occurs when burning ethanol. In contrast, all emissions from burning gasoline contribute to the pool of greenhouse gases, which will remain in the atmosphere for a long period of time. Specifically, the emissions of carbon dioxide, nitrous oxide, and methane from a kilogram of gasoline, as estimated in Kadam (2000), are 2,775 g of CO_2, 0.13 g of N_2O and 1.5 g of CH_4.

While corn ethanol offers only modest emission benefits, due to the high energy cost of growing and processing corn, cellulosic ethanol promises nearly zero net GHG emissions. The Argonne National Laboratory (ANL) (Wang et al., 1999) report calculated full fuel-cycle energy and GHG emissions associated with fuel ethanol. The ANL study tried to account for all potential GHG sources including product displacement. What they found was that corn ethanol used in E-10 currently reduces GHG emissions by approximately 1 percent per vehicle mile driven when compared to conventional gasoline. In other words, GHG emissions are reduced by 12 percent to nearly 20 percent for every gallon of corn ethanol consumed in E-10 blends (the difference in GHG emissions is attributed to efficiency differences between dry and wet corn milling). As expected, GHG emissions from cellulosic ethanol are considerably better. By 2005, every gallon of cellulosic ethanol used in either E-10, E-85, or E-90 blend mix was estimated to reduce GHG emissions by 84 to more than 100 percent. Table 37 presents GHG emission reductions per gallon of ethanol as estimated in the ANL report.

Table 37. Reductions in GHG emissions per gallon of ethanol in ethanol blends

	E-10		E-85	
	Dry-Mill	Wet-Mill	Dry-Mill	Wet-Mill
Corn ethanol-Current	19.2%	12.4%	23.8%	17.3%
Corn ethanol – near future (2005)	26.4%	24.1%	32.3%	30.1%
	Woody Biomass	Herbaceous Biomass	Woody Biomass	Herbaceous Biomass
Cellulosic ethanol - near future (2005)	130.6%	83.6%	129.7%	85.7%
Cellulosic ethanol – future (2010)	143.8%	112.0%	115.4%	85.6%

Source: Wang et al., 1999.

In addition, “recent reviews of the environmental behavior of gasoline oxygenates generally note that ethanol is not likely to accumulate or persist for long in the environment” (Armstrong, 1999, p. 1). According to the Interagency Assessment of Oxygenated Fuels (NSTC, 1997), “ethanol is expected to be rapidly degraded in groundwater and is not expected to persist beyond source areas” (p. 1). Armstrong (1999) notes that “ethanol in surface water is also expected to undergo rapid biodegradation, as long as it is not present in concentrations directly toxic to microorganisms (NSTC, 1997; Malcolm Pirnie, Inc., 1998)” (p. 1).

In Texas, regional population projections and rapid economic development will increase the number of cars on the roads, which in turn will increase the amount of greenhouse gases emitted to the atmosphere, if traditional transportation fuels continue to be used. Substituting lignocellulosic ethanol for gasoline in the form of various blends or as a pure fuel can significantly reduce these emissions as well as other pollutants (e.g. carbon monoxide, sulfur oxides, nitrogen oxides, etc.) improving air and water quality and subsequently reducing the health problems for the community.

8.18.1 Resource savings

Although most ethanol consumption is in conventional gasoline engines, which are limited to a 10-percent ethanol blend (E10), there is also some demand for ethanol blended in higher concentrations, such as E85 (a mixture of 85% ethanol and 15% of gasoline by volume). “Ethanol does not compete directly with gasoline, even at comparable costs, because its energy (BTU) content is lower than that of gasoline” (DiPardo, 2001, p. 2). For example, Tembo et al. (2003) show that, “in terms of energy, 1.6 gallons of ethanol would be required to replace one gallon of unleaded gasoline” (pp.1-2). Assuming that 20 MMGY ethanol plant supplies its total annual output to the market, this output would replace 12.5 million gallons of gasoline. In addition to the fossil fuel savings, replacing gasoline with ethanol will provide reduction in greenhouse gas emissions. Using the greenhouse gas emissions coefficients for gasoline from Dautremont-Smith (2002), which we applied in earlier section, we can calculate the greenhouse gas emissions that can be avoided as cars use less gasoline. Dautremont-Smith (2002) derived CO_2, CH_4 and N_2O emissions coefficients as 19.56 Lbs. CO_2 /gal motor gasoline, 0.0020 Lbs. N_2O /gal motor gasoline and 0.0019 Lbs. CH_4 /gal motor gasoline. This translates into emissions of 8880.24 g CO_2, 0.908 g N_2O and 0.8626 g CH_4 per gallon of motor gasoline. Multiplying these avoided emissions per gallon of motor gasoline by 12.5 million gallons of saved gasoline gives us the following annual reduction in emissions: 111,003 tons of CO_2, 11,350 tons of N_2O, and 10,783 tons of CH_4.

8.18.2 Hazards analysis

While conducting a site selection analysis in East Texas counties hazards such as tornadoes, hurricanes and earthquakes must be considered. Among the three events, tornadoes and hurricanes are of most concern for Texas. More so because Texas is part of the Tornado Alley which stretches from northwest Texas, across Oklahoma and Kansas. If the site is selected in the zone prone to tornadoes there is a risk that the plant and/or biomass feedstocks could be wiped out or severely damaged by this natural event. For example, analysis of the historical data for tornadoes in East Texas demonstrates that there is no county, which had not been hit by tornado. Eleven hundred sixty tornadoes have been identified in the region for the time period of 1950-1995 (The Tornado Project, 1999). Eight counties experienced even violent tornadoes rated Fujita Scale 4 (devastating). Counties which faced with this disaster the most during the indicated time period include Harris (157 tornadoes), Jefferson (91 tornadoes), Galveston (80 tornadoes), and Smith (47 tornadoes).

In general, compared with other states, Texas ranks number 1 for frequency of tornadoes, number 1 for number of deaths, number 1 for injuries, and number 1 for cost of damages. When we compare these statistics to other states by the frequency per square mile, Texas ranks number 10 for the frequency of tornadoes, number 16 for fatalities, number 21 for injuries per area, and number 21 for costs per area based on data from 1950 – 1995 (The Tornado Project, 1999).

A scientific analysis by Dixon and Fitzsimons (2001) developed a numerical index to assess relative vulnerability to hurricanes for Texas coastal counties. The index includes measures of both incidence and exposure. Incidence is measured by the number of landfalling hurricanes affecting a Texas county over the past century. Exposure is quantified by both population and property value subject to hurricanes. Analysis shows the Galveston/Houston/Freeport area to be the most hurricane vulnerable region of the state. In addition, when the recent hurricane Rita struck in 2005, the following counties from the study region were declared disaster areas: Angelina, Chambers, Hardin, Jasper, Jefferson, Liberty, Nacogdoches, Newton, Orange, Polk, Sabine, San Augustine, San Jacinto, Shelby, Trinity, Tyler, and Walker Counties.

8.19 Availability of local labor force

Skilled workers will be needed at the new ethanol plant since the technology of ethanol production from lignocellulosic feedstocks is fundamentally different from that for production from food crops. Skilled labor will be also required at the farm and forest site for procurement of biomass feedstocks. Information about current labor market in the study region can be obtained from the Texas Workforce Commission. Increasing demand for ethanol may decrease gasoline consumption and subsequently its production. This may reduce demand for labor at the petroleum refineries. People who lose their jobs at the petroleum refineries could be potential employees at the ethanol plant.

8.20 Social impacts

8.20.1 Health

Armstrong (1999) argues that “the scientific literature contains virtually no report of injury to humans from inhaled ethanol. The data strongly suggest that exposure of the general public to ethanol vapors coming from oxygenated gasoline is very unlikely to have any adverse consequences” (p. 2). The Swedish Institute for Environmental Medicine conducted survey of the literature regarding the inhalation toxicity of ethanol and concluded that the development of adverse effects can be caused only by a high blood concentration of ethanol and that “ethanol at low air concentrations should not present any health risk for the general population (Andersson & Victorin, 1996). In addition, very limited investigations of personal exposures during refueling vehicles have not detected ethanol, where detection limits were 50 ppm or less (HEI, 1996). Yet if ethanol was inhaled, inhalation exposures could be evaluated in terms of the blood alcohol concentrations they would produce, because ethanol’s important toxic effects require that the material first enter the bloodstream. Several critical factors that need to be considered following exposure to ethanol vapors include the concentration of ethanol in air, the duration of exposure, breathing rate, absorption of ethanol across the lungs, and the body’s elimination rate of ethanol (Armstrong, 1999).

In summary, unless the ethanol concentration in blood is high, there should be no concerns for the local community in the study region regarding inhaling ethanol while fueling vehicles at gas stations. However, educating the community regarding the possible harms of the high blood concentrations of ethanol would help avoid the health risks.

8.20.2 Job creation

In this section, we present the local and regional implications of building and operating a cellulosic biomass-to-ethanol manufacturing facility in East Texas. The economic impact of an in-state ethanol industry comes in two phases: 1) construction of the facility, and 2) operation of the facility. Capital expenditures associated with construction generate an impact in the construction sectors, to the extent that in-state constructors and related suppliers of materials and equipment are utilized. As the facility begins operating, additional impacts generate from feedstock handling, facility processing activities, and product marketing. All these activities contribute income to the economy of Texas due primarily to employment.

Since currently there is no operating commercial scale cellulosic ethanol plant in the U.S., the levels of employment for this facility are not well documented, and there is no existing data. The report by the Oregon DOE (ODOE, 2005) provides an estimate of direct employment for an ethanol facility by comparing the corn ethanol industry and the biomass power supply industry to a hypothetical cellulose ethanol facility. Their employment estimate for a 15 MMGY facility is about 30 people and is based on the work by Urbanchuk and Kapell (2002) who estimated that a 40 MMGY corn-to-ethanol dry mill plant would employ about 41 persons at the facility. The authors further argue that the 15 MMGY facility would require about 78 direct jobs associated with feedstock supply, depending upon the level of mechanization and the travel distance. Thus, total direct employment at the plant and for fuel supply would be about 108 jobs for a 15 million gallon/year facility. This estimate does not include jobs associated with the sale and distribution of ethanol.

For the purposes of this study, we assume that a hypothetical 20 MMGY cellulosic ethanol plant in East Texas would employ 35 people. Assuming further that this ethanol plant would consume approximately 601,504 tons of cellulosic biomass (amount we estimated for logging residues) and would operate 330 days a year 24 hours a day (Wallace et al., 2005), the daily consumption of biomass would be about 1,823 tons of feedstock. Based on the Oregon DOE estimate, the direct jobs associated with feedstock supply would be about 79 jobs, bringing the total direct jobs created to 114.

For comparative purposes, a study by the California Energy Commission (2001b) estimated that 1,600 direct jobs would be created to support a cellulose ethanol industry, which produces 200 million gallons/year in California. Estimated positions directly related to ethanol production included 250 ethanol plant positions and 1,350 biomass collection and hauling jobs. Based on this estimate, on a jobs per gallon basis, the 20 MMGY cellulosic ethanol plant would create 160 direct jobs in East Texas. Our estimate of 114 direct jobs differs from the California estimate, however, this difference could be due to use of different types of technology at the plant, biomass feedstock machinery, hauling distance and/or ethanol plant operation schedule, to name a few.

To estimate the regional impact of the ethanol plant, we utilized the IMPLAN model. Ideally, we would use the ethanol or distillers sector in the model to estimate the regional impacts. However, since there is no ethanol production or distilleries in Texas, we used multipliers from the breweries sector (NAICS 31212) to approximate the impacts. Using the breweries sector as a proxy, a 20 MMGY plant would support 114 jobs at the plant and feedstock supply side, and 392 secondary (224 indirect and 168 induced) jobs. Hence, by adding up the direct and secondary employment impacts the total expected jobs in the study region due to the 20 MMGY cellulosic ethanol plant is obtained at 506 jobs.

8.21 Discussion

Providing sufficient feedstocks to produce ethanol is a significant constraint for an ethanol plant that could be built in the East Texas region. Comparison of the annual feedstock requirements of the 20 MMGY ethanol plant with the availability of biomass feedstocks in East Texas reveals that no county in East Texas can individually sustain a 20 MMGY ethanol plant providing sufficient amounts of either switchgrass, bagasse or logging residues as a sole biomass resource. In addition, counties that can provide combination of switchgrass and logging residues or bagasse and logging residues (i.e., rice growing counties Chambers, Galveston, Hardin, Harris, Jefferson, Liberty, and Orange) also cannot provide biomass in sufficient amounts for this size ethanol plant. Therefore, instead of the county level the regional level decision should be made about choosing a location for the plant, types, and sources of biomass it will be utilizing and various environmental and infrastructure issues.

Feedstock analysis in the region shows that it will cost $33.86 to deliver a ton of switchgrass to the ethanol plant. The logging residue costs at the plant gate range between $19.21 and $26.91. These costs are comparable with the costs discussed in the literature. Extending the acreage in the rice counties by adding acreage from other agricultural crops does not increase switchgrass production potential to meet the plant biomass requirement. Increasing switchgass yield from 4.33 tons/ac to 9.09 tons/ac (i.e., 8 dry tons per acre) does not provide sufficient amount for the plant either, unless this yield is achieved on the extended acreage. Furthermore, examination of the feedstock requirements for a smaller size ethanol plant (10 MMGY) again indicates that switchgrass does not have a potential to support even a smaller size plant. These results suggest that currently switchgrass cannot be selected as an energy crop in the rice-growing region. Agronomic research is needed to improve the switchgrass yield and examine the potential to reduce its production cost. Unlike switchgrass, the region can supply sufficient amounts of sugarcane bagasse and logging residues for a smaller size plant, although large logging residue hauling distances and costs still remain a barrier in choosing this alternative

Comparison of CO_2-Eq. emissions from a gallon of ethanol and a gallon of gasoline indicate that, although a gallon of ethanol contains less energy than a gallon of gasoline, the life-cycle emissions for gasoline were significantly higher of those for ethanol. As an example, the per gallon CO_2-Eq. emissions from switchgrass are 5,949.04, which is 1.8 times less than gasoline CO_2-Eq. emissions. This is mainly because the larger fraction of gasoline emissions comes from its combustion in vehicles whereas biomass emissions are recaptured by plant growth. Applying the $4.96 per ton of lifecycle CO_2-Eq. reductions forecast price to the GHG emissions reductions achieved due to switching from gasoline to ethanol provide a value of $500,760 annually when ethanol is derived from switchgrass, a value of $9,436,311 annually when bagasse is utilized in ethanol production and a value range between $3,082,323 and $7,034,877 for logging residues.

There is a wide array of issues that need to be addressed before proceeding with the decision to construct a new ethanol plant. Developers in East Texas who contemplate building the plant must examine the most critical factors related to the plant site selection. These critical factors include locating the plant in regions less prone to natural hazards, in close proximity to feedstocks, local ethanol markets, and distribution infrastructure (e.g., highways, railroads, ports, etc). In addition, water, electricity and local labor force availability as well as the feedstock storage place must be considered. This chapter provided a general discussion of these critical factors that are site specific. Analyzing these and other site related issues in relation with various selected locations for a potential plant can help in identifying the most suitable plant location in the study region.

8.22 Conclusions

Comparison of the annual feedstock requirements of the 20 MMGY ethanol plant with the availability of biomass feedstocks in East Texas indicates that no county in East Texas can individually sustain a 20 MMGY ethanol plant providing sufficient amounts of either switchgrass, bagasse or logging residues as a sole biomass resource. In addition, counties that can provide combination of switchgrass and logging residues or bagasse and logging residues (i.e. rice growing counties Chambers, Galveston, Hardin, Harris, Jefferson, Liberty, and Orange) also cannot provide biomass mixture in sufficient amounts for this size ethanol plant. Therefore, instead of the county level the regional level decision should be made about choosing a location for the plant, types and sources of biomass it will be utilizing and various environmental and infrastructure issues.

Analysis of switchgrass potential as an energy crop suggests that currently switchgrass cannot serve as an energy crop in the rice-growing region. Agronomic research could improve the switchgrass yield and examine the potential to reduce its production cost. Unlike switchgrass, the region can supply sufficient amounts of sugarcane bagasse and logging residues, although large logging residue hauling distances and costs still remain a barrier in choosing this alternative.

Although selected biomass feedstocks are not feasible for the study region economically, they can provide significant environmental benefit by reducing the greenhouse gas emissions generated by use of gasoline. Comparison of CO_2-Eq. emissions from a gallon of ethanol and a gallon of gasoline indicate that, although a gallon of ethanol contains less energy than a gallon of gasoline, the life-cycle emissions for gasoline were significantly higher of those for ethanol.

Finally, there are number of issues that need to be addressed before proceeding with the decision to construct a new ethanol plant. These critical factors include locating the plant in regions less prone to natural hazards, in close proximity to feedstocks, local ethanol markets, and distribution infrastructure (e.g., highways, railroads, ports, etc). In addition, water, electricity and local labor force availability as well as the feedstock storage place must be considered.

CHAPTER IX

SUMMARY AND CONCLUSIONS

Use of fossil fuels has provided high living standards for years; however, their consumption has come with a number of significant problems and concerns. In recent years, concerns have been growing regarding the increasing U.S. dependence on imported oil, along with environmental consequences of heavy dependence on fossil fuels, particularly greenhouse gas emissions, and depletion of fossil fuel resources. Biofuels as a form of srenewable energy have potential to address these problems and concerns across the United States. The purpose of this study was, first, to examine the potential of providing biofuels from agricultural and forestry lands of the Eastern part of Texas, and, second, to provide information that can support local decision makers examining the potential of bioenergy particularly in the East Texas study region. Forty-four counties in East Texas were selected for this analysis. Regional biomass production and subsequent energy recovery was examined as a possible feedstock for electricity generation and ethanol production in the regional context. For ethanol production, a cellulosic ethanol producing plant was investigated. In terms of electricity generation, three alternatives were studied:

- co-firing coal with biomass (i.e., supplementing coal use in coal-fired boilers with biomass sources);
- retrofitting an existing power plant to use biomass; and
- building a new biomass dependent power plant.

The biomass feedstocks that were evaluated for East Texas region included the lignocellulosic feedstocks switchgrass, sugarcane bagasse and logging residues.

In evaluating these prospects, the study did a comprehensive analysis, which examined a broad range of economic, environmental, and community impacts from electricity and ethanol production in the region.

Economically in the U.S., profitability is a key current constraint to the commercial use of biomass feedstocks for energy production. Often the estimated market price of biomass-derived energy exceeds the market price of fossil fuel-derived energy (Walsh, 1998). Because biomass energy costs are a function of the feedstock, transportation, conversion and other costs, the economic analysis estimated the biomass feedstock availability in each county and in the region as a whole along with the feedstock production costs, hauling distances and costs, costs of feedstock delivery to the plant gate, and plant construction and retrofitting costs.

Environmentally the analysis focused on the impacts of biomass feedstock production on surface and groundwater, and soil quality as a result of land use change. Specifically, these impacts were evaluated for the selected biomass feedstocks and compared with the base-line scenario of rice acreage. In addition, life cycle greenhouse gas emissions from electricity generation and ethanol production were computed and compared with those from the conventional fossil fuels coal and gasoline.

The social analysis quantified the impacts of bioenergy production on employment and determined health concerns due to air pollution and surface and groundwater contamination in the region.

9.1 The methodology used in this research

The general methodology employed in this study first identified indicators of effects arising from substituting biomass for fossil fuels. These indicators were designed to provide an understanding of the biomass effects in the study region. Taken together with the biomass feedstock availability, the indicators were to draw a clear picture of whether biomass as a renewable energy has a potential to address the fossil fuel problems in the study area. Regional policymakers need such indicators and approaches to their quantification for measuring and assessing the current and future effects of bioenergy production on human society, environment, and economy in order to shape up the energy policy for the region.

Several methodologies and the modeling technique were employed to quantify the indicators. Economic engineering calculations were utilized to estimate the economic indicators such as the feedstock yields, hauling distances, and various costs. Regional economic multipliers were drawn from the IMPLAN (IMpact analysis for PLANning) input-output system which were then used to assess the anticipated economic and employment effects associated with the operation of the proposed ethanol facility and the biomass-alone power plant.

The environmental analysis was done using environmental models that quantified the changes in soil and water quality due to: (i) transfer of land under rice to grow energy crops, and (ii) collection of logging residues from the forest sites. The principal environmental model utilized here was the Soil and Water Assessment Tool (SWAT) and the Life Cycle Assessment (LCA) approach. An LCA approach was used to quantify greenhouse gases emmited from each stage of the bioenergy production processes. The SWAT model was first run to simulate environmental impacts from growing rice with rice acreage as a base-case scenario, and then it was run to simulate the impacts from our scenarios of switching rice land to grow switchgrass and sugarcane. In addition, SWAT was run to simulate the environmental impacts in the forest rich counties where the base-case scenario was leaving logging residues on the forest site for decay and then to simulate our scenario of collecting two thirds of the logging residues for further delivery to the power and ethanol plants.

Since performing a detailed health impact analysis related to production and use of fossil fuels was not an objective of this study, the social analysis included a discussion of the health risks related to fossil fuel emissions that communities in East Texas may face and demonstration of biomass contribution to addressing these health problems. Furthermore, the social analysis included the estimation of local jobs created in the region as a result of building a new power generating and cellulosic ethanol plants. These job openings assumed employment at the power and ethanol plants as well as at a farm and forest site for biofuel procurement.

9.2 Conclusions

9.2.1 General biofuel production

In terms of general biofuel potential the study finds that none of the counties in East Texas has a biomass potential to individually sustain either a 100 MW power plant or a 20 MMGY cellulosic ethanol plant. Therefore, biofuel development should be pursued at the regional level with the counties jointly supplying the feedstocks to the energy plants.

9.2.2 Potential of electricity

9.2.2.1 Potential of switchgrass

In terms of switchgrass with respect to electricity generation, the study found that

- The initial rice region cannot provide sufficient amount of switchgrass to support the 100 MW biomass-alone power plant (Appendix G, Table I-5).
- The expanded rice region also cannot supply enough switchgrass for the biomass-alone power plant (Appendix G, Table I-6).
- Adding logging residues available in the region to switchgrass harvested from the expanded acreage still leaves the rice region short of the required biomass.

Collectively then, switchgrass cannot be the energy feedstock for a biomass-only plant in this region. In addition, the real cost of switchgrass estimated in this study at $34.18 is higher than the coal cost of $27.30 indicating that currently switchgrass is not cost competitive with coal. For switchgrass to become cost competitive with coal, either higher coal prices, higher GHG emission prices or lower production costs will be needed. In terms of production costs, genetic research could contribute to improving switchgrass yields, developing lower cost establishment and growing practices, or determining lower cost harvest and transportation processes (Qin et al., 2006). These results suggest that currently switchgrass cannot improve the financial situation of the local rice farmers and therefore it cannot serve as an alternative crop to growing rice.

However, if switchgrass becomes competitive with coal and replaces rice in the region, it can bring several environmental benefits. The results of the SWAT simulation model show that switchgrass production on rice land provides significant reduction in average surface runoff (range of 20.7-79.6%), sediment yield (ranges of 69.4-93.4%), the amount of nitrogen and phosphorus content of surface and ground water and several other parameters. In addition, switchgrass reduces GHG emissions when it replaces coal in the combustion process. However, the Life-Cycle Analysis of GHG emissions shows that the emissions reduction is higher when switchgrass is co-fired with coal rather than when it is burned alone suggesting that currently co-firing is the better alternative for power plants in addressing the issue of reducing GHG emissions.

9.2.2.2 Sugarcane bagasse

Bagasse has the potential to support one power plant only when the additional crop acreage from corn, soybean, wheat, and sorghum in the rice counties is included (Appendix G, Table I-6). However, currently the region does not grow any sugarcane and the rice farmers would be considering switching to sugarcane if, among other factors, there was a sugar mill in relative proximity. Therefore, unless there is a decision made to bring a sugar mill into the region, bagasse too may not be a viable energy feedstock option and an attractive alternative crop for the local rice growers.

Similar to switchgrass, production of sugarcane provides significant environmental benefits reducing surface runoff and improving other selected parameters although sugarcane results are slightly lower from the ones for switchgrass. Burning sugarcane bagasse in the power plant boilers reduces GHG emissions. In addition, it helps to avoid carrying leftover bagasse to landfills and related costs.

9.2.2.3 Forestry

Forest region can generate logging residues in the amount sufficient to support up to three 100 MW biomass-alone power plants (Appendix G, Table I-4). However, because of the sparseness and remote location, logging residues are expensive to recover driving the transportation costs up. This would increase the cost of the electricity generation making it not cost competitive with electricity from traditional fossil fuels such as coal. To keep the transportation costs at the reasonable level and stay within the state boundaries while collecting biomass we assumed the maximum hauling distance at 200 miles. This distance limit helped to sort out the forest counties leaving out many counties that have small amount of available biomass. In addition, the logging residue costs which were estimated between $21.01- $26.95 per ton are competitive with coal cost of $27.30/ton only for counties with the average hauling distances up to 200 miles. Costs increase with the increase in the co-firing ratio which is explained by increase in required amount of biomass and therefore in the biomass hauling distance. For all distances greater than 200 miles, logging residue costs will not be competitive with coal suggesting that only a handful of the counties will be available for supplying logging residues to the plant. These findings can assist local forest producers in making a decision on whether or not to get into the collection of logging residues for bioenergy producers. In the long run, the technological improvements and/or possible increase in biomass availability, which would reduce the biomass feedstock and transportation costs, could make this alternative more attractive in which case the critical factors for a plant construction would have to be considered in order to support the plant site selection process.

As switchgrass and sugarcane bagasse, logging residues provide important environmental benefits to the region. The study results show that burning logging residues in the power plant boilers can contribute to the reduction of GHG emissions as carbon absorbed while trees are growing can compensate for carbon released when residues are burned at the plant. Moreover, collecting logging residues for energy production purposes as opposed to the current practice of leaving logging residues on forest sites for decay can contribute to the reduction of wildfire risks in the region. Because there is no consensus reached in the field regarding the effects of removing logging residues on erosion, nutrients, and water quality, additional research is needed to provide stronger scientific results for these parameters.

Table 39 summarizes the feedstock potential for a 100 MW biomass-alone power plant given various regional cases. For example, the “No” in the “Single county” column shows that biomass potential was tested in all 44 counties: in 7 rice counties for switchgrass and bagasse, and in 39 forest rich counties for logging residue availability; and none of these counties individually could supply enough biomass to support the power plant. Similarly, “No” in the “Sub-region” column shows that two tests for biomass potential in the rice region were performed: one for switchgrass and the other one for bagasse; and the results revealed that the rice region could not supply enough of either feedstock for the power plant. On the other hand, “Yes” in this column demonstrates that testing the forest region for potential of logging residues gave positive results. The other regions in the table were tested in a similar way: two tests were performed for the case of added agricultural acreage and only one test for “Whole region I” and “Whole region II” cases.

9.2.2.4 Contribution from co-firing

In contrast, currently co-firing biomass with coal appears to be the most attractive alternative for the study region. Analysis of feedstock availability in these cases suggests that some counties can support only 5% co-firing of biomass with coal, some counties can support 5- and 10% co-firing, and some counties can support all co-firing cases. Since co-firing takes place at the existing power plant, decision makers will have to choose a plant where co-firing could be tested and the feedstock(s) it will utilize. As many of the power plants in Texas have a life span of 50 years or more, this analysis also may be useful in making a decision about which plants to retire and which plants to retrofit for co-firing.

Table 38. Summary of biomass feedstock availability to sustain 100 MW power plant in East Texas

Feedstocks	Single county	Subregion*	Whole region I**	Other added agricultural crop acreage***	Whole region II****
Switchgrass	No	No	No	No	No
Bagasse	No	No	No	Yes	Yes
Logging Residues	No	Yes	Yes	-	Yes

Notes:
* Includes rice region with seven counties when analyzing switchgrass and bagasse and 39 forest counties when analyzing logging residues
** Includes all 44 counties with the original acreage
*** Includes initial acreage and additional acreage from corn, soybean, wheat, and sorghum in the rice counties
**** Includes expanded acreage from the rice counties and all forest counties

9.2.3 Ethanol

With respect to ethanol production, the study found that neither initial nor expanded rice region could supply sufficient amount of switchgrass to support a 20 MMGY cellulosic ethanol plant suggesting that currently switchgrass cannot be an attractive biomass feedstock neither for rice farmers nor for bioenergy producers (Appendix G, Tables II-5, II-6). Unlike switchgrass, the initial rice region could supply sufficient amount of bagasse for the plant’s annual operations (Appendix G, Tables II-5). In addition, the expanded acreage could increase the bagasse availability providing as much as 1.8 times more bagasse than the plant requirement (Appendix G Tables II-6). However, problems and concerns related to establishment and production of sugarcane in the region along with the lack of a sugar mill do not present bagasse as a viable feedstock alternative either. For logging residues, forest region can supply about 2.3 million tons of biomass, which is about 4 times the plant-required amount (Appendix G, Tables II-4). Large estimated average hauling distances and their costs though may become a big hurdle in choosing this option limiting the number of counties that could supply biomass to the ethanol plant.

Although selected biomass feedstocks are not feasible for the study region economically, they can provide significant environmental benefits by reducing the greenhouse gas emissions generated by use of gasoline. In the earlier section we discussed environmental benefits stemming from the production of biomass feedstocks on rice land. In addition, comparison of CO_2-Eq. emissions from a gallon of ethanol and a gallon of gasoline indicates that, although a gallon of ethanol contains less energy than a gallon of gasoline, the life-cycle emissions for gasoline were significantly higher of those for ethanol.

Since currently there is no ethanol plant in the region, assuming that this option was selected would require identifying a location for the ethanol plant construction, which could be another significant challenge. The plant construction would require that investors consider many issues such as availability of land, infrastructure needs such as modes of transportation, water availability and wastewater treatment, waste handling, and distribution of a final product, to name a few, with cost considerations of each one of them. The regional availability of all three feedstocks for the cellulosic ethanol plant is summarized in Table 40. Similar to the discussion of the results in Table 39, the “Yes” and “No” represent the same number of biomass potential tests as were performed for individual counties and regions for the power plant.

Table 39. Summary of biomass feedstock availability to sustain 20 MMGY ethanol plant in East Texas

Feedstocks	Single county	Sub-region*	Whole region I**	Other added agricultural crop acreage***	Whole region II****
Switchgrass	No	No	No	No	No
Bagasse	No	Yes	Yes	Yes	Yes
Logging residues	No	Yes	Yes	N/A	Yes

Notes:
* Includes rice region with seven counties when analyzing switchgrass and sugarcane bagasse and 39 forest counties when analyzing logging residues
** Includes all 44 counties with the initial acreage
*** Includes additional acreage from corn, soybean, wheat, and sorghum in the rice counties
**** Includes expanded acreage from the rice counties and all forest counties

Important implications can be drawn from this study for the land use in the region. For example, the feedstock availability analysis indicates that rice acreage is not sufficient to supply required amount of switchgrass to either energy plant. Adding other agricultural crop acreage in these counties did not increase the switchgrass potential. With the assumed yield of 4.33 tons/ac/year, it would take 117,575 acres for switchgrass to provide the amount required by the 100 MW power plant. This is 2.4 times more than current rice acreage in the region. Small production of electricity such as 100 MW may not justify dedicating large land acreages to grow the energy crop. However, in the long run, improvements in the crop yield could reduce the land requirements making switchgrass attractive as an energy crop in the region.

Finally, the study results provide important policy implications for the local government in pursuing the biofuels. The analysis of feedstock availability and costs suggests that if a decision about bringing biomass energies to the region were based solely on the feedstock economics, the answer would be not to pursue the power generation and ethanol production from the selected biomass feedstocks. However, as the indicators of biomass benefits demonstrate, if biomass is selected as a renewable energy alternative for the study region, it can contribute to the region in many ways such as: reduce GHG emissions; create local jobs in the energy sector as well as other supporting industries; contribute to the saving of finite fossil fuel resources (e. g., coal and gasoline); provide reliance on local resources reducing the dependence on imported sources; use waste materials such as sugarcane bagasse and logging residues as feedstocks which would otherwise end up in the landfills or decay not bringing revenue to the local economy. Finally, using biomass as a renewable energy source can bring significant health benefits through reduction of air and water pollution. These environmental and social benefits and the feedstock economics must be accounted for and incorporated into the analysis of costs and benefits of pursuing biomass energies so that local decision makers base their decision on the comprehensive accounting of all impacts. It should be recognized though that the set of costs and benefits listed above is not exhaustive, but is rather a sample set of selected impacts related to the bioenergy production processes. A small example of cost-benefit analysis of biomass potential in the study region is discussed in Appendix H. As can be seen from the example, electricity generation and cellulosic ethanol production would benefit the region bringing in about $12.3 and $18.0 millions, respectively. These numbers would be even higher if environmental and health effects listed in the table had their monetary values estimated. These results suggest that if the local government decides to support the biomass power production through subcidies up to the amounts of the calculated benefits, farmers and investors would receive a good incentive to get involved in the bioenergy business. The subcidies would gradually diminish and eventually fade away as farmers and investors gain more experience in growing feedstocks and establishing the electricity and ethanol production processes.

9.3 The limitations of this research and future research directions

It needs to be acknowledged that this study has its limitations. First, this was a regional scale bioenergy analysis performed in the region that is rich with biomass resources and has high production potential for energy crops. This analysis may not be applicable to other regions with different biomass potential, which raises a question about the generalizability of the results obtained in the study.

Second, although a wide variety of biomass feedstocks is under investigation for their bioenergy potential, this study examined only three lignocellulosic feedstocks, namely switchgrass (herbaceous energy crop), sugarcane bagasse (byproduct of sugarcane at a sugar mill) and logging residues (forest waste). Other residues such as rice straw or mill residues generated in the region or other energy crops such as willow and poplar also could be included in the analysis.

Third, for electricity generation case we considered the scenarios of co-firing coal with biomass feedstsocks at various co-firing ratios. There are many natural gas fired power plants in Texas. Therefore, scenarios of burning biomass with natural gas (process called gasification) could be investigated. Gasification is a process of converting solid biomass into a gaseous state, which is then burned in advanced gas turbines, such as combined-cycle turbines. Performing a preliminary feasibility assessment of biomass gasification/cofiring in a natural gas-fired boiler could provide useful information about potential for the future expansion of biomass generating capacity in the region.

Fourth, lack of data on mortality and respiratory diseases caused by fine particulate air pollution emitted by power plants in the region was a major obstacle in performing health impact analysis.

Fifth, we considered few feedstock scenarios in the region. In particular, we assumed that rice-growing farmers who are suffering income losses due to market and other conditions would consider switching rice land to grow switchgrass or sugarcane for further energy production. In addition, we assumed that foresters would consider collecting logging residues for further delivery to a biorefinery. Other scenarios, which would analyze various feedstocks including municipal solid waste from a large metropolitan Houston area, could be examined.

Based on the limitations listed above, following future research issues could be recommended:

- Examine various biomass resources available in the region (e.g., rice straw, municipal waste, willow and poplar as energy crops)

- Analyze feasibility of co-firing biomass with natural gas at the existing plant burning natural gas
- Investigate other feedstock scenarios which could also include combination of feedstocks examined in this study
- Collect data on mortality/ respiratory diseases caused by fine particulate air pollution from a power plant to perform a study on health impacts from fossil fuel burning power plants
- Incorporate analysis of technological efficiency to demonstrate a role of advanced technology in improving the biomass potential in energy production.

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APPENDIX A

COUNTIES IN THE EAST TEXAS STUDY REGION

1. Anderson	**12. Hardin**	**23. Montgomery**	**34. San Augustine**
2. Angelina	**13. Harris**	**24. Morris**	**35. San Jacinto**
3. Bowie	**14. Harrison**	**25. Nacogdoches**	**36. Shelby**
4. Camp	**15. Henderson**	**26. Newton**	**37. Smith**
5. Cass	**16. Hopkins**	**27. Orange**	**38. Titus**
6. Chambers	**17. Houston**	**28. Panola**	**39. Trinity**
7. Cherokee	**18. Jasper**	**29. Polk**	**40. Tyler**
8. Delta	**19. Jefferson**	**30. Rains**	**41. Upshur**
9. Franklin	**20. Lamar**	**31. Red River**	**42. Van Zandt**
10. Galveston	**21. Liberty**	**32. Rusk**	**43. Walker**
11. Gregg	**22. Marion**	**33. Sabine**	**44. Wood**

APPENDIX B

LOGGING RESIDUE YIELDS FOR BOTH TYPES

(SOFT AND HARDWOODS) BY COUNTY

Table B-1. Recovered softwood and hardwood logging residues by county

County	Forest Land (acres)	Recovered Softwood Residues (wet tons)	Recovered Hardwood Residues (wet tons)	Softwood Residue Yields (tons/acre)	Hardwood Residue Yields (tons/acre)
Anderson	345,002.0	19600.7	16,394.7	0.09	0.07
Angelina	304,374.4	90006.0	22,065.3	0.44	0.11
Bowie	239,859.7	26,551.3	32,794.0	0.17	0.21
Camp	48,659.5	6,390.7	5,646.7	0.20	0.17
Cass	458,182.3	70,436.0	57,064.0	0.23	0.19
Chambers	32,137.3	3,978.0	470.0	0.19	0.02
Cherokee	410,251.0	41,052.0	41,320.0	0.19	0.15
Franklin	84,275.2	544.7	2,091.3	0.01	0.04
Gregg	92,982.7	8,508.7	9,831.3	0.14	0.16
Hardin	450,214.1	66,989.3	19,530.7	0.22	0.07
Harris	186,921.9	13,950.7	8,842.7	0.11	0.07
Harrison	376,761.6	68,720.7	24,941.3	0.27	0.10
Henderson	181,180.4	3,926.0	7,385.3	0.03	0.06
Houston	333,910.3	44,228.0	19,086.7	0.20	0.09
Jasper	435,250.2	123,624.0	28,345.3	0.43	0.10
Jefferson	62,031.2	6,762.7	10,975.3	0.16	0.27
Liberty	337,639.9	30,197.3	21,813.3	0.13	0.10
Marion	203,184.5	34,848.7	24,375.3	0.26	0.18
Montgomery	353,306.1	33,222.7	9,781.3	0.14	0.04
Morris	65,569.5	8,440.0	6,195.3	0.19	0.14
Nacogdoches	374,914.0	67,646.7	25,160.0	0.27	0.10
Newton	498,957.2	82,072.7	21,258.0	0.25	0.06
Orange	110,231.4	10,784.0	5,350.7	0.15	0.07
Panola	334,356.7	55,863.3	27,820.0	0.25	0.12
Polk	515,137.9	132,825.3	19,470.0	0.39	0.06
Red River	323,355.4	10,591.3	27,759.3	0.05	0.13
Rusk	364,067.4	43,762.0	31,780.7	0.18	0.13

Table B-1. (Continued)

County	Forest Land (acres)	Recovered Softwood Residues (wet tons)	Recovered Hardwood Residues (wet tons)	Softwood Residue Yields (tons/acre)	Hardwood Residue Yields (tons/acre)
San Augustine	204,981.2	71,099.3	8,944.7	0.52	0.07
San Jacinto	225,649.5	33,032.0	5,840.0	0.22	0.04
Shelby	274,026.9	51,571.3	16,408.0	0.28	0.09
Smith	276,088.1	22,321.3	18,354.0	0.12	0.10
Titus	94,364.1	1,801.3	9,382.0	0.03	0.15
Trinity	269,918.9	55,892.0	23,036.7	0.31	0.13
Tyler	491,604.0	108,165.3	60,422.7	0.33	0.18
Upshur	206,974.9	12,762.0	11,640.7	0.09	0.08
Van Zandt	141,992.7	757.3	4,125.3	0.01	0.04
Walker	263,713.4	36,340.7	3,316.7	0.21	0.02
Wood	192,655.8	7,310.0	5,788.0	0.06	0.05

APPENDIX C

SWAT SIMULATION MODEL RESULTS FOR SWITCHGRASS AND SUGARCANE

Table C-1. Comparison of reductions in sediment yield, surface runoff, nitrogen, and phosphorus in surface and groundwater between the rice and biomass crops switchgrass and sugarcane

Watershed	SURQ (mm)	SYLD (mtons)	ORGN (kg)	ORGP (kg)	SEDP (kg)	NSURQ (kg N)	NO_3GW (kg N)	SOLP (kg P)
Lower Sabine								
Rice-baseline	278.88	512.36	802.94	234.04	57.72	18.19	8,251.14	63.65
Switchgrass	282.18	175.53	13.44	3.16	1.58	8.70	271.99	0.79
%Difference	***-1.2%***	***65.7%***	***98.3%***	***98.7%***	***97.3%***	***52.2%***	***96.7%***	***98.6%***
Sugarcane	444.67	218.23	30.05	51.79	1.58	15.81	1,199.46	67.60
%Difference	***-59.5%***	***57.4%***	***96.3%***	***77.9%***	***97.3%***	***13.0%***	***85.5%***	***-6.2%***
Lower Neches								
Rice-baseline	501.51	33.08	75.33	22.96	7.35	2.66	168.24	7.41
Switchgrass	282.22	4.97	0.88	0.24	0.08	0.48	13.41	0.04
%Difference	***43.7%***	***85.0%***	***98.8%***	***99.0%***	***98.9%***	***82.1%***	***92.0%***	***99.4%***
Sugarcane	461.08	6.20	2.81	3.18	0.32	1.22	88.82	8.13
%Difference	***8.1%***	***81.3%***	***96.3%***	***86.2%***	***95.6%***	***54.2%***	***47.2%***	***-9.8%***

Table C-1. Continued

Watershed	SURQ (mm)	SYLD (mtons)	ORGN (kg)	ORGP (kg)	SEDP (kg)	NSURQ (kg N)	NO_3GW (kg N)	SOLP (kg P)
Pine Island Bayou								
Rice-baseline	542.45	2,343.95	8,270.58	2,259.52	621.68	365.33	976.26	924.07
Switchgrass	364.79	374.54	187.27	35.31	7.68	64.47	201.09	6.14
%Difference	***32.8%***	***84.0%***	***97.7%***	***98.4%***	***98.8%***	***82.4%***	***79.4%***	***99.3%***
Sugarcane	553.86	529.58	285.51	287.05	30.70	139.69	650.84	1,108.27
%Difference	***-2.1%***	***77.4%***	***96.5%***	***87.3%***	***95.1%***	***61.8%***	***33.3%***	***-19.9%***
Lower Trinity-Kickapoo								
Rice-baseline	473.37	377.87	628.17	178.54	67.12	17.52	1,287.41	48.25
Switchgrass	480.99	33.79	30.51	5.42	1.24	7.01	84.64	0.57
%Difference	***-1.6%***	***91.1%***	***95.1%***	***97.0%***	***98.1%***	***60.0%***	***93.4%***	***98.8%***
Sugarcane	476.41	24.30	27.01	15.37	3.84	17.40	1,158.25	152.21
%Difference	***-0.6%***	***93.6%***	***95.7%***	***91.4%***	***94.3%***	***0.6%***	***10.0%***	***-215.5%***
Lower Trinity								
Rice-baseline	615.56	25,963.34	55,901.3	13,825.74	4,558.72	1,367.62	4,238.19	3,924.77
Switchgrass	423.09	2,243.75	2,008.69	320.54	49.86	341.90	790.65	21.37
%Difference	***31.3%***	***91.4%***	***96.4%***	***97.7%***	***98.9%***	***75.0%***	***81.3%***	***99.5%***
Sugarcane	548.38	1,438.85	1,937.46	1,082.70	178.08	762.16	2,115.53	9,138.81
%Difference	***10.9%***	***94.5%***	***96.5%***	***92.2%***	***96.1%***	***44.3%***	50.1%	***-132.8%***

Table C-1. Continued

Watershed	SURQ (mm)	SYLD (mtons)	ORGN (kg)	ORGP (kg)	SEDP (kg)	NSURQ (kg N)	NO_3GW (kg N)	SOLP (kg P)
West Fork San Jacinto								
Rice-baseline	267.95	47.39	72.37	21.85	6.34	1.98	127.71	5.68
Switchgrass	272.38	13.56	0.96	0.23	0.10	1.06	3.83	0.07
%Difference	***-1.7%***	***71.4%***	***98.7%***	***98.9%***	***98.4%***	***46.7%***	***97.0%***	***98.8%***
Sugarcane	270.61	13.46	1.35	0.96	0.20	1.72	57.52	16.10
%Difference	***-1.0%***	***71.6%***	***98.1%***	***95.6%***	***96.9%***	***13.3%***	***55.0%***	***-183.7%***
Spring								
Rice-baseline	359.21	8,690.28	14,368.19	3,812.31	1,446.05	268.51	23,388.51	867.07
Switchgrass	247.33	914.62	276.90	50.35	13.99	78.32	3,171.80	5.59
%Difference	***31.1%***	***89.5%***	***98.1%***	***98.7%***	***99.0%***	***70.8%***	***86.4%***	***99.4%***
Sugarcane	370.49	601.36	405.57	251.73	53.14	246.14	25,206.56	2,402.62
%Difference	***-3.1%***	***93.1%***	***97.2%***	***93.4%***	***96.3%***	***8.3%***	***-7.8%***	***-177.1%***
East Fork San Jacinto								
Rice-baseline	537.98	2,811.02	5,594.72	1,256.49	475.28	103.80	663.45	305.93
Switchgrass	426.83	185.74	268.29	41.28	5.46	30.35	88.02	2.43
%Difference	***20.7%***	***93.4%***	***95.2%***	***96.7%***	***98.9%***	***70.8%***	***86.7%***	***99.2%***
Sugarcane	512.64	121.40	211.24	101.37	19.42	67.98	333.85	792.74
%Difference	***4.7%***	***95.7%***	***96.2%***	***91.9%***	***95.9%***	***34.5%***	***49.7%***	***-159.1%***

Table C-1. Continued

Watershed	SURQ (mm)	SYLD (mtons)	ORGN (kg)	ORGP (kg)	SEDP (kg)	NSURQ (kg N)	NO_3GW (kg N)	SOLP (kg P)
Buffalo-San Jacinto								
Rice-baseline	492.53	4,890.14	8,488.81	2,532.40	854.86	271.16	13,399.64	852.56
Switchgrass	266.40	831.88	190.73	36.77	9.19	55.15	1,070.87	4.60
%Difference	***45.9%***	***83.0%***	***97.8%***	***98.5%***	***98.9%***	***79.7%***	***92.0%***	***99.5%***
Sugarcane	391.40	544.63	296.44	181.54	39.07	163.16	14,373.99	1,647.67
%Difference	***20.5%***	***88.9%***	***96.5%***	***92.8%***	***95.4%***	***39.8%***	***-7.3%***	***-93.3%***
Sabine Lake								
Rice-baseline	33.24	5,071.60	22,323.71	2,730.86	317.88	86.69	524.91	28.90
Switchgrass	6.77	433.47	1,733.88	216.74	28.90	14.45	35,920.21	14.45
%Difference	***79.6%***	***91.5%***	***92.2%***	***92.1%***	***90.9%***	***83.3%***	***80.3%***	***50.0%***
Sugarcane	17.28	606.86	2,860.90	346.78	43.35	43.35	24,100.93	14.45
%Difference	***48.0%***	***88.0%***	***87.2%***	***87.3%***	***86.4%***	***50.0%***	***-182.7%***	***50.0%***
East Galveston Bay								
Rice-baseline	560.56	38,649.46	77,564.54	19,346.86	6,618.66	1,903.70	7,880.42	5,345.84
Switchgrass	376.60	3,110.11	2,423.89	387.38	55.34	475.92	1,283.89	22.14
%Difference	***32.8%***	***92.0%***	***96.9%***	***98.0%***	***99.2%***	***75.0%***	***83.7%***	***99.6%***
Sugarcane	494.39	2,091.85	2,335.35	1,294.96	221.36	1,073.60	3,176.52	12,661.79
%Difference	***11.8%***	***94.6%***	***97.0%***	***93.3%***	***96.7%***	***43.6%***	***59.7%***	***-136.9%***

Table C-1. Continued

Watershed	SURQ (mm)	SYLD (mtons)	ORGN (kg)	ORGP (kg)	SEDP (kg)	NSURQ (kg N)	NO_3GW (kg N)	SOLP (kg P)
North Galveston Bay								
Rice-baseline	277.30	2,261.11	4,503.15	552.89	110.58	110.58	3,389.76	381.0
Switchgrass	128.18	507.13	560.51	72.45	15.25	53.38	221.15	7.63
%Difference	***53.8%***	***77.6%***	***87.6%***	***86.9%***	***86.2%***	***51.7%***	***93.5%***	***-100%***
Sugarcane	275.98	1,182.03	457.56	449.93	30.50	141.08	674.90	189.51
%Difference	***0.5%***	***47.7%***	***89.8%***	***18.6%***	***72.4%***	***-27.6%***	***80.1%***	***-49.7%***
West Galveston Bay								
Rice-baseline	202.20	3,626.39	15,124.54	1,850.20	195.11	141.29	15,117.82	673.01
Switchgrass	98.65	1,110.12	1,540.71	195.11	20.18	74.01	1,372.51	13.46
%Difference	***51.2%***	***69.4%***	***89.8%***	***89.5%***	***89.7%***	***47.6%***	***90.9%***	***-100%***
Sugarcane	189.00	1,749.28	854.46	383.50	74.01	235.48	8,537.83	359.95
%Difference	***6.5%***	***51.8%***	***94.4%***	***79.3%***	***2.1%***	***-66.7%***	***43.5%***	***-53.48%***

APPENDIX D

SWAT SIMULATION MODEL RESULTS FOR LOGGING RESIDUES

Table D-1. SWAT model results for all 34 HRUs with logging residues in the East Texas region

Watershed	SURQ (mm)	SYLD (mtons)	ORGN (kg)	ORGP (kg)	SEDP (kg)	NSURQ (kg N)	NO_3GW (kg N)	SOLP
Upper Sabine								
LR - baseline	0.22	56.87	0.00	0.00	0.12	0.00	461.54	0.00
LR – 2/3 removed	0.22	58.75	0.00	0.00	0.12	0.00	332.73	0.00
%Difference	***0.9%***	***-3.3%***	***--***	***--***	***0%***	***--***	***27.9%***	***--***
Middle Sabine								
LR - baseline	160.31	13,340.31	1,227.44	193.81	64.60	549.12	121,839.37	129.20
LR – 2/3 removed	165.48	14,438.55	1,453.55	193.81	64.60	581.42	101,328.24	96.90
%Difference	***-3.2%***	***-8.2%***	***-18.4%***	***0%***	***0%***	***-5.9%***	***16.8%***	***25.0%***
Lake Fork								
LR - baseline	46.84	211.12	2.33	0.47	0.47	2.33	849.61	0.93
LR – 2/3 removed	50.14	233.96	2.80	0.47	0.47	2.80	715.39	0.93
%Difference	***-7.1%***	***-10.8%***	***-20.0%***	***0%***	***0%***	***-20.0%***	***15.8%***	***0%***
Toledo Bend Reservoir								
LR - baseline	352.99	88,045.76	4,752.47	750.39	500.26	11,255.85	427,222.04	3,001.56
LR – 2/3 removed	364.06	96,550.18	6,253.25	750.39	500.26	11,255.85	343,928.75	2,751.43
%Difference	***-3.1%***	***-9.7%***	***-31.6%***	***0%***	***0%***	***0%***	***19.5%***	***8.3%***

Table D-1. Continued

Watershed	SURQ (mm)	SYLD (mtons)	ORGN (kg)	ORGP (kg)	SEDP (kg)	NSURQ (kg N)	NO_3GW (kg N)	SOLP
Lower Sabine								
LR - baseline	335.29	95,368.58	2,526.32	315.79	315.79	9,789.49	392,211.18	2,210.53
LR – 2/3 removed	348.68	108,631.76	3,157.90	315.79	315.79	9,789.49	331,579.50	1,894.74
%Difference	***-4.0%***	***-13.9%***	***-25.0%***	***0%***	***0%***	***0%***	***15.5%***	***14.3%***
Upper Neches								
LR - baseline	125.45	7,089.36	498.64	86.72	43.36	303.52	62,048.16	86.72
LR – 2/3 removed	132.60	7,913.20	628.72	86.72	43.36	325.20	48,953.44	65.04
%Difference	***-5.7%***	***-11.6%***	***-26.1%***	***0%***	***0%***	***-7.1%***	***21.1%***	***25.0%***
Middle Neches								
LR - baseline	233.14	60,006.24	1,964.49	357.18	178.59	5,000.52	582,739.17	1,428.72
LR – 2/3 removed	239.38	65,185.35	2,678.85	357.18	178.59	5,000.52	507,909.96	1,428.72
%Difference	***-2.7%***	***-8.6%***	***-36.4%***	***0%***	***0%***	***0%***	***12.8%***	***0%***
Lower Neches								
LR - baseline	279.36	54,535.41	818.85	163.77	163.77	5,731.95	515,547.96	1,637.70
LR - 2/3 removed	298.17	64,361.61	1,637.70	163.77	163.77	6,223.26	466,744.50	1,637.70
%Difference	***-6.7%***	***-18.1%***	***-100.0%***	***0%***	***0%***	***-8.6%***	***9.5%***	***0%***
Upper Angelina								
LR - baseline	207.32	9,229.54	1,035.97	156.97	62.79	784.83	78,670.86	219.75
LR – 2/3 removed	218.48	10,328.30	1,224.33	156.97	62.79	816.22	64,732.37	188.36
%Difference	***-5.4%***	***-11.9%***	***-18.2%***	***0%***	***0%***	***-4.0%***	***17.7%***	***14.3%***

Table D-1. Continued

Watershed	SURQ (mm)	SYLD (mtons)	ORGN (kg)	ORGP (kg)	SEDP (kg)	NSURQ (kg N)	NO_3GW (kg N)	SOLP
Lower Angelina								
LR - baseline	197.09	99,455.20	170.30	0.00	0.00	170.30	50,919.70	0.00
LR – 2/3 removed	200.20	105,415.70	340.60	0.00	0.00	170.30	43,767.10	0.00
%Difference	***-1.6%***	***-6.0%***	***-100.0%***	***--***	***--***	***0%***	***14.1%***	***--***
Village								
LR - baseline	85.75	173,184.48	229.08	0.00	0.00	229.08	1,411,820.04	458.16
LR – 2/3 removed	88.98	192,198.12	687.24	0.00	0.00	229.08	1,297,050.96	458.16
%Difference	***-3.8%***	***-11.0%***	***-200.0%***	***--***	***--***	***0%***	***8.1%***	***0%***
Pine Island Bayou								
LR - baseline	72.60	55,720.70	79.60	0.00	636.81	716.41	397,527.39	159.20
LR – 2/3 removed	75.19	62,247.98	238.80	0.00	636.81	796.01	380,333.58	159.20
%Difference	***-3.6%***	***-11.7%***	***-200.0%***	***--***	***0%***	***-11.1%***	***4.3%***	***0%***
Upper Trinity								
LR - baseline	390.25	4.40	3.58	0.47	0.07	1.13	6.42	0.38
LR – 2/3 removed	402.28	4.85	3.74	0.49	0.07	1.13	5.46	0.38
%Difference	***-3.1%***	***-10.2%***	***-4.6%***	***-5.0%***	***0.0%***	***0.0%***	***15.0%***	***0%***
Cedar								
LR - baseline	0.87	65.85	0.12	0.00	0.12	0.00	525.62	0.00
LR – 2/3 removed	0.84	69.50	0.12	0.00	0.12	0.00	409.24	0.00
%Difference	***4.4%***	***-5.6%***	***0%***	***--***	***0%***	***--***	***22.1%***	***--***

Table D-1. Continued

Watershed	SURQ (mm)	SYLD (mtons)	ORGN (kg)	ORGP (kg)	SEDP (kg)	NSURQ (kg N)	NO_3GW (kg N)	SOLP
Lower Trinity-Tehuacana								
LR - baseline	204.86	1,680.47	327.21	52.51	8.08	96.95	11,912.78	24.24
LR – 2/3 removed	213.30	1,821.86	432.24	60.59	8.08	100.99	9,420.35	28.28
%Difference	***-4.1%***	***-8.4%***	***-32.1%***	***-15.4%***	***0%***	***-4.2%***	***20.9%***	***-16.7%***
Lower Trinity-Kickapoo								
LR - baseline	282.50	125,219.10	2,878.60	863.58	287.86	10,075.10	1,064,794.14	2,015.02
LR – 2/3 removed	297.75	143,354.28	7,772.22	1,151.44	287.86	10,650.82	948,210.84	2,302.88
%Difference	***-5.4%***	***-14.5%***	***-170.0%***	***-33.3%***	***0%***	***-5.7%***	***11.0%***	***-14.3%***
Lower Trinity								
LR - baseline	527.25	9,442.25	1,403.26	261.62	47.57	1,569.74	7,777.37	285.41
LR – 2/3 removed	552.18	10,726.58	2,116.78	285.41	47.57	1,641.10	6,397.90	332.98
%Difference	***-4.7%***	***-13.6%***	***-50.9%***	***-9.1%***	***0%***	***-4.5%***	***17.7%***	***-16.7%***
West Fork San Jacinto								
LR - baseline	58.84	104,767.60	147.56	0.00	0.00	885.36	188,729.24	147.56
LR – 2/3 removed	60.05	112,440.72	147.56	0.00	0.00	1,032.92	173,383.00	147.56
%Difference	***-2.1%***	***-7.3%***	***0%***	***--***	***--***	***-16.7%***	***8.1%***	***0%***
Spring								
LR - baseline	57.59	43,345.96	145.95	0.00	0.00	437.84	498,989.37	72.97
LR – 2/3 removed	59.84	45,389.21	218.92	0.00	0.00	437.84	459,729.90	145.95
%Difference	***-3.9%***	***-4.7%***	***-50.0%***	***--***	***--***	***0%***	***7.9%***	***-100.0%***

Table D-1. Continued

Watershed	SURQ (mm)	SYLD (mtons)	ORGN (kg)	ORGP (kg)	SEDP (kg)	NSURQ (kg N)	NO_3GW (kg N)	SOLP
East Fork San Jacinto								
LR - baseline	69.33	114,997.47	188.83	0.00	0.00	1,510.64	956,612.78	188.83
LR – 2/3 removed	72.08	128,215.57	566.49	0.00	0.00	1,510.64	868,618.00	377.66
%Difference	***-4.0%***	***-11.5%***	***-200.0%***	***--***	***--***	***0%***	***9.2%***	***-100.0%***
Buffalo-San Jacinto								
LR - baseline	173.80	576.61	19.05	4.01	1.00	15.04	4,426.36	3.01
LR – 2/3 removed	177.52	630.76	31.09	5.01	1.00	16.04	4,225.80	3.01
%Difference	***-2.1%***	***-9.4%***	***-63.2%***	***-25.0%***	***0%***	***-6.7%***	***4.5%***	***0%***
East Galveston Bay								
LR - baseline	332.03	69.10	7.42	1.41	0.24	4.94	787.13	1.06
LR – 2/3 removed	336.00	72.86	10.24	1.53	0.24	4.94	762.17	1.18
%Difference	***-1.2%***	***-5.5%***	***-38.1%***	***-8.3%***	***0%***	***0%***	***3.2%***	***-11.1%***
Lower Brazos								
LR - baseline	151.41	12,485.20	230.78	46.16	23.08	392.33	133,621.62	92.31
LR – 2/3 removed	153.53	13,316.01	369.25	46.16	23.08	415.40	122,359.56	92.31
%Difference	***-1.4%***	***-6.7%***	***-60.0%***	***0%***	***0%***	***-5.9%***	***8.4%***	***0%***
Bois D'arc-Island								
LR - baseline	52.36	49.78	1.64	0.22	0.11	0.00	0.00	0.22
LR – 2/3 removed	57.78	57.11	1.86	0.33	0.11	0.00	0.00	0.22
%Difference	***-10.4%***	***-14.7%***	***-13.3%***	***-50.0%***	***0%***	***--***	***--***	***0%***

Table D-1. Continued

Watershed	SURQ (mm)	SYLD (mtons)	ORGN (kg)	ORGP (kg)	SEDP (kg)	NSURQ (kg N)	NO_3GW (kg N)	SOLP
Kiamichi								
LR - baseline	355.11	89,124.86	8,978.18	1,313.88	218.98	0.00	0.00	1,532.86
LR – 2/3 removed	365.61	95,694.26	9,197.16	1,313.88	218.98	0.00	0.00	1,532.86
%Difference	***-3.0%***	***-7.4%***	***-2.4%***	***0%***	***0%***	***--***	***--***	***0%***
Pecan-Waterhole								
LR - baseline	221.44	12,478.49	747.68	103.13	25.78	0.00	0.00	128.91
LR – 2/3 removed	222.64	13,638.68	850.81	128.91	25.78	0.00	0.00	154.69
%Difference	***-0.5%***	***-9.3%***	***-13.8%***	***-25.0%***	***0%***	***--***	***--***	***-20.0%***
Mckinney-Posten Bayous								
LR - baseline	190.40	7,779.60	1,102.11	162.08	32.42	0.00	0.00	226.91
LR – 2/3 removed	183.52	8,103.75	1,004.87	129.66	32.42	0.00	0.00	194.49
%Difference	***3.6%***	***-4.2%***	***8.8%***	***20.0%***	***0%***	***--***	***--***	***14.3%***
Bayou Pierre								
LR - baseline	270.25	24,692.66	3,651.73	434.73	86.95	0.00	0.00	434.73
LR – 2/3 removed	272.42	28,170.50	3,477.84	434.73	86.95	0.00	0.00	521.68
%Difference	***-0.8%***	***-14.1%***	***4.8%***	***0%***	***0%***	***--***	***--***	***-20.0%***
Lower Sulphur								
LR - baseline	52.70	15,507.02	397.62	49.70	24.85	0.00	0.00	49.70
LR – 2/3 removed	50.99	16,824.13	347.91	49.70	24.85	0.00	0.00	49.70
%Difference	3.3%	-8.5%	12.5%	0%	0%	--	--	0%

Table D-1. Continued

Watershed	SURQ (mm)	SYLD (mtons)	ORGN (kg)	ORGP (kg)	SEDP (kg)	NSURQ (kg N)	NO_3GW (kg N)	SOLP
White Oak Bayou								
LR - baseline	318.84	288.18	112.50	13.87	2.31	0.00	0.00	7.71
LR – 2/3 removed	326.57	341.35	110.96	15.41	2.31	0.00	0.00	8.48
%Difference	-2.4%	-18.5%	1.4%	-11.1%	0%	--	--	-10.0%
Cross Bayou								
LR - baseline	54.27	21,840.98	323.57	32.36	0.00	0.00	0.00	64.71
LR – 2/3 removed	54.92	23,620.61	323.57	32.36	0.00	0.00	0.00	64.71
%Difference	-1.2%	-8.2%	0%	0%	--	--	--	0%
Lake O'the Pines								
LR - baseline	58.17	10,575.36	224.64	34.56	17.28	0.00	0.00	17.28
LR – 2/3 removed	58.08	11,439.36	224.64	34.56	17.28	0.00	0.00	17.28
%Difference	***0.2%***	***-8.2%***	***0%***	***0%***	***0%***	**--**	**--**	***0%***
Caddo Lake								
LR - baseline	68.11	44,413.94	770.18	128.36	0.00	0.00	0.00	128.36
LR – 2/3 removed	66.79	46,852.86	706.00	128.36	0.00	0.00	0.00	128.36
%Difference	***1.9%***	***-5.5%***	***8.3%***	***0%***	**--**	**--**	**--**	***0%***
Little Cypress								
LR - baseline	63.08	5,589.99	218.83	29.84	9.95	0.00	0.00	19.89
LR – 2/3 removed	64.14	6,196.73	218.83	29.84	9.95	0.00	0.00	19.89
%Difference	***-1.7%***	***-10.9%***	***0%***	***0%***	***0%***	**--**	**--**	***0%***

APPENDIX E

HAULING OF LOGGING RESIDUES FOR ELECTRICITY

Table E-1. List of average hauling distances for softwood logging residues for biomass fired alone and all co-firing cases (miles):

County	Fired alone	5% Co-fire	10% Co-fire	15% Co-fire
Anderson	300.90	67.28	95.15	116.54
Angelina	131.89	29.49	41.71	51.08
Bowie	215.57	48.20	68.17	83.49
Camp	197.91	44.25	62.58	76.65
Cass	182.92	40.90	57.85	70.85
Chambers	203.85	45.58	64.46	78.95
Cherokee	226.73	50.70	71.70	87.81
Franklin	892.14	199.49	282.12	345.52
Gregg	237.09	53.02	74.98	91.83
Hardin	185.93	41.58	58.80	72.01
Harris	262.53	58.70	83.02	101.68
Harrison	167.93	37.55	53.11	65.04
Henderson	487.22	108.95	154.07	188.70
Houston	197.07	44.07	62.32	76.32
Jasper	134.58	30.09	42.56	52.12
Jefferson	217.22	48.57	68.69	84.13
Liberty	239.82	53.63	75.84	92.88
Marion	173.18	38.72	54.76	67.07
Montgomery	233.89	52.30	73.96	90.58
Morris	199.91	44.70	63.22	77.42
Nacogdoches	168.85	37.76	53.39	65.39
Newton	176.84	39.54	55.92	68.49
Orange	229.30	51.27	72.51	88.81
Panola	175.46	39.24	55.49	67.96
Polk	141.24	31.58	44.67	54.70
Red River	396.29	88.61	125.32	153.48
Rusk	206.87	46.26	65.42	80.12
Sabine	142.73	31.92	45.14	55.28

Table E-1. Continued

County	Fired alone	5% Co-fire	10% Co-fire	15% Co-fire
San Augustine	121.78	27.23	38.51	47.16
San Jacinto	187.46	41.92	59.28	72.60
Shelby	165.33	36.97	52.28	64.03
Smith	252.24	56.40	79.76	97.69
Titus	519.10	116.08	164.16	201.05
Trinity	157.61	35.24	49.84	61.04
Tyler	152.90	34.19	48.35	59.22
Upshur	288.83	64.59	91.34	111.86
Van Zandt	982.06	219.59	310.55	380.35
Walker	193.20	43.20	61.10	74.83
Wood	368.20	82.33	116.43	142.60

Table E-2. List of average hauling distances for hardwood logging residues for biomass fired alone and all co-firing cases (miles):

County	Fired alone	5% Co-fire	10% Co-fire	15% Co-fire
Anderson	561.89	125.64	177.68	217.62
Angelina	454.93	101.72	143.86	176.19
Bowie	331.26	74.07	104.75	128.30
Camp	359.57	80.40	113.70	139.26
Cass	347.08	77.61	109.76	134.42
Chambers	1012.85	226.48	320.29	392.28
Cherokee	385.95	86.30	122.05	149.48
Franklin	777.55	173.87	245.88	301.14
Gregg	376.69	84.23	119.12	145.89
Hardin	588.09	131.50	185.97	227.77
Harris	563.16	125.93	178.09	218.11
Harrison	476.06	106.45	150.54	184.38
Henderson	606.68	135.66	191.85	234.97
Houston	512.32	114.56	162.01	198.42
Jasper	479.98	107.33	151.78	185.89
Jefferson	291.20	65.11	92.08	112.78
Liberty	481.90	107.76	152.39	186.64
Marion	353.64	79.08	111.83	136.96
Montgomery	736.15	164.61	232.79	285.11

Table E-2. Continued

County	Fired alone	5% Co-fire	10% Co-fire	15% Co-fire
Morris	398.48	89.10	126.01	154.33
Nacogdoches	472.83	105.73	149.52	183.12
Newton	593.42	132.69	187.66	229.83
Orange	555.96	124.32	175.81	215.32
Panola	424.64	94.95	134.28	164.46
Polk	630.04	140.88	199.24	244.01
Red River	418.05	93.48	132.20	161.91
Rusk	414.57	92.70	131.10	160.56
Sabine	577.31	129.09	182.56	223.59
San Augustine	586.36	131.11	185.42	227.10
San Jacinto	761.38	170.25	240.77	294.88
Shelby	500.56	111.93	158.29	193.87
Smith	475.06	106.23	150.23	183.99
Titus	388.46	86.86	122.84	150.45
Trinity	419.27	93.75	132.59	162.38
Tyler	349.38	78.12	110.48	135.31
Upshur	516.49	115.49	163.33	200.04
Van Zandt	718.61	160.69	227.25	278.32
Walker	1092.21	244.23	345.39	423.01
Wood	706.67	158.02	223.47	273.69

APPENDIX F

HAULING LOGGING RESIDUES FOR ETHANOL

Table F-1. Average hauling distances for delivering logging residues to the potential ethanol plant in East Texas

County	Average hauling distance for softwood residues (miles)	Average hauling distance for hardwood residues (miles)
Anderson	264.62	494.13
Angelina	115.99	400.07
Bowie	189.57	291.32
Camp	174.04	316.21
Cass	160.86	305.23
Chambers	179.27	890.71
Cherokee	199.39	339.41
Franklin	784.56	683.79
Gregg	208.50	331.27
Hardin	163.51	517.17
Harris	230.87	495.25
Harrison	147.68	418.65
Henderson	428.47	533.52
Houston	173.30	450.54
Jasper	118.35	422.10
Jefferson	191.02	256.08
Liberty	210.90	423.79
Marion	152.30	310.99
Montgomery	205.68	647.38
Morris	175.80	350.43
Nacogdoches	148.48	415.81
Newton	155.51	521.86
Orange	201.65	488.91
Panola	154.31	373.43
Polk	124.21	554.07
Red River	348.50	367.64
Rusk	181.92	364.58
Sabine	125.52	507.69
San Augustine	107.09	515.65
San Jacinto	164.85	669.57
Shelby	145.39	440.20
Smith	221.82	417.77

Table F-1. Continued

County	Average hauling distance for softwood residues (miles)	Average hauling distance for hardwood residues (miles)
Titus	456.51	341.62
Trinity	138.61	368.71
Tyler	134.46	307.25
Upshur	254.00	454.21
Van Zandt	863.63	631.95
Walkers	169.91	960.50
Wood	323.80	621.45

APPENDIX G

COMPARISON OF AVAILABLE BIOMASS WITH BIOMASS REQUIRED FOR A 100 MW POWER PLANT AND A 20 MMGY ETHANOL PLANT ON A COUNTY AND REGIONAL LEVEL IN EAST TEXAS

This Appendix presents the results of comparing switchgrass, sugarcane bagasse, and logging residue availability in East Texas counties with the biomass requirements of a 100 MW power plant and a 20 MMGY ethanol plant. The electricity generation case includes biomass-only and 5%-, 10%-, and 15% co-firing cases. The comparison is given first for individual counties, then for the forest region comprised of 39 forest counties; for the rice region comprised of seven counties, called the “initial rice region”; and ,finally, for the rice region comprised of seven rice counties, which includes acreage from corn, soybean, wheat, and sorghum acreage along with the rice acreage (called “expanded rice region”). The following tables show the amount of biomass available in the study region by county and by region. In addition, the tables present the ratios of available biomass to the biomass required by the power and ethanol plants. The ratio resulting in “one” would indicate that a county or region has just enough biomass to sustain one power or ethanol plant. The ratio that is less than “one” would suggest that a county or region does not have a sufficient amount of biomass to sustain the power or the ethanol plant. Finally, the ratio that is larger than “one” would indicate that a county or region has more than the required amount of biomass to support the power or ethanol plant.

I. Electricity generation

1.1 Case of individual counties

1.1.1 Logging residues

Table I-1. Comparison of logging residues available in the forest counties with the logging residue requirement of a 100 MW power plant

County	Available logging residues (tons/year)	Ratio of available logging residues to amount of logging residues required by a 100 MW power plant			
		Biomass-alone	5% co-firing	10% co-firing	15% co-firing
Anderson	53,993	0.1	1.4	0.7	0.5
Angelina	168,107	0.2	4.3	2.2	1.4
Bowie	89,018	0.1	2.3	1.1	0.8
Camp	18,056	0.0	0.5	0.2	0.2
Cass	191,250	0.2	4.9	2.5	1.6
Chambers	6,672	0.0	0.2	0.1	0.1
Cherokee	123,558	0.2	3.2	1.6	1.1
Franklin	3,954	0.0	0.1	0.1	0.0
Gregg	27,510	0.0	0.7	0.4	0.2
Hardin	129,780	0.2	3.3	1.7	1.1
Harris	34,190	0.0	0.9	0.4	0.3
Harrison	140,493	0.2	3.6	1.8	1.2
Henderson	16,967	0.0	0.4	0.2	0.1
Houston	94,972	0.1	2.4	1.2	0.8
Jasper	227,954	0.3	5.9	2.9	2.0
Jefferson	26,607	0.0	0.7	0.3	0.2
Liberty	78,016	0.1	2.0	1.0	0.7
Marion	88,836	0.1	2.3	1.1	0.8
Montgomery	64,506	0.1	1.7	0.8	0.6
Morris	21,953	0.0	0.6	0.3	0.2

Table I-1. Continued

County	Available logging residues (tons/year)	Ratio of available logging residues to amount of logging residues required by a 100 MW power plant			
		Biomass-alone	5% co-firing	10% co-firing	15% co-firing
Nacogdoches	139,210	0.2	3.6	1.8	1.2
Newton	154,996	0.2	4.0	2.0	1.3
Orange	24,202	0.0	0.6	0.3	0.2
Panola	125,525	0.2	3.2	1.6	1.1
Polk	228,443	0.3	5.9	2.9	2.0
Red River	57,526	0.1	1.5	0.7	0.5
Rusk	113,314	0.1	2.9	1.5	1.0
Sabine	81,825	0.1	2.1	1.1	0.7
San Augustine	120,066	0.2	3.1	1.5	1.0
San Jacinto	58,308	0.1	1.5	0.7	0.5
Shelby	101,969	0.1	2.6	1.3	0.9
Smith	61,013	0.1	1.6	0.8	0.5
Titus	16,775	0.0	0.4	0.2	0.1
Trinity	118,393	0.2	3.0	1.5	1.0
Tyler	252,882	0.3	6.5	3.3	2.2
Upshur	36,604	0.0	0.9	0.5	0.3
Van Zandt	7,324	0.0	0.2	0.1	0.1
Walker	59,486	0.1	1.5	0.8	0.5
Wood	19,647	0.0	0.5	0.3	0.2

1.1.2 Switchgrass

Table I-2. Comparison of switchgrass available in the rice counties with switchgrass required by biomass-alone and all co-firing cases

County	Available switchgrass (tons/year)	Ratio of available switchgrass to switchgrass required by a 100 MW power plant			
		Biomass-alone	5% co-firing	10% co-firing	15% co-firing
Chambers	69383.9	0.1	2.7	1.4	0.9
Galveston	3667.5	0.0	0.1	0.1	0.0
Hardin	3299.5	0.0	0.1	0.1	0.0
Harris	6590.3	0.0	0.3	0.1	0.1
Jefferson	86400.8	0.2	3.4	1.7	1.1
Liberty	45356.8	0.1	1.8	0.9	0.6
Orange	389.7	0.0	0.0	0.0	0.0

1.1.3 Sugarcane bagasse

Table I-3. Comparison of bagasse available in the rice counties with bagasse required by biomass-alone and all co-firing cases

County	Available bagasse (tons/year)	Ratio of available bagasse to bagasse required by a 100 MW power plant			
		Biomass-alone	5% co-firing	10% co-firing	15% co-firing
Chambers	171,136	0.2	4.0	2.0	1.3
Galveston	9,046	0.0	0.2	0.1	0.1
Hardin	8,047	0.0	0.2	0.1	0.1
Harris	16,072	0.0	0.4	0.2	0.1

Table I-3. Continued

County	Available bagasse (tons/year)	Ratio of available bagasse to bagasse required by a 100 MW power plant			
		Biomass-alone	5% co-firing	10% co-firing	15% co-firing
Jefferson	210,714	0.2	4.9	2.5	1.6
Liberty	110,616	0.1	2.6	1.3	0.9
Orange	950	0.0	0.0	0.0	0.0

1.2 Semi - regional analysis

1.2.1 Forest region

Table I-4. Comparison of logging residues available in the forest region with the logging residue requirement of a 100 MW power plant

County	Available logging residues (tons/year)	Ratio of available logging residues to logging residues required by a 100 MW power plant			
		Biomass-alone	5% co-firing	10% co-firing	15% co-firing
Logging residues	2,255,933.3	2.9	58.0	29.0	19.3

1.2.2 Initial rice region

Table I-5. Comparison of switchgrass and bagasse available in the rice region with the switchgrass and bagasse requirements of a 100 MW power plant

County	Available biomass (tons/year)	Ratio of available biomass to biomass required by a 100 MW power plant			
		Biomass-alone	5% co-firing	10% co-firing	15% co-firing
Switchgrass	215088.5	0.4	8.4	4.2	2.8
Sugarcane bagasse	526581.9	0.6	12.3	6.2	4.1

1.2.3 Expanded rice region

Table I-6. Comparison of switchgrass and bagasse available in the expanded rice region with the switchgrass and bagasse requirements of a 100 MW power plant

County	Available biomass (tons/year)	Ratio of available biomass to biomass required by a 100 MW power plant			
		Biomass-alone	5% co-firing	10% co-firing	15% co-firing
Switchgrass	370,535.4	0.7	14.6	7.3	4.9
Sugarcane bagasse	909,652.0	1.1	21.3	10.7	7.1

II. Ethanol production

2.1 Case of individual counties

2.1.1 Logging residues

Table II-1. Comparison of logging residues available by county with the logging residue requirement of a 20 MMGY ethanol plant

County	Available biomass (tons/year)	Ratio of available biomass to plant required biomass
Anderson	53,993	0.1
Angelina	168,107	0.3
Bowie	89,018	0.1
Camp	18,056	0.0
Cass	191,250	0.3
Chambers	6,672	0.0
Cherokee	123,558	0.2
Franklin	3,954	0.0
Gregg	27,510	0.0
Hardin	129,780	0.2
Harris	34,190	0.1
Harrison	140,493	0.2
Henderson	16,967	0.0
Houston	94,972	0.2
Jasper	227,954	0.4
Jefferson	26,607	0.0
Liberty	78,016	0.1
Marion	88,836	0.1
Montgomery	64,506	0.1
Morris	21,953	0.0
Nacogdoches	139,210	0.2
Newton	154,996	0.3

Table II-1. Continued

County	Available biomass (tons/year)	Ratio of available biomass to plant required biomass
Orange	24,202	0.0
Panola	125,525	0.2
Polk	228,443	0.4
Red River	57,526	0.1
Rusk	113,314	0.2
Sabine	81,825	0.1
San Augustine	120,066	0.2
San Jacinto	58,308	0.1
Shelby	101,969	0.2
Smith	61,013	0.1
Titus	16,775	0.0
Trinity	118,393	0.2
Tyler	252,882	0.4
Upshur	36,604	0.1
Van Zandt	7,324	0.0
Walker	59,486	0.1
Wood	19,647	0.0

2.1.2 Switchgrass

Table II-2. Comparison of switchgrass available by county with the switchgrass requirement of a 20 MMGY ethanol plant

County	Available biomass (tons/year)	Ratio of available biomass to plant required biomass
Chambers	69,383.9	0.2
Galveston	3,667.5	0.0
Hardin	3,299.5	0.0
Harris	6,590.3	0.0
Jefferson	86,400.8	0.2
Liberty	45,356.8	0.1
Orange	389.7	0.0

2.1.3 Sugarcane bagasse

Table II-3. Comparison of bagasse available by county with the bagasse requirement of a 20 MMGY ethanol plant

County	Available biomass (tons/year)	Ratio of available biomass to plant required biomass
Chambers	171,136.3	0.3
Galveston	9,046	0.0
Hardin	8,046.7	0.0
Harris	16,072.3	0.0
Jefferson	21,0714.2	0.4
Liberty	11,0616	0.2
Orange	950.4	0.0

2.2 Semi - regional analysis

2.2.1 Forest region

Table II-4. Comparison of logging residues available in forest region with the logging residue requirement of a 20 MMGY ethanol plant

Feedstock	Available biomass (tons/year)	Ratio of available biomass to plant required biomass
Logging residues	2,255,933.3	3.8

2.2.2 Initial rice region

Table II-5. Comparison of switchgrass and bagasse available in the initial rice region with the switchgrass and bagasse requirement of a 20 MMGY ethanol plant

Feedstock	Available biomass (tons/year)	Ratio of available biomass to plant required biomass
Switchgrass	215,088.5	0.5
Sugarcane bagasse	526,581.9	1.0

2.2.3 Expanded rice region

Table II-6. Comparison of switchgrass and bagasse available in the expanded rice region with the switchgrass and bagasse requirement of a 20 MMGY ethanol plant

Feedstock	Available biomass (tons/year)	Ratio of available biomass to plant required biomasss
Switchgrass	370,535.4	0.8
Sugarcane bagasse	909,652.0	1.8

APPENDIX H

EXAMPLE OF BIOENERGY COST-BENEFIT ANALYSIS

The following is a small example of cost-benefit analysis which demonstrates how incorporating environmental and social benefits stemming from production of biomass feedstocks and bioenergies can affect a decision about whether or not to pursue these energies in the study region. The cost-benefit analysis will be presented for switchgrass as an example. Analysis for logging residues and sugarcane bagasse will have to follow the same pattern. In addition, it should be recognized that the set of costs and benefits included here is not exhaustive, but is rather a sample set of selected impacts related to the bioenergy production processes. The set of costs and benefits is listed in Table H-1 along with their effects on the region (positive (+) or negative (-)) and monetary values. The effects were discussed earlier in Chapters VI, VII, and VIII.

We were able to put a monetary value on some of the impacts and benefits listed in the table. Other benefits such as health effects, reduction in soil erosion, surface and groundwater contamination were only quantified here, but not valued.

The “Total effect” line in Table H-1 shows that accounting for a full range of benefits and impacts indicates that it is worth pursuing biomass energies in the study region. This result is opposite to what we concluded based only on the feedstock economics in earlier sections. Moreover, this conclusion will be even stronger when environmental benefits listed in the table with the question mark will get their monetary values. However, the “Total effect” figure would be reduced if we performed more accurate analysis and included values for jobs lost in the rice production, petroleum refineries, and coal mining sectors as a result of bioenergy production. The dollar amount of the "Total effect" could suggest the regional policy makers the size of subsidies or incentives, which would help make the power generation and ethanol production the viable energy alternative in the region.

Table H-1. Cost-benefit analysis of pursuing power generation and ethanol production in East Texas using switchgrass

Factor	Impact (+/-)	Electricity (U.S. $)	Ethanol (U.S. $)
Renewable resource	+	?	?
Coal saving	+	6,825,000.00	N/A
Gasoline saving	+	N/A	20,125,000.00
Reduction in CO2Eq Emissions	+	10,458,720.00	1,514,400.00
Reduction in:			
- soil erosion	+	?	?
- surface water contamination	+	?	?
- ground water contamination	+	?	?
Feedstock cost (w/o transport)	-	14,651,869.22	12,934,899.24
Transport	-	2,749,134.60	2,308,829.52
Subsidies	+	10,800,000.00	10,200,000.00
Jobs	+	1,569,868.00	1,436,450.00
Health	+	?	?
Total effect		**12,252,584.18**	**18,032,121.24**

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