THE USABILITY OF SWITCHGRASS, RICE STRAW, AND LOGGING RESIDUE AS FEEDSTOCKS FOR POWER GENERATION IN EAST TEXAS

A Thesis

by

SUNG WOOK HONG

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

MASTER OF SCIENCE

May 2007

Major Subject: Agricultural Economics

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Approved by :

Chair of Committee,	Bruce A. McCarl
Committee Members,	David Bessler
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ABSTRACT

The Usability of Switchgrass, Rice Straw, and Logging Residue as Feedstocks for Power
Generation in East Texas. (May 2007)
Sung Wook Hong, B.A., Korea University
Chair of Advisory Committee: Dr. Bruce A. McCarl

This thesis examines the economic implications of using agriculturally based feedstock for bio-energy production in East Texas. Specifically I examined the use of switchgrass, rice straw, and logging residue as a feedstock for electrical power generation in East Texas replacing coal.

To examine the effects of such a substitution, an environmental bio-complexity approach is used to analyze the interactions of agricultural, technological, economic, and environmental factors. In particular, lifecycle analysis (LCA) and Cost-Benefit analysis is used.

The results show that as we use more bio-energy for power generation, we will get less Greenhouse Gas (GHG) emission, which will be an environmental benefit in the long run. The main problem is that cost increases. Current biomass feedstock production costs are generally too high for biomass feedstock to replace coal in power generation. However I find that GHG offset prices can make biomass economically attractive. In particular GHG offset prices and forgiveness for the emissions from combustion based on photosynthetic absorption would raise the price people would be willing to pay for biomass feedstock making it competitive.

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CHAPTER I

INTRODUCTION

1.1 Climate Change and the Kyoto Protocol

Climate change is one of the greatest environmental, social and economic threats facing the Earth. The Earth's global average surface temperature has been increasing since 1861. Over the twentieth century the global surface temperature has increased by 0.6 ± 0.2° C and it is projected to continue rising with a forecast increase ranging from 1.5°C to 4.5°C by the end of this century (Intergovernmental Panel on Climate Change, 2001). Such a temperature rise is likely to generate serious consequences for humanity and other life forms alike, including a rise in sea levels of an estimated 9 to 88 cm by the end of this century, which will endanger coastal areas and small islands, and a greater frequency and severity of extreme weather events (Intergovernmental Panel on Climate Change, 1996). Human activities that contribute to climate change include the burning of fossil fuels and deforestation, both of which cause emissions of carbon dioxide (CO_2), the main greenhouse gas.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change strengthens the international response to climate change. Adopted by consensus at the third session of the Conference of the Parties in December 1997, it contains legally binding emissions targets for Annex I countries (developed countries) for the post-20th

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This thesis follows the style of *American Journal of Agricultural Economics*.

century. By arresting and reversing the upward trend in greenhouse gas emissions that started in these countries 150 years ago, the Protocol promises to move the international community one step closer to achieving the Convention’s ultimate objective of preventing "dangerous anthropogenic [man-made] interference with the climate system". The developed countries committed themselves to reducing their collective emissions of greenhouse gases by at least 5%. This group target will be achieved through cuts of 7% by the US, 8% by the European Union, and 6% by Canada, Hungary, Japan, and Poland. Russia, New Zealand, and Ukraine are to stabilize their emissions. Each country’s emissions target must be achieved by the period of 2008-2012. In particular, an international emissions trading regime will be established allowing industrialized countries to buy and sell emissions credits among themselves. They will also be able to acquire emission reduction units by financing certain kinds of projects in other developed countries through a mechanism known as Joint Implementation. They will be able to pursue emissions cuts in a wide range of economic sectors. The Protocol encourages governments to cooperate with one another, improve energy efficiency, reform the energy and transportation sectors, promote renewable forms of energy, phase out inappropriate fiscal measures and market imperfections, limit methane emissions from waste management and energy systems, and protect forests and other carbon sinks.

There are so many countries just beginning to address the overriding reality of the need to exploit more sustainable and politically secure energy resources. The supply of fossil fuels is shifting geographically as existing sources are depleted and new, more economic resources are opened up. This change is dependence on imported energy will grow rapidly in the next decade. The politics of environmental protection, especially with regard to Climate Change is forcing governments to initiate programs to reduce carbon emissions, improve energy efficiency and exploit less carbon intensive energy sources. Bio-energy is at the center of these changes as the only renewable carbon fuel with the potential to address the full range of energy markets including heat, electricity and transport. The renewable energy strategies of the United States expect the bio-energy sector to be pre-eminent in the global market for secure, indigenous and renewable energy supplies in the next century and to play a vital role in underpinning the overall transition to sustainable energy.

1.2 Objectives

The main objective of the study is to economically evaluate the possibility for generating electric power from agricultural and forest biomass in East Texas. Specifically, the study will assess the economic costs and benefits of electric power production using switchgrass, rice straw and logging residues.

The economic estimation will consider the costs of energy production, feedstock production, and greenhouse gas emission mitigation. Also a life cycle assessment approach will be applied to this analysis.

The study will analyze electricity generation of energy by utilizing biomass. In this study, two scenarios will be examined for electricity generation:

a) Fired alone using biomass

b) Co-firing using coal and biomass (i.e., supplementing coal usage in coal-fired boilers with biomass sources).

The study will propose a framework that can be used to assist regional planners in their decision-making process regarding whether or not to pursue a sustainable bio-energy strategy and what types of feedstock to choose.

1.3 Organization of the Thesis

The remaining chapters are organized as follows. Chapter II presents a literature review on the issues related to biomass as a feedstock for generating electricity and reducing greenhouse gas emissions. Chapter III introduces the methodology that will be used to develop the analysis of the usability of switchgrass, rice straw and logging residue as alternative feedstock for generating electricity in East Texas region. Chapter IV presents the economic analyses on each of the three feedstocks. Chapter V draws conclusions and outlines future studies.

CHAPTER II

LITERATURE REVIEW

The pros and cons of using biomass feedstock for energy purposes have been discussed in many United States and international studies. Here we present a literature review on environmental and economic issues in relation with biomass feedstock for generating electricity.

2.1 Biomass and Bio-energy Systems

Biomass or bio-energy[1] was the early principal source of energy usage with early man burning wood to cook food and to provide heat. At present, wood is still one of the largest biomass energy resources but reliance on it was greatly diminished during the 20th century. Biomass is often argued to be the largest, most diverse and readily exploitable resource. Biomass comes from a wide range of sources: all water and land-based vegetation and trees, and all waste biomass such as municipal solid waste (MSW), municipal bio-solids (sewage), animal waste (manures), forestry and agricultural residues, and certain types of industrial wastes (Klass et al, 2004). Even the fumes from landfills can be used as a biomass energy source.

Biomass has a potential to improve the environmental and economic issues in relation with energy producing processes. From the environmental point of view,

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[1] Bio-energy is the energy generated using biomass matter as a feedstock.

biomass, especially energy crops, can benefit the environment through reduction in air and water pollution, soil quality improvement and soil erosion reduction reference. Biomass requires less fertilizers and pesticides than traditional agricultural crops. It also reduces the soil erosion as well as water pollution by cutting back the agricultural runoff to the nearby water bodies. For example, since some energy crops are replanted only every 10 years, less soil erosion plowing is needed. Hohenstein and Write (1994) estimated 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 the biomass impact on concentrations of atmospheric CO_2. The population increase and anthropogenic activities such as energy consumption, land use changes due to urbanization, conversion of forests to agricultural and pasture lands contribute to atmospheric CO_2 build-up (Hohenstein et al, 1994). 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 energy generation carbon dioxide emissions by 90% compared to fossil fuels. It also substantially reduces amounts of sulfur dioxide and other pollutants in the air. Kline, Hargrove and Vanderlan (1998) argued that switching to biomass-fueled power plants would reduce net emissions by 95%. From an economic point of view, biomass energy will become more widely used only if they are economically competitive with traditional energy sources. 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 feedstock to produce energy in the U.S. (Walsh M.E., 1998). Biomass energy cost depends on numerous factors, such as the feedstock type, availability and yields, transportation costs and etc. In addition, the process of converting the bio-fuels into energy needs to be reliable and efficient. The cost-effectiveness of bio-fuels as an energy resource depends largely on site-specific circumstances. Since bio-fuels have low energy content per ton compared to fossil fuels, they must be used close to their source of production to minimize transportation and handling costs (Klass, 2004). 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 bio-fuel energy.

2.2 Biomass Source

There are many types of plants in the world, and many ways they can be used for energy production. In general, there are four types of biomass: plants that are grown specifically for energy use which are commonly called energy crops (e.g., switchgrass, willow, hybrid-poplar) and residues from plants that are used for other purposes (e.g. residuals from corn, wheat etc.), conventional products that can be diverted to energy generation like trees, corn, wheat, sugarcane and agricultural wastes such as manure, milling byproducts, and bagasse. According to the Oak Ridge National Laboratory estimations, the total world biomass resources are huge comprising of 99% of crop biomass and 80% of forest biomass (ORNL, 2004).

The choice of plant species as biomass feedstocks depends largely upon the end-use and the bio-conversion option of interest, e.g. combustion, gasification, pyrolysis, fermentation or mechanical extraction of oils (McKendry, 2002). The plants that have been 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).

In this study, we examine selected biomass feedstock which is perennial grasses switchgrass, rice straw and logging residues. These feedstocks are selected because they have high potential to the biomass feedstock of East Texas region. These feedstocks are discussed in the following sections.

2.3 Switchgrass as Bio-energy

Switchgrass is a native plant to North America where it grows naturally from Canada to deep into Mexico, mostly as a prairie grass. Because it is native, switchgrass is resistant to many pests and plant diseases. It is also capable of producing high yields with very low applications of fertilizer. According to Bransby (2004), switchgrass is “very tolerant of poor soils, flooding and drought, which are widespread agricultural problems in the southeast of Texas”. It grows fast, capturing lots of solar energy and turning it into chemical energy such as cellulose that can be liquified, gasified, or burned directly. Switchgrass reaches deep into the soil for water, and uses the water very efficiently. It is an 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. In addition, switchgrass normally requires herbicide use only during the establishment year, whereas corn and other annual crops require annual applications (McLaughlin et al., 1998). With its network of stems and roots it holds onto soils so it slows down runoff and anchors soils. Switchgrass can also filter runoffs from the fields planted with traditional row crops. For example, buffer strips, planted along stream banks and around wetlands, could remove soil particles, pesticides, and fertilizer residues from surface water before they reach groundwater or streams.

Switchgrass removes carbon dioxide (CO_2) from the air as it grows, therefore it has the potential to reduce the build-up of this greenhouse gas in the atmosphere and lower the risk of global warming. Unlike fossil fuels, which simply release more and more CO_2 that has been stocked in geologic storage for millions of years, energy crop switchgrass recycles CO_2 over and over again, with each year's cycle of growth and use.

Switchgrass has been researched extensively as a forage crop particularly in Midwestern and Northeastern U.S (Vogel, and Masters, 1998). However, until recently little research has been done on switchgrass as a biomass or forage crop in Texas. According to Faidley (1995), there are nineteen million hectares that are potentially suited for switchgrass production in Texas. The Texas Agricultural Experimental Station was chosen by the U.S. Department of Energy Biomass Feedstock Development Program in 1992 as one of three regional cultivars and management testing centers to focus on switchgrass as a bioenergy feedstock (Sanderson et al, 1999). The five-year trial comparing commercially available switchgrass cultivars in five locations in four physiographic regions of Texas (e.g. Stephenville, Beeville, Dallas, Temple, and College Station) reported that Alamo switchgrass is the best-adapted commercially available switchgrass cultivar for biomass feedstock production in Texas. Therefore, the Alamo cultivar is used for switchgrass potential analysis in East Texas in this paper.

2.4 Rice Straw as Bio-energy

Rice straw is a source of biomass used today for energy. It is mainly disposed by field burning, and only 40 percent of rice straw is used for steam and/or power production. Rice straw gets accumulated during rice harvesting process. Average stem weight ranges from 1.3g to 2.6g and higher stem weight corresponds to higher yield but lower stand density (Summers et al, 2002). Forty percent of biomass is in the internode sections of the stem, 53% is in the leaf and sheath, 4% in the nodes and 3% in the panicle (excluding hull and seed). Since many properties vary by botanical fraction, height of cut influences both the yield and composition of the straw. The ability to predict the amount and composition of the biomass material allows for greater control in the design and mobilization of the harvesting system.

Rice is heavily produced in areas of East Texas with 51,800 acres, and rice straw yielding is approximately 8,399.185 tons/year thus could be an important biomass source.

2.5 Logging Residue as Bio-energy

Residues from the wood products and forestry industries are the largest source of biomass used today for energy. They supply about 64% of the total used in the United States (Climate Change Technologies, 2000).

Logging residues get accumulated during wood harvesting process and are defined as woody 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 (Weihuan et al, 2005).

Various industrial and consumer products can be made from logging residues. They can be combusted, fermented, or used in bioreactors (to make carbon and hydrogen) for the production of energy or to produce fuels or industrial chemicals (Burden et al 2003). The vast majority of Texas forests are located in East Texas. This part of the state is the home and heart of Texas forest industry. Forest land dominates the landscape of East Texas, where forests are 56% of the land. 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)).

2.6 Electric Power Generation

The United States currently obtains more than 55% of its electricity from coal, and coal-fired power plants consume 87% of all U.S. coal produced (U.S. DOE). Traditional coal-fired power plants emit toxic chemicals and greenhouse gases into the atmosphere, and create toxic and nuclear waste. Coal-fired power plants are responsible for 93.4% and 80.2% of power production related SO_2 and NO_x emissions, respectively (Mann M.K. and P. Spath, 2001). Additionally, coal is responsible for 35.8% of all CO_2 emission and 73.5% of all CO_2 emission from power plants (U.S. DOE 1998). In Texas, electricity is generated by using coal and lignite, as well as natural and nuclear power. For example, according to state summary of Texas Environmental Profiles in Electricity in Texas, in 2000, 46% of electricity came from natural-gas-fired plants, 41% came from coal-powered plants and 13% came from nuclear-powered plants. Since 1995, 56 new power plants have been built in the state with another 14 approved power plants being on hold, all of which were to use fossil fuels as source of energy. The Texas power plants release a total of 263 million tons of greenhouse gas into the air each year (Texas Environmental Profiles, 2005). In contrast, a biomass-fired power plant emits CO_2 into the atmosphere, which is then removed from atmosphere by biomass plant growth through photosynthesis (McCarl et al, 2000).

2.7 Electric Power Generation from Biomass

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 bio-processed gases and liquids. Forest products and other biomass are currently being used for conversion to electric power through conventional combustion technology. The biomass power industrial plants in the U.S. are composed of about 350 plants with combined capacity of about 7,800 megawatts, according to a DOE database. In addition, according to Department of Energy in Oregon

State, another 650 industrial plants generate electricity with biomass for their own use. It is estimated that 50,000 megawatts of bio-power could be generated by 2010 using advanced technologies and improved feedstock supplies.

The primary technologies for the conversion of biomass to electricity production are 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.

Most 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.

Co-firing involves substituting biomass for a portion of coal in an existing power plant furnace. It is the most economic near term option for introducing new biomass power generation (Biomass Program: Electric Power Generation in US DOE). Because much of the existing power plant equipment can be used without major modifications, co-firing is far less expensive than building a new biomass power plant. Compared to the coal it replaces, biomass reduces sulfur dioxide (SO_2), nitrogen oxides (NO_x), and other emissions. Coal-fired power plants generally have higher efficiencies, lower capital requirements, and lower electricity generating costs than combusting the same fuels in dedicated biomass and waste fuel power plants. The local availability and cost of biomass and waste resources are principal factors 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 or waste to easily support the level of co-firing and where the cost of the resource is less than that of coal. Studies by the Electric Power Research Institute 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 ranges from $1.00 to $1.50 per million BTU, it is difficult for biomass to compete.

Texas has an immense amount of biomass resources and produces and uses more electricity than any other state in the U.S. (Texas Environmental Profiles, 2005). However, no biomass-fired electricity generating plant exists in the state. Two scenarios of producing electric power from biomass that are considered in this study are:

a) Fired alone switchgrass, rice straw or logging residues in an existing power plant

b) Co-firing switchgrass, rice straw or logging residues with coal in an existing power plant.

2.8 Case Study – East Texas

The East Texas region is selected to evaluate the complexity of concerns related to fossil fuels usage and examine the role of biofuels in addressing these concerns. The East Texas area resides in one of the nation’s leading agricultural states, Texas. The area has vast agricultural and forest acreage.

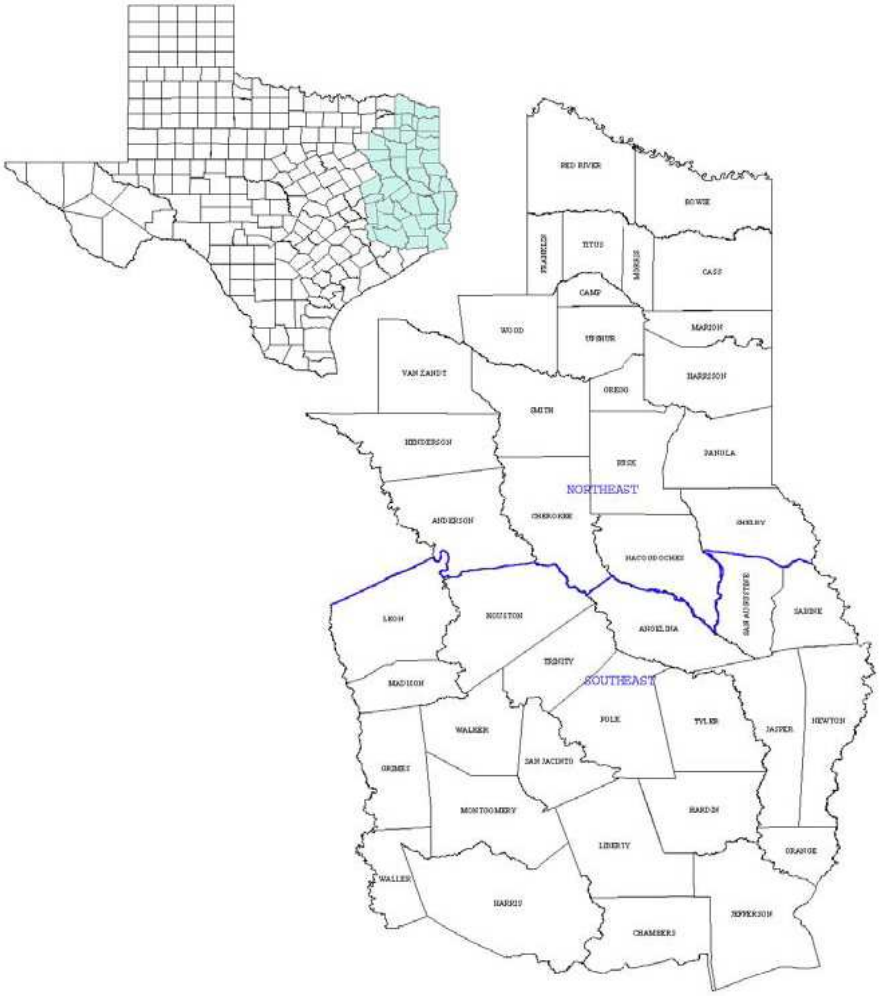

Fig. 1 Study Area

Figure 1 shows the study area. It includes the counties of Orange, Harris, Liberty, Hardin, Chambers, Galveston, and Jefferson that are part of the area known historically as the rice producing area. Rice farmers in these counties are facing various production process challenges. The 1996 Farm Bill and resultant market environment have put an increasing economic pressure on rice farmers. Namely, as a consequence of reducing governmental payment rates for rice, increasing competition for water, lacking of economically viable rotation crops and rising costs to comply with governmental programs and environmental regulations, there has been a tremendous drop in rice production in Texas (Balas et al., 1993). 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 (Texas Agricultural Statistics Service, 2002). Furthermore, the average market price for Texas rice has dropped sharply since its peak in 1996 from $10 per hundredweight to $6 per hundredweight in 2000 (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. One of the options for farmers and forest producers to face their challenges would be to participate in the nation’s biomass-to-energy effort by selling their biomass feedstock to energy producing facilities.

Another reason, why the East Texas region is selected, 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. The population projections for the study region of 44 counties indicate that the area population will increase from 5.78 million 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 the already serious air pollution and water contamination problems and cause various environmental and health problems in the region. Moreover, air pollution of East Texas region exceeds national pollution standards (SECO Fact Sheet, No. 25) and is required to use oxygenates in gasoline.

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 to be 9,140,000 dry tons per year (State Bioenergy, 2004). According to Texas Energy Overview, 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 (State Bioenergy, 2004).

Furthermore, 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 on-line, 2005). Precipitation is not evenly distributed over 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 on-line, 2005). This high rainfall gives rise to a very important lumbering industry, and a good supply of grasses for livestock grazing and agricultural yields. Energy crops like switchgrass, which will be investigated in this study, require substantial rainfall and/or irrigation and the region are believed to create favorable conditions for their production.

CHAPTER III

METHODOLOGY

In this study several methodologies and modeling techniques will be employed to estimate the economic and environmental impacts of bio-energy production in the study area. The main categories used are Life Cycle Assessment (LCA) and simple budgeting.

3.1 Life Cycle Assessment (LCA)

LCA has emerged 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). LCA takes into account the environmental burdens 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. In addition, it assists in identifying and evaluating opportunities to affect environmental improvements. One of the key advantages of using LCA is that it allows a direct comparison between two products or services with regards to the environmental and energy impact (LCA).

LCA has been employed to research similar problems in the U.S. and worldwide. For example, Mann and Spath conducted an LCA on coal-fired power systems that co-fires wood residue and captured 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*. used LCA unified with an economic analysis to examine the competitiveness of switchgrass as a biomass resource in comparison with the energy sources that biomass would replace, including coal. Analysts from the U.S. National Bioenergy Center at NREL also employed LCA 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.

In this study, LCA analysis will be couples with an economic analysis and will be utilized to examine the economic, environmental and energy implications of replacing coal with switchgrass, rice straw and woody residues in the electricity generation process. Specifically, LCA will be used to quantify the energy and other resource consumption and greenhouse gas emissions from the feedstock production processes up to the point of burning those feedstocks to generate electricity.

3.2 Cost-Benefit Analysis

Cost-benefit analysis is a technique to ‘assess the relative desirability of competing alternatives in terms of the economic worth to society’ (Sinden and Thampapillai, 1995). It is widely used in government throughout the world to assist with choices involving public and private projects or government programs because it has the most developed theoretical foundation of the available techniques.

3.2.1 Theoretical Basis of Cost-Benefit Analysis

This foundation begins with an ethical view (Sinden and Thampapillai, 1995) that:

- Activities to be undertaken or goods to be produced should be assessed in terms of their usefulness to humans.
- Usefulness should be judged in terms of usefulness to individuals, as judged by those individuals who will best know their own welfare.
- The welfare of all individuals in society must be included.

The technique is therefore human centered and individualistic. That is, the analyst or the agency should have no role in determining what is useful, only in observing what all individual humans in society find useful. Alternative ethical frameworks might see a normative view imposed as to what is good for society or for the ecology. Cost-benefit analysis is agnostic on these issues, and is only concerned with measuring how people do value things, not how they should value them.

CHAPTER IV

ANALYSIS OF BIOMASS FEEDSTOCK

4.1 Yields and Production Cost of Biomass Feedstock

Many factors affect yield, including plant characteristics,. soil characteristics, climate factors (rainfall, temperature frost free days temperature extremes among other factors), solar radiation, fertilizer, herbicide and pesticide use, and management practices (such as planting and harvesting schedules, tillage practices, and harvesting methods). In addition, for woody crops the number of trees planted per acre, the number of years between harvests and the use of coppicing (re-growth from the stump instead of replanting), are the important factors (King et al., 1999). In this section issues such as feedstock availability, yield and feedstock budgets will be discussed for each of feedstock considered as a potential biomass source in East Texas region.

4.1.1 Switchgrass

Switchgrass is as a perennial grass with high potential for energy production. Switchgrass yield performance has been researched by many scientists.

McLaughlin and Kszos (2005) report that current average annual yields from switchgrass in small plots over multiple years at 23 US locations from 4.2 to 10.2 dry tons per acre, with most locations having an average between 5.5 and 8 dry tons per acre.

Switchgrass production trials established in various locations in Texas during 1992 to 1996 have revealed that the Alamo cultivar was the best adapted switchgrass producing yields of 3.6 to 8 dry tons per acre (Sanderson et al, 1999). Based on the Walsh et al., average yield results for the South Plains region, which includes Texas, exhibits yield of 5.8 dry tons per acre with a stand life of 10 years. In addition it grows well in East Texas and since that is a high rainfall region has no need for additional irrigation.

Switchgrass production costs in this study are adapted from Qin et al (2006). For the scenario of converting rice land to switchgrass, we use the Qin et al (2006) production process assumptions but modified their yields to 5.8 tons per acre per year. So we assume that switchgrass is established on crop land, harvested loose for hauling and chopping, and transported by compression into modules. In general, establishment of switchgrass requires a two-year period. It is assumed that approximately 25% of the fields are not successfully established during the first year and reseeding is carried out for these fields (Ney et al., 2002). Establishment includes seeding of the fields, application of herbicides and lime, and soil preparation, and it is assumed that the field equipment such as herbicide applicator and no till-drill are used. Further maintenance of switchgrass fields is assumed to be a relatively low cost process which mainly includes fertilizer application and mechanical weed control. These operations require a fertilizer spreader and a sickle mower. A Mower-conditioner and silage chopper with a wagon is assumed to be are utilized for harvesting alone with loose hauling and chopping. The switchgrass budget cost for the yield of 5.8 tons per acre reflecting the establishment, maintenance, and harvesting amounts to $ 174.92 per acre, or $ 30.16 per ton.

4.1.2 Rice Straw

Straw makes up about 50% of the dry weight of a rice plant, with a significant variation from 40% to 60% according to the cultivar and cultivation method. For every tone of grain harvested, about 1.35 tones of rice straw remain in the field (Summers et al, 2002). Rice straw has a high potential as a source of lignocellulosic biomass because of the high yield of rice straw per hectare. The proportion of recoverable straw depends on the technique of reaping and harvesting (manual or mechanical) and on the condition of the field (wet or dry) and crop (lodged or not). About 5.6 - 6.7 t ha (2.5 - 3 tons per acre) of dry straw is an average net production (Kadam et al, 2000). The rice acreage in East Texas is estimated about 210,000 acres in 2001 (Texas Water Resource Institute, 2001). The yield of rice straw is calculated from the following formula,

Residue after harvest = Yield * Straw-to-Grain Ratio* Weight Conversion Factor.

Straw-to-Grain Ratios is 1.27 and the weight conversion factor is assumed to be 0.05 taken from Summers et al (2003).

According to USDA National Agricultural Statistics Services the East Texas region average rice harvested acres for what year are 51,800 acres and yields are 2,916,020 hundredweights.

Table 1 represents Average Annual Production Rice Straw in East Texas Counties in 2002. Annual average rice straw production in East Texas is 185,167.27 hundredweights/year or 8,399.185 ton/year.

Table 1. Average Annual Production Rice Straw in East Texas Counties in 2002

County	Harvested (acres)	Yield (pounds/acre)	Production (hundredweights)	Rice straw (hundredweights)
Bowie	1,700	6,760	115,000	7,302.5
Chambers	16,000	5,530	885,000	56,197.5
Galveston	1,000	8,300	83,000	5,270.5
Harrison	1,600	6,250	100,000	6,350
Jefferson	19,900	5,230	1,041,000	66,103.5
Liberty	10,500	6,400	672,000	42,672
Orange	1,100	1,820	20,020	1,271.27

The method commonly used to harvest and handle rice straw is baling, and even this has been done only on a limited basis because of the lack of demand for the rice straw.

If rice straw were to be harvested on a large scale a total harvest system as discussed by Horsfield et al (1977) and Dobie et al (1973) is likely to arise. Such a system removes both straw and grain in a single operation and hauls it to a designated location at the edge of the field, the farmstead, or the grain elevator for separation. The major pieces of equipment needed consist of a collector device, a stationary or modified combine, straw drying equipment, and a large baler. The grain collected can be separated from the straw outside the field with the unthreshed rice unloaded to form long, high piles. A combine with a modified feeding device would process these piles, threshing the rice and dropping the straw in an adjacent pile. An air duct beneath the straw pile would then let natural or heated air to be blown through the pile to dry the straw.

In this study, harvest assumptions of rice straw are the following: swathing into windrows, baling in large square bales, and moving to road side for transport. Harvesting costs are $13.54 per ton based on Fife and Miller (1999) and Summers (2003).

4.1.3 Logging Residue

The volumes of logging residues in the study area are available from the Texas Forest Service (Xu and Carraway, 2005). Residue data estimates are based on a mill survey conducted by the Texas Forest Service and a wood utilization study published by (Bentley and Johnson, 2004). The Texas Forest Service includes stumps, tops, limbs, and unutilized cull trees in defining the logging residues types. Cass, Harrison, Nacogdoches, Panola, Cherokee, Tyler, Polk, Jasper, Angelina and Newton have been identified as top potential producers of logging residue. In 2003, a total of 3.38 million tons of logging residues were produced in East Texas, 68.8 percent from softwood and 31.2 percent from hardwood. Total amount of logging residues in East Texas in 2003 were 3.38 million tons.

Table 2 shows the average annual recoverable logging residues in east Texas counties.

Table 2. 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 per acre we divide the volumes of residue from the above acreage by the private forest land acreage from the 2003 Forest Inventory Analysis (FIA). Logging residue harvest cost of $8.71 per ton is taken from the Forest Residues Transportation Costing Model (FRTCM) (Rummer, 2001). This cost estimate accounts for all fixed, variable and labor costs involved in the logging residue harvest process and does not consider costs involved during forest establishment, maintenance and tree harvest stages.

4.2 Power Plant Requirement and Cost for Biomass Feedstock

McCarl et al. (2000) assumed that the annual energy requirement for a 100 MW power plant is 7 trillion Btu (TBtu). In this study, we use that assumption. The following Higher Heating Values (HHV) and moisture levels were used to calculate the thousands of tons of wet biomass required to provide 7 TBtus annually. Following Table 3 shows Higher Heating Values (HHV) and moisture levels of each feedstock.

Table 3. Higher Heating Values (HHV) and Moisture Levels of Each Feedstock

Biomass	HHV	HHV units	Moisture Percent
Switchgrass	15991	kJ/kg wet	11.99%
Rice straw	15200	kJ/kg dry	15%
Logging Residues	4500	Btu/lb wet	50.00%

Using the conversion factors of 0.9478171 Btu/kJ, 907.18474 kg/ton, and 1.1023113 ton/tonne, the amounts of feedstock that the 100 MW plant would require for its annual operations are shown in Table 4.

Table 4. Annually Required Quantity of Feedstock at the 100MW Power Plant

Feedstock	Btu/ton	Tons
Switchgrass	13,749,785	509,099
Rice Straw	13,069,147	630,108
Logging Residues	9,000,000	777,778

Subsequently, the amounts of feedstock required for fired alone, 5%-, 10%-, and 15% co-firing (mass basis) scenarios are shown in Table 5.

Table 5. Annually Required Quantity of Feedstock as Scenario at the 100MW Plant

Feedstock (wet tons)	Fired Alone	5% co-firing	10% co-firing	15% co-firing
Switchgrass	509,099	25,454.95	50,909.9	76,364.85
Rice Straw	630,108	31,505.4	63,010.8	94,516.2
Logging Residues	777,778	38,888.9	77,777.8	116,666.7

4.3 Hauling Distance and Costs

4.3.1 Hauling Distance

Hauling distance is one of the major barriers that prevent biomass from becoming an energy source on a commercial scale. The average hauling distances that are used in this study were calculated following McCarl et al (2000) who relied on a formula derived by 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 per acre in BTUs Y, the average hauling distance (D) formula is:

$$Distance = 0.4714 * \left[\frac{Mass}{(640 * Biomass\ Density * Biomass\ Yield\ \ per\ Acre)} \right]^{0.5}$$

where 'Distance' is the average hauling distance and 'Mass' is the amount of biomass required for the energy production. Obviously, the average distance changes as the amount of feedstock required to produce energy changes.

Switchgrass average hauling distance was calculated using a required mass of 509,099 tons, yield of 5.8 tons/acre (Kiniry et al, 2005) and the 10% density. The assumption of 10% density is justified because currently there are no switchgrass fields grown as conventional crops but what is the rice density in the counties where it would be replaced.

For rice straw, average hauling distance was calculated using the required mass of 630,108 tons, yield of 3 tons/acre (Kadam et al, 2000). And biomass density was 3.8% based on a procedure used in the FASOM model. First, the 2001 acreage for rice and the total acres by county were downloaded from on-line USDA data. The top 5 rice producing counties were then selected. The selected county combined acreage totals were then added and then the result was divided by the sum of the selected counties total acreage to yield a weighted average rice straw density for the agricultural region.

For logging residue, densities by FASOM region were determined by calculating a weighted average stand rotation from the FASOM rotation data. One was divided by the average stand rotation and the result was multiplied by 0.8 yielding the logging residue density. The 0.8 is the practical forest density for forest lands as determined from the map, Forest Density in the Conterminous U.S., US Environmental Protection Agency. Yields are 1000 cuft per acre which were converted to tons per acre using the factors of 27.5 lbs per cuft for softwood and 33.0 lbs per cuft for hardwood (Carpenter, 1980).

Table 6. Average Hauling Distances for Switchgrass, Rice Straw and Logging Residues

Feedstock	Combustion Type	Average Hauling Distance (miles)
Switchgrass	Fired alone	17.46
	5% co-firing	3.90
	10% co-firing	5.52
	15% co-firing	6.76
Rice Straw	Fired alone	43.808
	5% co-firing	9.796
	10% co-firing	13.853
	15% co-firing	16.967
Logging residue	Fired alone	5.05
	5% co-firing	1.129
	10% co-firing	1.597
	15% co-firing	1.956

Notice that the distance does not change linearly with the increase in the co-firing ratio.

In turn the average hauling distance for hauling the residues to power plant for residue fired alone and co-fired at 5%, 10%, and 15%. Table 6 presents the average hauling distances for all the scenarios.

4.3.2 Hauling Cost

Transportation from field edge to plant gate represents a significant cost and source of added embodied energy. The larger the plant and the more diffuse the resource, the greater the impact on cost and embodied energy of transportation. The cost of hauling biomass from a field to a power plant is largely a function of the hauling distance. In addition, increasing the co-firing ratio will also increase the hauling cost as it will require collecting biomass from a larger radius from the plant location given the same bio-density. Noon et al estimated the average switchgrass transportation cost in Alabama to be \$8.00/dry tonne for 25 miles hauling distance (Noon et al, 1996). Graham and others at Oak Ridge National Laboratory evaluated the cost of delivering wood chips to different size plants in Tennessee. Their transportation cost estimates ranged from \$7 to \$16 per dry ton, accounting for 18% to 29% of plant-gate cost (Graham et al, 1997 and Downing and Graham, 1996). James et al (2001) computed the transportation costs by adding a fixed cost of \$5.50 to a variable 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. The three different feedstocks examined in this study have different hauling distance and transportation considerations. Hence, the hauling costs are estimated differently for each case.

To calculate the hauling costs per ton of feedstock we utilized the formula derived by McCarl et al (2000):

$$Hauling\ Cost = \frac{(Fixed\ Load\ Cost + 2 \times Average\ Dis\tan ce \times Cost\ \ per\ Mile)}{Load\ Size}$$

Average Distance is from the hauling distances from above in Table 6. Using these distances in the above formula we calculated the logging residue hauling costs for East Texas region. The truck load size was assumed to be 14, 20 and 25 tons for switchgrass, rice straw and logging residue, respectively.

Switchgrass hauling parameters are taken from Qin et al (2006). Based on these parameters, cost per mile was calculated including the fixed, variable and labor costs of the hauling process. Switchgrass is assumed to be cut, chopped, and compressed into a module at the farm for hauling in a module truck. The fixed load cost included all harvest costs through module building. Switchgrass hauling cost per mile, which accounts for all fixed costs, was then calculated at $1.62 per mile.

For rice straw, according to Sokhansanj (2006), hauling cost parameters assumptions are the following: fixed load costs are $90, cost per mile is $2.20, and load size is 20 ton. Harvesting cost is $13.54 per ton based on Summers study.

The hauling cost parameters (fixed load cost, cost per mile, and load size) for logging residue were taken from the Forest Residues Transportation Costing Model (Rummer, 2001). We assumed that residue was loaded by a knuckle-boom 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 bio-energy producing facility. This model was amended to produce cost per mile from its standard model results. Fixed load cost included all harvest costs through the chipping process. Table 7 presents the hauling costs for switchgrass, rice straw and logging residue.

Table 7. The Hauling Costs for Biomass Feedstock

Feedstock	Combustion Type	Hauling Cost ($/ton)
Switchgrass	Fired alone	7.00
	5% co-firing	3.86
	10% co-firing	4.23
	15% co-firing	4.52
Rice Straw	Fired alone	14.138
	5% co-firing	6.655
	10% co-firing	7.548
	15% co-firing	8.233
Logging Residues	Fired alone	9.955
	5% co-firing	3.236
	10% co-firing	4.359
	15% co-firing	5.006

As we can see from the table, costs per ton decrease as co-firing ratio increases, in general. This happens due to the spread of fixed costs over the longer hauling distance.

The hauling costs per ton were then multiplied by the required biomass quantity to determine the supplying cost for a 100 MW power plant. The results are presented in Table 8.

Table 8. Annual Hauling Cost for Biomass Feedstock

Feedstock	Combustion Type	Annual Hauling Cost ($/power plant)
Switchgrass	Fired alone	3,563,693
	5% co-firing	98,256
	10% co-firing	215,348
	15% co-firing	345,169
Rice Straw	Fired alone	8,908,466
	5% co-firing	209,668
	10% co-firing	475,605
	15% co-firing	778,151
Softwood Residues	Fired alone	7,803,806
	5% co-firing	2,541,530
	10% co-firing	3,414,331
	15% co-firing	3,921,981
Hardwood Residues	Fired alone	7,613,303
	5% co-firing	2,456,064
	10% co-firing	3,333,178
	15% co-firing	3,833,076

4.4 Greenhouse Gas Emissions

Biomass feedstock requires fossil fuel inputs for various stages of their production processes. The major fossil fuel energy inputs include fertilizer (mostly nitrogen which is made from natural gas), fossil fuel used in operating equipments during the planting, maintenance, and harvesting stages, and transporting feedstock to bio-refineries (Cook, and 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 switchgrass production and logging residues harvest. We do not include analysis of emissions related to the rice straw production here because rice straw is a byproduct of the rice, and rice straw is not specifically grown for energy generation usage. However, we will quantify the greenhouse gas emissions from harvesting, hauling and using rice straw at the energy producing stage in the power generating plants. We take a similar approach with regard to the logging residues. We do not consider emissions related to the forest production process. We only account for the emissions which accumulate the logging residue during the harvest stage and haul it to the power plant.

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 bio-energy plant. Qin et al (2006) analyzed the various pathways for switchgrass production for the lowest GHG emissions and concluded that the optimal combination of activities was establishing switchgrass after exiting 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. Table 9 summarizes the energy consumption and the greenhouse gas emissions accumulated from machinery operations, except transportation, for switchgrass production process:

Table 9. GHG Emissions and Energy Consumption from Preparation of Switchgrass

Switchgrass preparation stage	Alternative 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	Re-crop 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 and 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 87 Btu/kg. Adding to this the energy consumption of 447 Btu/kg of switchgrass derived from use of lime and chemicals, total energy consumption is 534 Btu/kg of switchgrass.

Adding up the CO_2-equivalent emissions from switchgrass production activities and usage of lime and chemicals we arrived at a total of 198.2 grams of CO_2-equivalent emissions per kilogram of switchgrass. Table 10 shows GHG Emissions and energy consumption from use of lime and chemicals.

Table 10. 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. (2005)

Applying these estimates to the amount of switchgrass that can be produced by East Texas counties converting rice to switchgrass we have the annual results shown in Table 11.

Table 11. Annual Energy Consumption and GHG Emissions from Switchgrass Preparation in East Texas

Region	Switchgrass (tons/year)	Total Energy consumption (Btu/year)	Total CO_2 Emissions (grams/year)	Total N_2O Emissions (grams/year)	Total CH_4 Emissions (grams/year)	Total CO_2-eq. Emissions (grams/year)
East Texas	215088.4	1.04392E+11	8.664E+09	39642358.1	14224606.2	2.0742E+10

In the case of rice straw, another procedure was used to quantify the greenhouse gas emissions related to the harvest of rice straw. Summers et al evaluated GHG emissions during the rice straw harvest. Their harvesting scenario assumed rice straw harvesting process is comprised of: swathing into windrows, baling in large square bales, and moving to road side for transport. The resultant GHG emission factors are shown in Table 12. Table 13 represents the annual fuel consumption and GHG emissions from rice straw harvest.

Table 12. Emission Factors during Harvest of Rice Straw

Operation	CO2 Emissions (g/kg)	NO_x Emissions (g/kg)	CH_4 Emissions (g/kg)	CO_2-eq. Emissions (g/kg)
Swathing	5.156	0.128	0.003	5.210
Ranking	1.238	0.012	0.001	1.249
Bailing	5.952	0.109	0.002	5.990
Roadsiding	2.527	0.045	0.001	2.543
Total	14.873	0.294	0.007	14.992

Source : M.D. Summers et al.

Table13. Annual Fuel Consumption and GHG Emissions from Rice Straw Harvest

Region	Rice straw (tons/year)	Total CO_2 emissions (g/kg)	Total NO_x emissions (g/kg)	Total CH_4 emissions (g/kg)	Total CO_2-Equivalent emissions (g/kg)
East Texas	8399.187	124,921,114	2,469,361	58794.31	1.26E+08

A different procedure was used to quantify the greenhouse gas emissions related to the harvest of logging residues. The Forest Residues Transportation Costing Model (FRTCM) (Rummer, 2001) was utilized to evaluate the logging residue harvest scenario. This spreadsheet calculator is designed to help users create scenarios by comparing alternative methods of moving biomass from the forests to a bio-energy facility and allows estimating loading and hauling costs for different combinations of equipment as well as consideration of several other operations. It is available from the USDA Forest Service website. We assumed that logging residues were loaded by a knuckleboom 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 bio-energy producing facility. The gallons of diesel required per ton of harvested residue were then determined from the model as 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 load size, the weight of diesel, conversions to kilograms, and moisture content. Finally, the diesel amounts were multiplied by the following diesel emission factors to get the total residue emissions:, 3188.068276 grams of Carbon Dioxide per kilogram of diesel, 0.08 grams of Methane per kilogram of diesel and 0.107918583 Nitrous Oxide grams of Methane per kilogram of diesel (Wang and Santini, 2000). Table 14 summarizes the results of emission calculations. Table 15 represents the annual fuel consumption and GHG emissions from logging residue harvest.

Table 14. GHG Emissions from Collection of Logging Residues per kg of Residue

	Energy consumption (Btu/kg)	CO_2(g/kg)	N_2O(g/kg)	CH_4(g/kg)	CO_2-Eq. emission (g/kg)
Logging residue	137.5	11.28	0.00038	0.00028	11.403

Table 15. Annual Fuel Consumption and GHG Emissions from Logging Residue Harvest

Region	Recoverable logging residue (wet tons)	Total CO_2 emissions (g/kg)	Total N_2O emissions (g/kg)	Total CH_4 emissions (g/kg)	Total CO_2-Equivalent emissions (g/kg)
East Texas	3,383,900	40,428,158,593	1,368,524.514	1014486.644	4.04E+10

4.4.1 GHG Emissions from Hauling Biomass Feedstock

Greenhouse gases are emitted during the biomass feedstock establishment, maintenance, harvest, hauling and combustion stages. Here we present estimates for emissions from hauling the feedstock to the power plant. Switchgrass hauling emissions were adapted from Qin et al (2006), shown in Table 16.

Table 16. GHG Emission from Hauling Switchgrass

Biomass		CO_2 emissions (g/kg)	N_2O emissions (g/kg)	CH_4 emissions (g/kg)	CO_2-eq emissions (g/kg)
Switchgrass	Fired-alone	13.21	0.0008	0.0148	13.78
	5%	8.73	0.0005	0.0098	9.105
	10%	9.26	0.0005	0.0104	9.663
	15%	9.67	0.0006	0.0108	10.09

Emissions from hauling rice straw were adapted Switchgrass model by Qin et al (2006). Here we assume to use 20 ton load size truck.

Table 17. GHG Emission from Hauling Rice Straw

Biomass		CO_2 emissions (g/kg)	N_2O emissions (g/kg)	CH_4 emissions (g/kg)	CO_2-eq emissions (g/kg)
Rice straw	Fired-alone	15.35	0.001	0.017	16.01
	5%	7.48	0.0004	0.0084	7.797
	10%	8.41	0.0005	0.0094	8.776
	15%	9.13	0.0005	0.0102	9.528

Table 17 shows the GHG emission from hauling rice straw. Emissions from hauling logging residue were estimated using the GREET Model. We first determined the gallons of diesel required to haul a ton of harvested feedstock. This was done by dividing twice the average hauling distance by truck fuel efficiency, which was assumed at 5 miles per gallon. Table 18 represent the calculating result of GHG emissions from hauling logging residue to the power plant

Table 18. GHG Emissions from Hauling Logging Residue to the Power Plant

Biomass		CO_2 emissions (g/kg)	N_2O emissions (g/kg)	CH_4 emissions (g/kg)	CO_2-eq emissions (g/kg)
Logging Residue	Fired-alone	0.461	1.56E-05	1.16E-05	4.60E-01
	5%	0.103	3.49E-06	2.58E-06	1.03E-01
	10%	0.146	4.93E-06	3.65E-06	1.46E-01
	15%	0.178	6.04E-06	4.48E-06	1.78E-01

4.4.2 GHG Emissions from Combustion of Biomass Feedstock

Numerous studies indicate that biomass fuels provide substantial environmental benefits through absorbing carbon dioxide during growth and emitting it during combustion (McCarl et al, 2000 and Demirbas, 2004) [A graph showing the recycling process will be good]. This way biomass fuels participate in 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). This analysis also holds for rice straw and logging residue as the switchgrass burned alone case was constructed based on extrapolation of results from wood-fired power generation.

Overall, all three biomass feedstock contribute no CO_2 emission during the combustion process. In contrast, combustion of coal generates significant amounts of 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 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)). Carbon dioxide emissions from coal were derived by Qin et al. using the U.S.EPA (2002) report and are summarized in Table 19. Table 20 is shown the calculated result of GHG emission from switchgrass, and logging residue combustion.

Table 19. GHG Emission from Coal Combustion

Emission species	CO_2	N_2O	CH_4	SO_x	CO
Emission factors (g/kg coal)	2085	0.0313	0.022	17.16	0.25
Emissions (g/kWhr)	935	0.0145	0.010	7.69	0.12

Table 20. GHG Emission from Switchgrass, and Logging Residue Combustion

Emission species	CO_2	N_2O	CH_4	SO_x	NO_x	CO
g/kg switchgrass	1525	0.09	0.14	0.17	3.37	4.12
g/kWhr by switchgrass	1660	0.10	0.16	0.19	3.66	4.49
g/kg logging residue	1755	0.12	0.19	0.22	1.98	5.40
g/kWhr by logging residue	1509	0.10	0.16	0.19	1.70	4.64

For rice straw, the methodology for estimating greenhouse gas emissions from combustion of rice straw is consistent with the Revised 1996 IPCC Guidelines (IPCC/UNEP/OECD/IEA, 1997). In order to estimate the amounts of carbon and nitrogen released during combustion, the following equations were used:

Carbon Released = (Residue/Crop Product Ratio) × (Dry Matter Content of the Residue) × (Burning Efficiency) × (Carbon Content of the Residue) × (Combustion Efficiency)

Nitrogen Released = (Residue/Crop Product Ratio) × (Dry Matter Content of the Residue) × (Burning Efficiency) × (Carbon Content of the Residue) × (Combustion Efficiency)

Table 21. Assumptions for Estimating Emissions from Rice Straw Combustion

	Residue/Crop Ratio	Dry matter fraction (%)	Carbon fraction (%)	Nitrogen fraction (%)
Rice	1.27	0.91	0.3806	0.0072

The assumed parameters are shown Table 21. The burning efficiency and combustion efficiency for rice straw were assumed to be 0.93 and 0.88, respectively.

Table 22. Greenhouse Gas Emission Ratios

Greenhouse Gas	CO_2	CH_4	CO	N_2O	NO_x
Emission Ratio	3.67	0.005	0.060	0.007	0.121

Table 22 shows the GHG emission ratio each emission factors. GHG emissions from combustion rice straw are derived by above formula, which is shown Table 23.

Table 23. GHG Emission from Rice Straw Combustion

Emission species	CO_2	N_2O	CH_4	NOx	CO
g/kg rice straw	1320	0.477	1.80	0.82	21.60
g/kWhr rice straw	1188	0.4293	1.62	0.738	19.44

4.4.3 GHG Emissions from Co-firing Cases

The following analysis is based on the retrofitting an existing coal fired boiler to us the switchgrass, or rice straw or logging residue as co-firing feedstock. We examined all three biomass feedstock at 5, 10 and 15% co-firing.

Table 24. Emissions from Biomass Feedstock Co-firing Scenarios

Cofiring Ratio – 5% Emission Species	CO_2(g/kWh)	N_2O(g/kWh)	CH_4(g/kWh)
Switchgrass	971.2838	0.018235	0.016995
Rice Straw	947.6535	0.034802	0.09038
Logging Residue	963.695	0.018493	0.01754

Cofiring Ratio – 10% Emission Species	CO_2(g/kWh)	N_2O(g/kWh)	CH_4(g/kWh)
Switchgrass	1007.57	0.022434	0.024125
Rice Straw	960.3095	0.055567	0.170895
Logging Residue	992.3926	0.02295	0.025215

Table 24 continued

Cofiring Ratio - 15% Emission Species	CO_2(g/kWh)	N_2O(g/kWh)	CH_4(g/kWh)
Switchgrass	1043.857	0.026632	0.031255
Rice Straw	972.9656	0.076332	0.25141
Logging Residue	1021.09	0.027407	0.03289

4.5 Sequestration of Carbon Dioxide

Carbon sequestration occurs in the soil during switchgrass production. McLaughlin et al. analyzed soil carbon gains in the soil. Their studies indicated that carbon accumulation is comparable to, or greater than the 1.1 tonne carbon per hectare-year reported for perennial grasses (McLaughlin et al, 1998). Several years of switchgrass cultivation are required to realize the benefit of soil carbon sequestration (Ma et al, 2000). Using a conservative estimation, the credit for soil carbon dioxide sequestration was 179.9 g/kg switchgrass (Qin et al, 2006). However, switchgrass is grown for 10 years on the same fields, CO_2 accumulation in the soil is likely to reach a saturation value, which should be taken into account into any long-term studies.

4.6 Coal

According to D.O.E report Texas need 69,810,000 tons of coal for generating electricity and generated 99,866,000 MWhr of electricity. And Coal average price is $26.56/ton ($1.32 Million Btu) at 2004. According to Qin et al., 0.44844 Kg of coal need for 1KWh generate electricity.

In this study, we use the assumption that is assumed by McCarl et al. (2000) that the annual energy requirement for a 100 MW power plant is 7 trillion Btu (TBtu). We can calculate required Coal quantity to produce 7 trillion Btu. According to my calculation, required Coal quantity is 345,942 tons. Per Unit Cost of Coal is $26.56/ton, and Total Cost per year is $9,188,219.52/year.

4.6.1 GHG Emissions from Coal before Combustion

Stages of Coal from mine to generating power are divided by Mining, Transportation, and Combustion. Greenhouse gases are emitted during stages. Coal Mining and Transportation stage emissions were adapted from GREET Model, were shown Table 25.

Table 25. GHG Emission from Coal Mining and Transportation

Emission species	CO_2	N_2O	CH_4	CO_2–Eq
Emission factors (g/kg coal)	64.246	0.00303	2.6024	124.9997

Coal Combustion stage Emission describes at Chapter IV, 4.4.2 GHG Emissions from combustion of biomass feedstock. Here, Calculate total GHG Emission from Coal during whole life cycle. The results are represented in Table 26.

Table 26. GHG Emission from Coal

Emission species	CO_2	N_2O	CH_4	CO_2–Eq
Emission factors (g/kg coal)	2213.946	0.0373	5.2272	2345.217

4.7 Total Cost of Biomass Feedstock

We calculate total cost of biomass feedstock using the following method.

For switchgrass,

per unit cost ($/ton) = Production Cost + Harvesting Cost + Hauling Cost

For rice straw and logging residue,

Per unit cost ($/ton) = Collecting Cost + Hauling Cost

Where, Production Cost = Establishment Cost + Maintenance Cost.

Unit Cost of Switchgrass is $30.16 per ton which is more expensive than other feedstock. Because Switchgrass is newly cultivated, total unit cost includes Production Cost. Rice Straw and Logging Residue are currently cultivated, so we just include Collecting Cost and Hauling Cost. Table 27 and Table 28 show the total unit cost and annually cost of biomass feedstock. Figure 2 and 3 represent them graphically.

Table. 27. Total Unit Cost of Biomass Feedstock

	Fired-Alone ($/ton)	5% Cofiring ($/ton)	10% Cofiring ($/ton)	15% Cofiring ($/ton)
Switchgrass	37.16	34.02	34.39	34.68
Rice Straw	27.68	20.19	21.09	21.77
Logging Residue	18.67	11.95	13.07	13.72

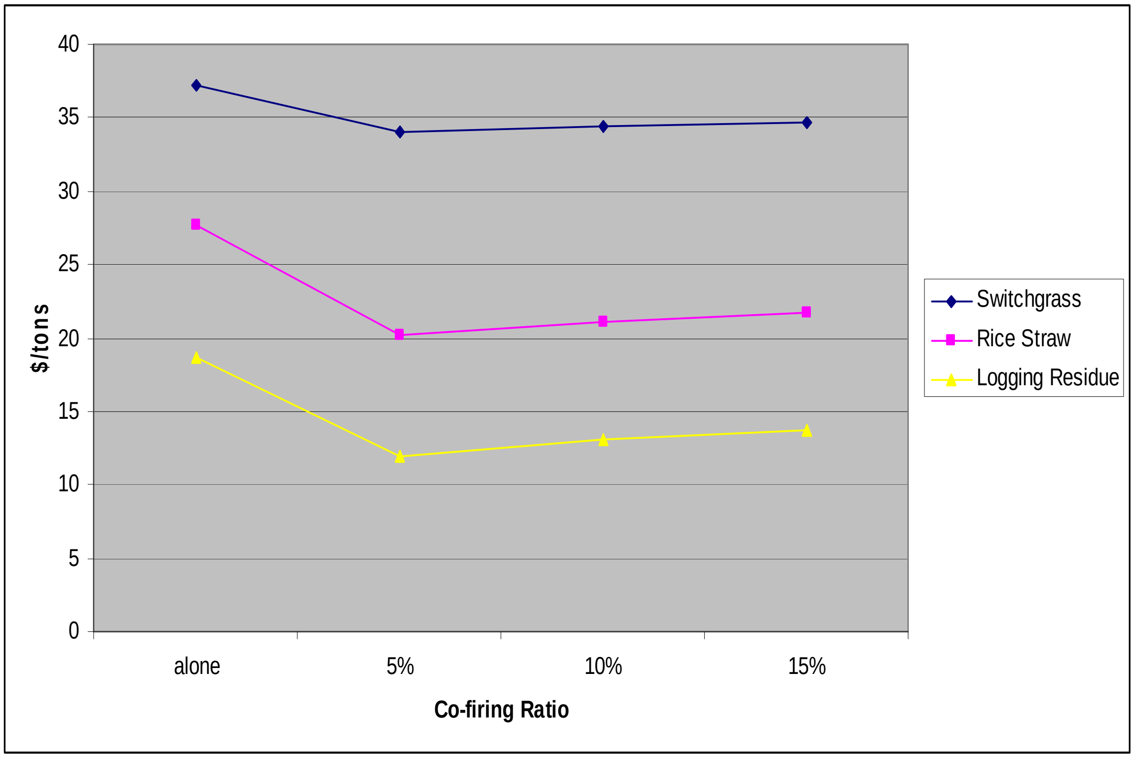

Fig 2. The Total Cost per Unit of Biomass Feedstock

Table. 28. Total Annual Cost of Biomass Feedstock ($/Annually Required Amount)

	Fired-Alone	5% Cofiring	10% Cofiring	15% Cofiring
Switchgrass	18918118.84	865977.399	1750791.461	2648332.998
Rice Straw	17440129.22	636251.553	1328771.75	2057901.223
Logging Residue	14517226.37	464566.7994	1016478.068	1600200.457

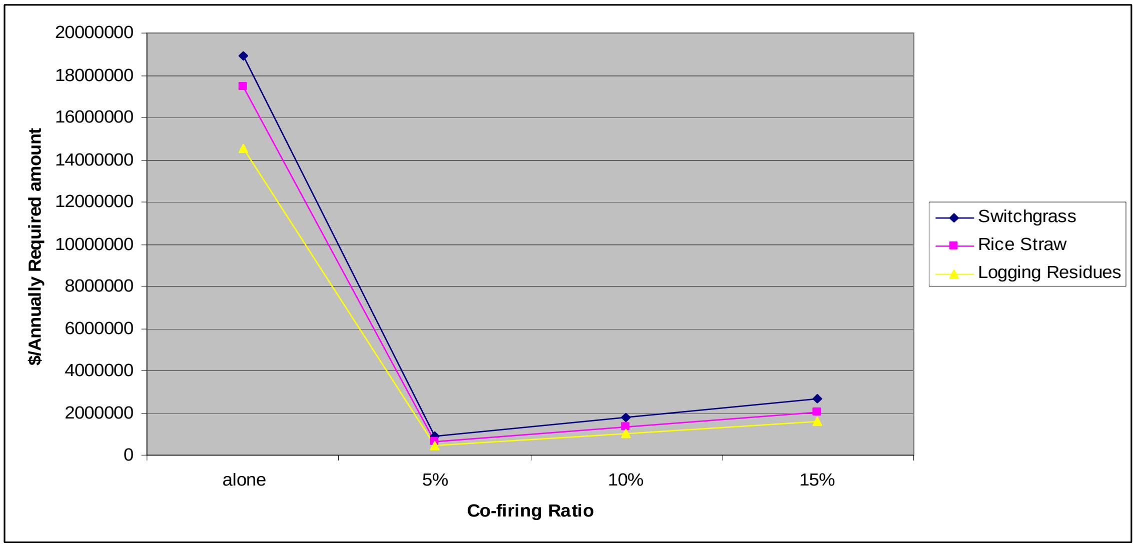

Fig 3. The Total Cost per Year of Biomass Feedstock

4.8 Total GHG Emission until Generating Electricity

At Chapter IV, 4.4 Greenhouse Gas Emissions, we already found GHG Emission from each biomass feedstock. The summation of each biomass feedstock's GHG Emission and compare to Coal at Table 29 and Figure 4.

Table 29. Total GHG Emission from Biomass Feedstock and Coal

Emission species	CO_2	N_2O	CH_4	CO_2–Eq.
Coal (g/kg)	2213.946	0.0373	5.2272	2345.217
Switchgass (g/kg)	1620.01	0.49697	0.2932	1809.755
Rice Straw (g/kg)	1350.233	0.772	1.824	1407.762
Logging Residue (g/kg)	1766.741	0.1204	0.19029	1842.328

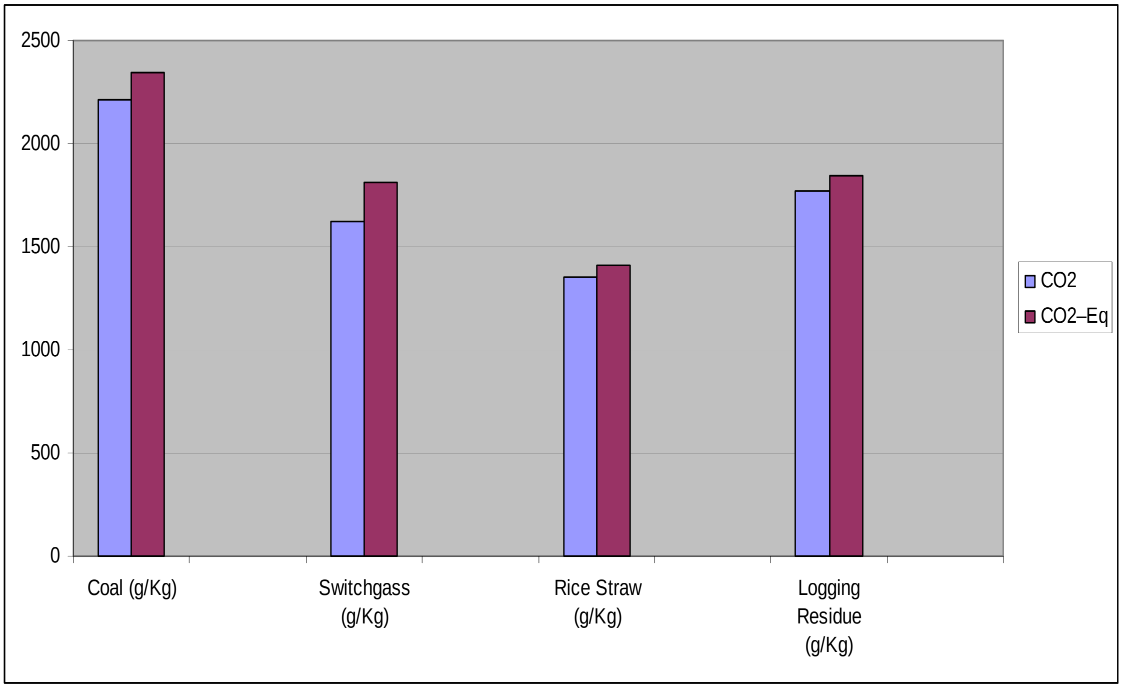

Fig 4. The Total CO_2 and CO_2-Equivalent Emission from Biomass Feedstock and Coal

4.9 Lifecycle GHG Emission Relative to Co-firing Ratio

The equations for calculate Lifecycle GHG emission (about CO_2) are as follows.

Switchgrass Case : Emission of $CO_2 = \frac{\sum E.E}{10} + \sum E.M + \sum E.H + \sum E.T + \sum E.C - \sum Se$

Where E.E is Emission from Establishment,

E.M is Emission from Maintenance,

E.H is Emission from Harvesting,

E.T is Emission from Hauling,

E.C is Emission from Coal combustion

Se is Sequestration from soil.

Rice Straw Case : Emission of CO_2 = $\sum E.H + \sum E.T + \sum E.C$

Where E.H is Emission from Harvesting,

E.T is Emission from Hauling,

E.C is Emission from Coal combustion.

Logging Residue Case : Emission of CO_2 = $\sum E.H + \sum E.T + \sum E.C$

Where E.H is Emission from Harvesting,

E.T is Emission from Hauling,

E.C is Emission from Coal combustion.

All Cases do not consider Emission from Biomass feedstock combustion, because all of biomass feedstock do CO_2 (Carbon dioxide) offset during they grow. That amounts are almost same as the amount of Emission from Combustion.

Table 30 and Figure 4 show the quantity of Lifecycle GHG Emission with co-firing ratio from each biomass feedstock and the trend of lifecycle GHG emissions with the co-firing ratio. The simulated relation gives a linear function during the low co-firing ratio from 5, 10, and 15% as

Switchgrass case : Emission of CO_2 = - 9.117 * co-firing % + 934.997
Rice straw case : Emission of CO_2 = - 9.350 * co-firing % + 934.997
Logging residue case : Emission of CO_2 = - 9.249 * co-firing % + 934.997

Table 30. Lifecycle GHG Emission (about CO_2) from Biomass Feedstock (g/Kg)

Co-firing Ratio	Switchgrass	Rice Straw	Logging Residue
5%	889.4122	888.2475	888.7523
10%	843.827	841.4977	842.5072
15%	798.2418	794.7478	796.262

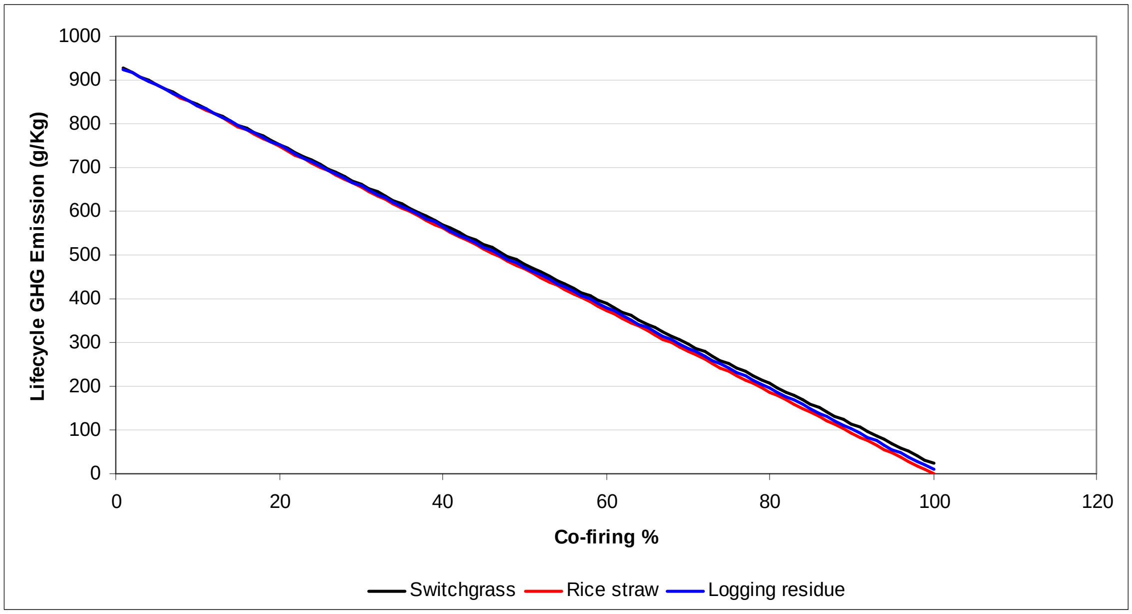

Fig 5. Lifecycle GHG Emissions as a Function of Co-firing Ratio

CHAPTER V

GHG INVESTIGATION

5.1 Breakeven Price between Biomass and Coal Prices

Currently, the price of biomass is currently do the comparison in a table not competitive compared with the price of coal and the low thermal efficiency of biomass makes the situation even worse. The economic issue is commercializing biomass for power generation. Co-firing can much better improve the situation, but the economic barrier is still unsurpassable without stimulating policy such as taking CO_2 offset subsidy or imposing CO_2 tax. Therefore, the breakeven price can be a kind of index for making policy.

Figure 6 shows the breakeven price of switchgrass, rice straw, logging residue and coal without other subsidy. If we take the average coal price of 26.56 $/ton, then the breakeven switchgrass price must be about 10.94 $/ton for it to replace coal, which is much lower than the real cost. However, Rice Straw and Logging Residue do not need to consider cultivate costs (Establishment cost and maintenance cost). So their costs are relatively cheaper than Switchgrass. Consequently, the breakeven rice straw price must be about 13.23 $/ton, and the breakeven logging residue price must be about 13.85 $/ton, which is little different to the real cost. The analysis also shows that even if switchgrass, rice straw, and logging residue have production costs (37.16 $/ton, 27.68 $/ton, 18.67 $/ton, respectively), switchgrass can match up with coal only when the price of coal reaches 90.24 $/ton, rice straw can match up with coal only when the price of coal reaches 55.56 $/ton, and logging residue can match up with coal only when the price of coal reaches 35.8 $/ton. In Switchgrass case, the coal price needed is much higher than current average level of coal price. In Rice Straw and Logging Residue case, the coal price needed is little higher than current average level of coal prices.

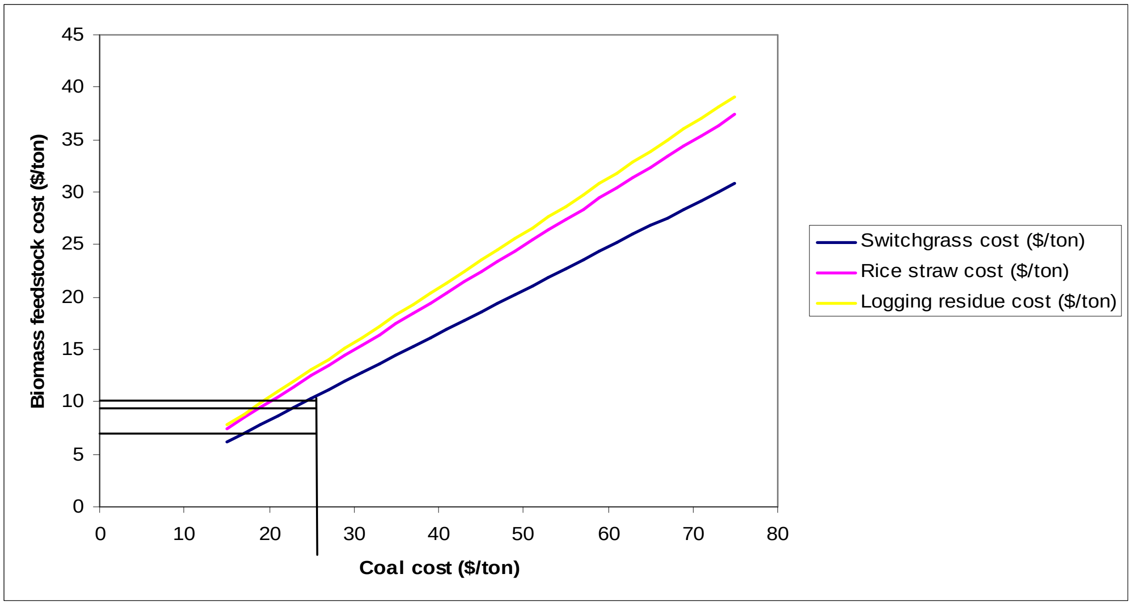

Fig 6. Effect of Biomass Feedstock and Coal Cost as Breaks Even

5.2 CO_2 Offset Subsidy

The high cost of producing biomass is a big obstacle for biomass to become a practical method to mitigate GHG emissions from power generation (Qin et al, 2006). Lifecycle analyses of biomass and co-firing system with biomass and coal indicate that biomass will generate less GHG emissions than fossil fuels. But co-firing system would only be beneficial. The reasons is the costs of biomass fired alone plant (modification cost, additional labor costs, maintenance costs, etc.) are more than expensive to operate the co-firing plant. For these reasons, CO_2 Offset Subsidy is needed for biomass which would be made the commercialization.

The major costs in the co-firing system include the cost of fuel and the capital cost of modification of the power plant to required biomass to be co-firing with coal. However, the important thing is that valuing the CO_2 offset is included in the cost of biomass. The calculation of CO_2 offset subsidy is based on the idea that generating equal amount of electricity.

According to previous chapters, we can know as the Co-firing Ratio increase, the CO_2 reduction quantity is increase. The equation of CO_2 reduction quantity is the same as follows.

In Switchgrass case, the CO_2 reduction quantity is equal to

$$\sum GHG\ Emission - \sum Lifecycle\ GHG\ Emission + \sum Carbon\ Sequestration\ Quantity$$

In Rice Straw and Logging Residue case,

The CO_2 reduction quantity = $\sum GHG\ Emission - \sum Lifecycle\ GHG\ Emission$

Table 31 and Figure 7 show the CO_2 reduction quantity of switchgrass, rice straw, logging residue as co-firing ratio.

Table 31. The CO_2 Reduction Quantity from Biomass Feedstock (g/Kg)

Co-firing Ratio	Switchgrass	Rice Straw	Logging Residue
5%	262.936	59.406	75.448
10%	345.973	118.812	150.895
15%	429.009	178.218	226.342

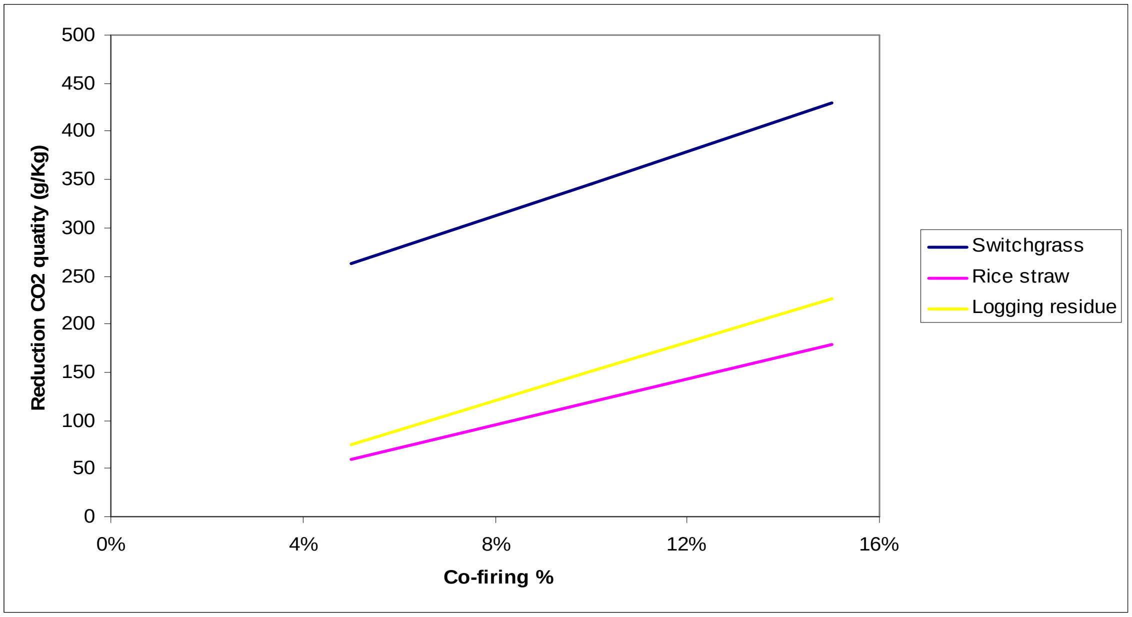

Fig 7. CO_2 Reduction as a Function of Co-firing Ratio

Policy makers can use the CO_2 reduction quantity from Biomass feedstock as an index of measurement of subsidy. One of the method for subsidy is policy makers assign the Carbon prices. That means the cost of coal fired alone is made to be equal to the cost of biomass fired alone or the cost of biomass co-firing with coal after CO_2 offset subsidy is added.

5.3 Biomass Fired Alone

Currently the application of biomass as the sole source of fuel for power plants with large capacity is not common or economical (Qin et al, 2006). These power plants are not very competitive without research innovations or subsidies (McCarl et al, 2000). In addition, bio-fuels have higher volatility, lower sulfur and ash content, and a lower heating value compared to coal. Some bio-fuels can have a relatively high alkaline metal content, and are also rich in chlorine and silica (Nelson, 2001). This nature of biomass brings other problems to power generation such as slagging and fouling which make the biomass only a less attractive investment alternative. As mentioned earlier, a 100 MW power plant requires about seven trillion BTUs and this in turn would require burning 509,099 tons of switchgrass, 630,108 tons of rice straw, or 777,778 tons of logging residues. Based on our estimations of biomass production and hauling costs, the cost of a ton of biomass feedstock delivered to the power plant would be: $37.16 for switchgrass, $27.678 for rice straw, and $18.665 for a ton of logging residues, respectively. This translates into the total cost of delivering the annual required amount of feedstock to the power plant of $18,918,118.84 for switchgrass, $17,440,129.22 for rice straw, and $14,517,319.7 for logging residues. Additionally, the amount of required coal is 345,942 ton per year, and the annual cost of coal fired alone power plant is $9,188,219.52 per year at same conditions. Figure 8 represent the annual costs of biomass feedstock and coal graphically.

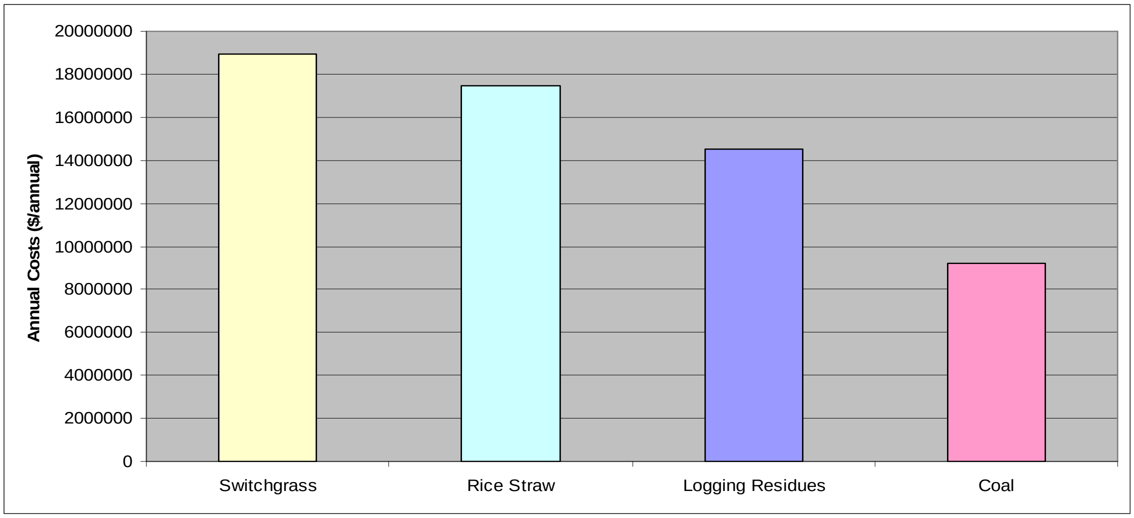

Fig 8. Annual Costs of Biomass Feedstock and Coal

In addition, comparing the biomass availability in East Texas counties with a 100 MW power plant biomass requirement reveals that if rice growing counties decided to switch land to grow switchgrass, individually they would not be able to supply the required amount of biomass feedstock. 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 which is almost 42 percents of the plant requirement of 509,099 tons. This analysis indicates that East Texas rice producing counties can not currently support a 100 MW rice straw fired biomass power plant. However, co-firing could be a more feasible alternative for these counties.

In contrast, our estimates of logging residue indicate that although the counties are rich in forest land they would not be able to individually supply the required amount of logging residue (777,778 tons) for generating electricity, they could jointly generate about 3.3 million tons of logging residue for biomass. Significantly large average hauling distances that were estimated in Chapter IV show that transportation cost could be a main obstacle in delivering feedstock to the power plant. In addition, choosing a location for a power plant which would minimize the feedstock hauling costs and still be economically feasible may be a significant challenge.

In the long run, the technological improvements and an increase in biomass availability and costs could make this alternative viable. In this case, construction of biomass-only power plant in East Texas will require several important considerations. The feedstock availability analysis in the forest rich counties shows that Angelina, Cass, Jasper, Newton, Polk, and Tyler are each able to supply over 100,000 tons of logging residue to the power plant with Tyler County providing the largest volume, 168,588 tons per year. In addition, Tyler County is surrounded with several other counties (e.g. Hardin, Harrison, Nacogdoches, San Augustine, and Trinity) which could be also considered as second large suppliers of logging residue biomass. Assuming that the biomass feedstock is uniformly spread over the forest acreage of these counties, a potential location for a power plant could be proposed in the Tyler County. One additional possibility would be to assume that a power plant would be receiving various biomass feedstock. In this case, we would consider locating a power plant in Chambers, Hardin, Harris, Jefferson, Liberty, or Orange County, i.e. counties which could supply switchgrass, rice straw and logging residue to a power plant. However, our feedstock estimates for these counties indicate that this case is also infeasible. None of these counties can generate enough biomass to support the annual operations of the 100 MW power plants.

In summary, the co-firing alternative appears to be the most feasible in the East Texas region. Moreover, some recent studies proved that co-firing could also overcome the problems of stemming from the biomass nature (e.g. slagging, fouling) and perhaps is also environmentally beneficial (Boylan et al, 2000).

5.4 Co-firing

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 (Nelson, 2001). The local availability and cost of biomass feedstock are the most important factors 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, rice straw or logging residue biomass feed stream. We adjusted the biomass required amounts, greenhouse gas emissions, and feedstock cost by the co-firing ratio. Co-firing budgets were created for all three biomass feedstock at 5%, 10% and 15% co-firing.

The feedstock costs at the power plant gate are calculated based on the feedstock production and hauling costs estimated for our feedstock in earlier sections. For example, switchgrass per ton costs at the plant gate are $25.35 for 5%, $25.72 for 10%, and $26.01 for 15% co-firing cases, costs for rice straw case are $20.105 for 5%, $21.088 for 10%, and $21.773 for 15% co-firing cases. Same costs for a ton of logging residue are $11.946, $13.069, and $13.716, respectively. 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.

Further, the analysis of feedstock potential of East Texas counties to support the annual power plant operations shows that the counties ranged differently in this respect. With regard to co-firing coal with 5% of switchgrass, only Chambers, Jefferson and Liberty counties demonstrate the adequate potential. With 10% co-firing, it is only Chambers and Jefferson counties, and only Jefferson County has a potential to support the 15% co-firing operation. In terms of rice straw, again Chambers, Jefferson and Liberty counties show the potential for only 5% co-firing cases. Logging residue potential analysis indicate that only Cass, Jasper, Polk, and Tyler counties have a biomass potential 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.

5.5 Future Work

We examine the economic, energy and GHG issues of using switchgrass, rice straw, and logging residue as alternate or supplementary feedstock for power generation using an integrated approach. Progress in evaluating economic issues associated with biomass feedstock has been made, but deficiencies still exist. In particular it is important to quantify and value the social and private benefits (and costs) that might result from large-scale production and use of biomass feedstock.

For the future work analytical needs include,

1. Improved biomass feedstock supply and demand curves
2. Improved understanding of the implications of land competition between biomass feedstock and conventional crops
3. Estimates of the farm income and rural employment impacts of producing biomass feedstock
4. Estimates of the impact of competing uses on the price of biomass feedstock

5. Evaluation of the role risk plays in farmer decisions to produce biomass feedstock

CHAPTER VI

SUMMARY

In this thesis an integrated analysis was done that examined the economic implications of using agriculturally based feedstocks for bioenergy production in East Texas. Specifically I examined the use of switchgrass, rice straw, and logging residue as feedstocks for electrical power generation in East Texas as a replacement for coal fired power generation. Life cycle analysis and Cost-Benefit analysis were used.

Considering the total cost of a ton of biomass feedstock delivered to the power plant I found logging residue is the cheapest of the feedstocks. However the required quantity of biomass feedstock and energy efficiency is least with switchgrass. But I find that of the volumes of rice straw and switchgrass available would not be sufficient to support the required quantity for a solely fired power plant. Consequently, co-firing is likely the only feasible alternative with those feedstocks in East Texas.

In the logging residue case, the counties in East Texas are not individually able to supply the required amount of logging residue for generating electricity, but they could jointly supply the required quantity. Both cases, fired alone and co-firing, could be feasible in the region.

As we use more bio-energy for power generation, we will get less GHG emission, which will be an environmental benefit in the long run. The main problem is cost. Biomass feedstock production, harvesting and hauling costs are too high to commercialize biomass feedstock for power generation. So, I examined the break-even price relative to coal. Switchgrass requires a price than the other feedstocks, because it is not a byproduct requiring establishment, and maintenance costs. Moreover, in the logging residue case, I find the coal price needed is lower than current average level of coal price meaning there are cases where low degrees of co-firing is currently economically feasible.

Bio-energy would also be made more competitive by the combination of a CO_2 GHG offset price that would penalize fossil fuel use and an exemption from the tax for renewable energy. I find GHG offset prices can make biomass economically feasible. Such practices would raise the price people would be willing to pay for biomass feedstock which the value of the GHG net emissions in the fuels replaced.

In presenting this research I must note several limitations that could be addressed in future work. First, the results are driven by the quality of the underlying data. Many data were derived from assumptions and basic models, and thus echo the quality and accuracy of these assumptions and models. Second, the findings reflect currently available technologies and associated data. However, technology may evolve rapidly, because of increased research efforts many of which are government funded. Also, progress in evaluating economic issues associated with biomass feedstock has been made, but deficiencies still exist.

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