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I am submitting herewith a dissertation written by William Joseph Hewitt entitled "Economic Feasibility of Switchgrass Production and Utilization in Tennessee." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Agricultural Economics.

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We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor and
Dean of The Graduate School

ECONOMIC FEASIBILITY OF SWITCHGRASS PRODUCTION AND UTILIZATION IN TENNESSEE

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

William Joseph Hewitt
August, 1997

Thesis
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.H49

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DEDICATION

This dissertation is dedicated to my wife,

Jane Adele Hewitt,

and my father

William Edward Hewitt

whose courage and love have given me the strength to succeed.

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There are far too many people that I would like to thank for their help in my dissertation and graduate schooling. I would like to thank my wife, Jane, and my parents, William E. Hewitt, Kathy and Bill Otley, and James and Eleanor Kuna for all of their love and support, both moral and financial. A special thanks goes to Jim Canipe whose moral support eased the difficulty of this journey. Without the support of all of my family and friends, this degree would not be possible.

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ABSTRACT

Renewable resources are a potentially important, but little developed, part of the national energy strategy in the United States. One type of renewable resource is bioenergy crops. Bioenergy crops are crops produced specifically for their energy content. Bioenergy crops have few emissions when burned. These crops also have potential to reduce soil erosion. Switchgrass is a bioenergy crop that can be produced and utilized in Tennessee. Currently, there is no market for switchgrass, and no commercial production.

This study examined the economic feasibility of switchgrass production and utilization for electric power production in Tennessee. Economic feasibility of switchgrass utilization as a feedstock for electric power generation is related to location of production area, electric facility location, production and transport costs, and harvesting method.

Break-even analysis was used to determine a production cost for switchgrass. A geographical information system, the Regional Integrated Biomass Assessment (RIBA) model, established a link between soil types, anticipated yields, political boundary data, natural boundary data, harvesting techniques, and costs of production of switchgrass as well as costs of production of other traditional crops. Five scenarios were developed to examine the economic feasibility of switchgrass utilization relative to coal as a fuel source for electric power generation in Tennessee. Three of these scenarios incorporated use of a subsidy to examine economic feasibility of using switchgrass as a feedstock to electric power production instead of coal. These three subsidies were based upon studies of abatement costs for sulfur dioxide and carbon

dioxide emissions caused by burning coal. Another scenario incorporated use of the one and one-half cent per kilowatt hour rebate to electricity producers established by the 1992 National Energy Renewable Act. These scenarios analyzed two types of harvesting systems for three different size switchgrass electric generation plants.

Economic feasibility of switchgrass production and utilization as a feedstock for electric generation was examined at the state level, regional level and plant level. The state and plant levels showed considerable reductions in both production costs and transport costs of switchgrass by the utilization of the staggered harvest method instead of the base (traditional farming) method. The regional level analysis consisted of dividing Tennessee into three regions: east, middle, and west. The initial electric generation plant would be located in the lowest delivered cost region, East Tennessee. The West Tennessee Region has the highest delivered cost of three regions. A social cost analysis comparing the combined sulfur dioxide and carbon dioxide subsidy to the one and one-half cent per kilowatt hour rebate was performed. There was a greater gain to society in using the combined sulfur dioxide and carbon dioxide subsidy than by rebating electric producers the $0.015 per kwh subsidy for using switchgrass as a fuelsource in electric power plants.

Conclusions of this study are that switchgrass production, harvesting, and transport for end use in electric power generation is economically feasible in Tennessee if environmental impacts are included in the costs of competing fuels. The location of marginal land in East Tennessee allows the initial opportunity for switchgrass production in the state. However, for switchgrass usage in Tennessee to approach its full potential

for producing large amounts of electric power, land in Middle and West Tennessee are needed for switchgrass production. Compared to traditional farming methods, the staggered harvest method provided an opportunity to greatly reduce costs and increase output of switchgrass.

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Chapter 1 **INTRODUCTION**

Background

The development of reliable and renewable sources of energy has been a major goal of the national energy strategy of the United States (National Biofuels Roundtable 1994). There are many types of renewable energy sources for electrical power generation: solar, wind, geothermal, hydroelectric and biomass. Biomass is a classification of plants (living or recently living), residues or wastes that are used as a fuel source for heating, mechanical, or electrical power. Unlike solar and wind energy sources of fuel, which generate electricity when the sun shines or the wind blows, there are no restrictions on when biomass can be used to generate electricity.

Biomass electrical power generation is the second most commonly used renewable resource. Bioenergy[1] reserves include agricultural and forestry residues, animal wastes, municipal solid wastes, and dedicated energy crops. The greatest potential for biomass is from plants specifically grown for their energy content. These plants could be burned directly, gasifed, or converted into other fuels such as methanol and ethanol for use in the transportation and electrical power generation sector (Renewing Our Energy Future 1995).

Bioenergy crops include annual energy row crops such as corn and sorghum, perennial grasses (herbaceous energy crops, or HEC's) such as switchgrass, and short

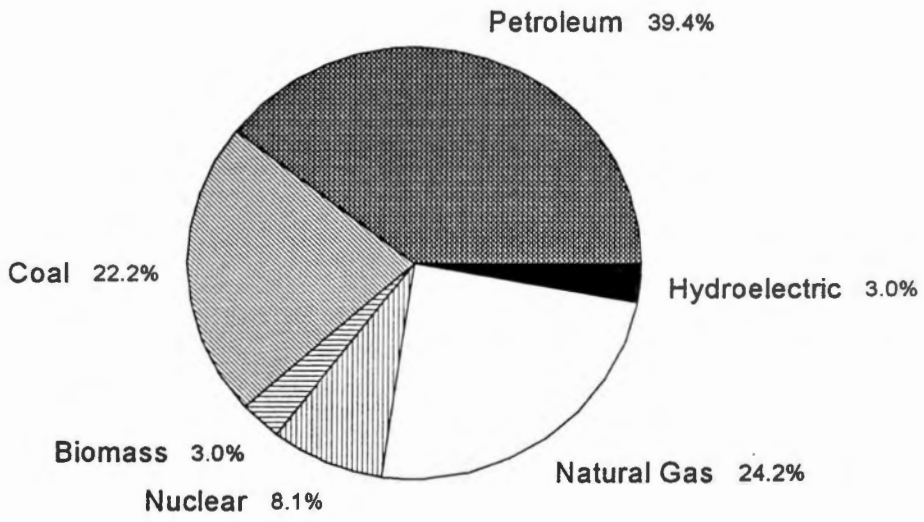
[1] In this study, biofuels are fuels grown specifically for energy production. Municipal wastes, logging and mill residues, and agricultural residues are excluded from this study.

rotation woody crops (SWRC's). HEC's are analogous to growing hay, with the crop being harvested for energy rather than for forage. SWRC's consist of a field of closely spaced trees that are harvested on a three to ten year cycle. After harvest, HEC's regrow from the remaining stubble and SRWC's regrow from the remaining stumps. Such harvesting may continue for ten to twenty years without replanting. Fertilizer and other inputs may be required on an annual basis. Because HEC's are grown like forage crops, they require only modest changes in traditional farming practices (Bhat and English 1993).

In 1992, an estimated 2,785 trillion British Thermal Units (Btu)[2] of energy were consumed in the United States. The three largest sources of energy consumption in the United States are petroleum with 39.4 percent, natural gas with 24.2 percent and coal with 22.2 percent (Figure 1.1). Biomass fuel sources represent 3 percent of total U.S. energy production. (Renewing Our Energy Future 1995).

Cogeneration is a process that generates electricity from by-products of production processes. For example, the pulp and paper industry uses the residues from primary product manufacturing to generate electricity. Cogeneration is currently the dominant use of biomass energy. Cogeneration allows industries to turn a waste product into a resource. The electricity generated is usually used in further processing in the plant and any remainder is sold to an electrical power utility. Roughly, 4 percent of pulp and paper revenues come from the cogeneration of electricity (Bain, Overend and Craig 1996).

[2] A Btu is a British thermal unit. It is the amount of heat required to raise one pound of water 1° F (Hart and Hart 1990)



Source: Electric Power Statistics Sourcebook 1995.

Figure 1.1 U.S. Consumption of Energy by Source, 1992

Economic Uses of Biomass

The production, harvesting, and processing of biomass has the potential to create jobs at both the farm and community level. This additional employment will result in spending, which will generate jobs in the community service sector. It is expected that biomass energy sector will provide an increased tax base for local municipalities. Finally, the creation of more jobs in the rural sector will reduce the migration of population from the rural sector to the urban sector (Renewing Our Energy Future 1995).

Biomass has the potential for the reduction of risk and allows farmers to obtain flexibility in their planning decisions. Because biomass production and harvesting is similar to traditional crops, little capital investment is needed to begin production. Finally, biomass perennial crops require fewer inputs than traditional crops thereby reducing variable cost to farmers (Renewing Our Energy Future 1995).

Environmental Benefits of Biomass

Rachel Carson's book, *Silent Spring*, has alerted many to the problems of excessive use and indiscriminate application of chemicals in the environment (Carson 1962). Non-point source pollution is a serious problem in the United States, especially in agricultural areas. A cause of non-point source pollution is groundwater contamination by residues of fertilizers, pesticides and herbicides. The contaminated groundwater makes its way to streams where it can be toxic to aquatic life (Carson 1962).

There are many beneficial environmental impacts of growing bioenergy crops compared to growing traditional agricultural crops. Bioenergy crops require less fertilizer, less herbicide and no pesticide applications when compared to traditional crops (Bhat and English 1993). By requiring less chemicals than traditional crops, bioenergy crops can reduce the effect of chemicals on soils, water, and habitat. Bioenergy crops have heavier and deeper root patterns than their annual counterparts. These root patterns allow energy crops to more fully utilize water, fertilizers and other agricultural chemicals as they migrate down through the soil (Bhat and English 1993). Because of these extensive root patterns, properly managed HEC's and SRWC's can help stabilize erosive soils and may act as filters to prevent agricultural chemical runoff and sediment erosion.

Another environmental gain of energy crops over conventional crops is the type of crops used. Energy crops are perennials; most agricultural crops are annuals. Perennial crops require tillage only during establishment, every 10 to 20 years, and then maintain the year round protective cover of the soil. Less tillage reduces both soil erosion and soil compaction.

Compared with current energy fuel sources, bioenergy's use as a fuel source can also reduce greenhouse gas emissions. Bioenergy crops use carbon dioxide during growth. When these crops are harvested and burned, the carbon dioxide emitted is equal to the carbon dioxide the crops used while growing. Subsequently, biomass produces a no net gain to carbon dioxide emissions. At a global level, bioenergy crops make little or no contribution to the rising levels of atmospheric carbon dioxide, a key greenhouse gas (Renewing Our Energy Future 1995).

Electrical Power Sector Benefits

Renewable energy technologies have the potential to significantly contribute to electricity supplies in a cost effective and environmentally sound manner. More than one-third of all U.S. energy goes to producing electricity. Biofuels currently provide for 3 percent of U.S. primary energy consumption. Currently, 8,000 megawatts (MW) of electric power generating capacity, using biomass as a fuelsource, is connected to the U.S. power grid[3]. In 1979, only 200 MW of electric power was generated that used biomass as a fuelsource. Today, there are also additional bioenergy fueled electrical generation facilities off-grid. This increase in bioenergy fueled electric generation facilities is due to the development of a variety of new handling and conversion technologies developed that reduce costs (Grub 1991).

To generate electricity, biomass can be either cofired with coal in conventional coal plants, burned alone in either current coal facilities or burned in new bioenergy dedicated electric generation facilities. Bioenergy can also be gasifed to power gas turbines, fuel-cells, or internal combustion engines. All of these uses of biomass are analogous to their fossil fuel counterparts. Virtually all of the electric generation plants that use biomass as a fuelsource are steam turbine driven. The bioenergy fueled electric generation plants usually have a lower output (between 10 to 30 MW[4]) compared to the traditional output of fossil fueled electric generating plants. Bioenergy plant's lower

---

[3] The power grid is the vast interconnection of electrical generation and transmission facilities throughout the United States.

[4] A megawatt (MW) is a units of electrical power. One megawatt is one million watts (Hart and Hart 1990)

power output is due to the limited availability of biomass feedstock. Biomass conversion facilities are also less efficient when compared to coal. The efficiency of biomass conversion to electricity averages 20 percent. A coal plant of similar size has an average efficiency of 35 percent (Grubb 1991).

There can be a potential environmental payoff to using biomass as a fuelsource in an electrical generation plant. Unlike burning coal, burning biomass generates no sulfur dioxide (SO_2). There is also a no net gain of carbon dioxide (CO_2) in burning biomass (National Biofuels Roundtable 1994).

Intermittency, power quality and site specificity are concerns that arise when integrating renewable energy sources into the power grid. Intermittency is the inconsistent generation of electrical power. An example of intermittency is the generation of electric power from solar sources. Solar resources can be utilized only when the sun shines (Grubb 1991). Power quality relates to the type of power output. An example of poor power quality is wind power. Wind power has variances in electrical output. These variances are related to the speed and frequency of the windmill.

Finally, site specificity restricts renewable energy technologies to unique locations. Geothermal energy, for example, is site specific because it is only available where geysers are located. Bioenergy sources are not as site specific as other renewable resources (Renewing Our Energy Future 1995).

Switchgrass

Switchgrass (*Panicum Virgatum*) is a grass native to the prairie region of the United States. Switchgrass has heavily seeded stalks that reach from three to six feet tall at maturity. Switchgrass is both winter-hardy and drought-resistant, which allows it to grow well under a wide variety of soil and climate conditions. Currently, switchgrass is used for pasture and land restoration and is frequently planted with a mixture of other grasses such as: Little Bluestem, Big Bluestem and Indiangrass (Seedsource Catalogue 1997).

Switchgrass is an ideal energy crop because of several distinct characteristics. Switchgrass is fast growing relative to other energy crops. Switchgrass can be harvested within the first year of planting while SRWC's require a three to five years of growth before harvesting. Switchgrass also contains larger amounts of cellulose[5] than most other HEC's. Switchgrass has deep root patterns allowing a more efficient use water and nutrients. These root system hold onto soil to slow runoff and prevent erosion (Ehrenshaft 1997).

Switchgrass production and harvesting is similar to hay production and harvesting. Switchgrass is the ideal bioenergy crop for Tennessee because of the availability of large amounts of equipment and experience by farmers in hay production and harvesting. Switchgrass is planted once every 10 years. Annual applications of nitrogen fertilizer are

[5] Cellulose is a complex carbohydrate, $(C_6 H_{10} O_5)n$, that is composed of glucose units, forms the main constituent of the cell wall in most plants. In general, the denser the cellulose, the greater the Btu heat content when burned (Renewing Our Energy Future 1995).

needed. Herbicides are necessary only until the switchgrass is established. Switchgrass harvesting is assumed to consist of mowing, raking and round baling.

Agriculture in Tennessee

Tennessee agriculture is a complex and varied industry that benefits Tennesseans as well as many people outside the boundaries of the state. Cash receipts to Tennessee farmers generally total approximately $2 billion each year. The impact on the state's overall economy is estimated at least $6 billion annually. This economic impact is much larger when the food manufacturing, marketing and distribution as well as forestry related industries are considered (Tennessee Agriculture 1996).

Farming and forestry dominate Tennessee's landscape. About 12.3 million acres, or roughly one half of the state's land area is farmland. Agricultural products are produced on approximately 84,000 farms in Tennessee. Total farm cash receipts are equally divided between livestock production and crop sales (Tennessee Agriculture, 1996).

Tennessee agricultural production is generally divided into three distinct regions: East, Middle and West. The agricultural production in East Tennessee is: beef cattle, dairy, tobacco and fruits and vegetables. Large amounts of pasture land in Middle Tennessee make beef cattle and dairy operations practical choices. A variety of row crops also flourish in Middle Tennessee. The West Tennessee region is largely flatland created by the Mississippi River's flood plains. This flatlands makes West Tennessee suited for row crop operations. The state's largest production of soybeans, wheat, corn, cotton and sorghum traditionally come from West Tennessee (Tennessee Agriculture 1996).

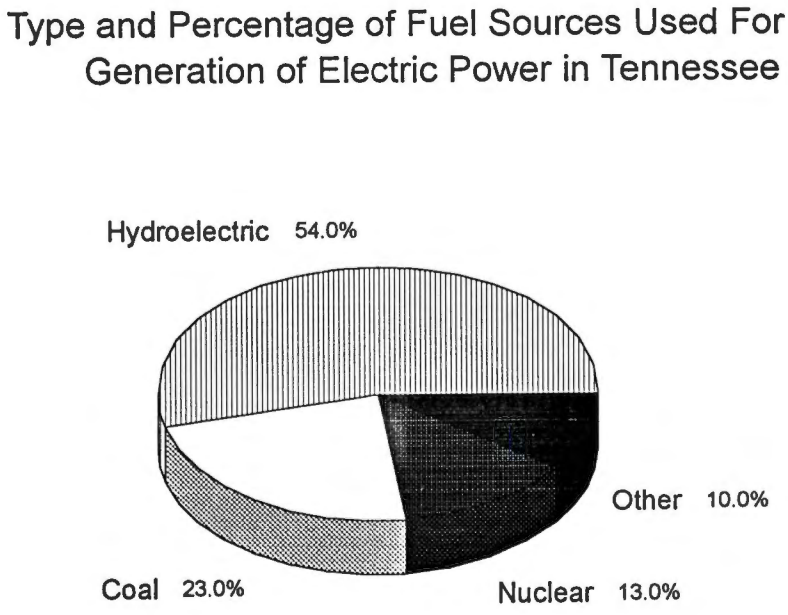
Tennessee's forests produce enough timber to manufacture almost 840 million board feet of hardwood lumber in 1993. Tennessee is one of the leading produces of hardwood lumber in the United States (Tennessee Agriculture 1996).

Electrical Power Production in Tennessee

The Tennessee Valley Authority (TVA) is the nation's largest electrical power generating system and is currently a corporate agency of the federal government. Created by Congress in 1933, TVA supplies electrical power to approximately three million industrial, residential and commercial customers in its 80,000 square mile region. TVA's region encompasses all of Tennessee and portions of six adjoining states. While there are other electrical power producers in Tennessee besides TVA, many are small in size, area, and customers serviced (Gadsden 1989).

TVA's generating capacity consists of more than thirty-two million kilowatts, 53.54 percent which is in coal-fired steam plants, 13 percent in nuclear plants, and 12 percent in hydroelectric dams (Figure 1.2). The remainder is provided by four gas turbine installations and one pumped-storage hydro plant (Gadsden 1989).

The agency's Tennessee coal-fired plants have a capacity of 10 million kilowatts, representing about 57 percent of TVA's coal fired plant capacity. Nuclear capacity in Tennessee equals 2.4 million kilowatts or 41percent of the agency's nuclear capacity; while the hydro plants have a capacity of 1.5 million kilowatts, about 46 percent of TVA's total hydro plant capacity. Combustion turbines have a capacity of 2 million kilowatts in



Source: Gadsen, C., G. Davis, and R. Lamp. *Electricity in Tennessee*. Nashville, TN: Department of Economic and Community Development, 1989.

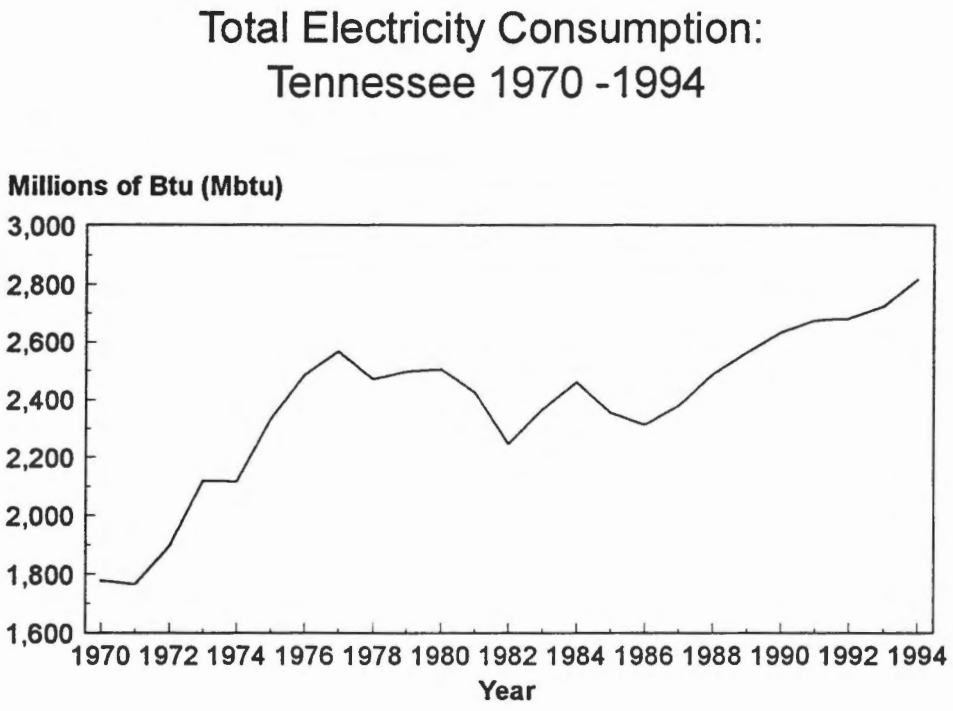
Figure 1.2 Electric Generating Capacity in Tennessee

Tennessee or about 81percent of TVA's total combustion turbine plant capacity (Gadsden 1989).

The majority of cogenerators within the TVA region are located in Tennessee. Cogeneration facilities have a combined capacity of 424.46 Megawatts (MW) or almost two percent of TVA's total generating capacity. Facilities range in size from Sparta's Hardwoods 125 kW per year plant to Eastman's Kingsport plant generating 170,000 kW per year of electrical power (Gadsden 1989).

Electrical power generated in any portion of the TVA region may be directed to other places in the system based upon need and availability. More than 10,000 of the agency's 17,000 miles of transmission lines are located in Tennessee. TVA has exchange arrangements and connections with 15 neighboring utilities so that TVA may exchange power with other utilities when the demand for electricity is greater than the available supply at TVA's plants. Approximately two-thirds of TVA's total sales are to Tennessee customers. In fiscal year 1987, TVA sold 107.9 billion kilowatthours (kWh) of electricity with more than 63 percent going to Tennesseans. TVA power is managed by 160 distributors throughout the Tennessee Valley region. 110 are defined as municipalities and 60 are cooperatives. TVA also serves over 40 industrial companies and 4 federal agencies located in Tennessee (Gadsden 1989).

The total consumption for electricity includes consumption from residential, commercial and industrial sources (Figure 1.3). There is a general upward trend in the consumption of electricity in Tennessee between the years 1970-1994. Consumption of electricity was increasing until 1976, when a peak of 2,600 Mbtus were consumed.



Source: U.S. Department of Energy, Energy Information Service, Electric Power Annual, 1995

Figure 1.3 Tennessee Total Electricity Consumption: 1970 - 1994

Between 1976 and 1986, there were a series of peaks and troughs. Since 1986, however, electricity consumption has been steadily increasing. In 1994, 2,800 Mbtu or 274,509 kilowatts were consumed in Tennessee.

Linkage of Agricultural Sector to Power Sector

Figure 1.4 shows the relationship between the two sectors examined in this study. Currently, the linkage between these two sectors is electrical power produced by TVA sector and sold to the agricultural sector. Another minor product (in terms of quantity) produced by the electric power sector in Tennessee is chemical fertilizer.

This study presents a return link to the power sector from the agricultural sector. That return link is through bioenergy, specifically switchgrass, feedstock production. The potential benefits for the agricultural producers are an increase in, and a stable source of, farm income. The agricultural sector also benefits from less erosion of soil when using switchgrass as opposed to traditional agriculture. For the power sector, the benefits are a potential source of a cheaper fuelstock and a cleaner burning fuelstock.

Society benefits overall from the linkages of these two sectors. American society benefits with more efficient utilization of resources and a reduction in environmental damage. Resources that would be used to enforce the power sector for pollution control could be employed elsewhere in the economy. Society also benefits form the use of switchgrass as a fuel source that does not cause as much environmental damage as fossil fuels. Also, switchgrass sources of energy may have the potential to reduce our dependence on foreign supplies of raw materials for energy.

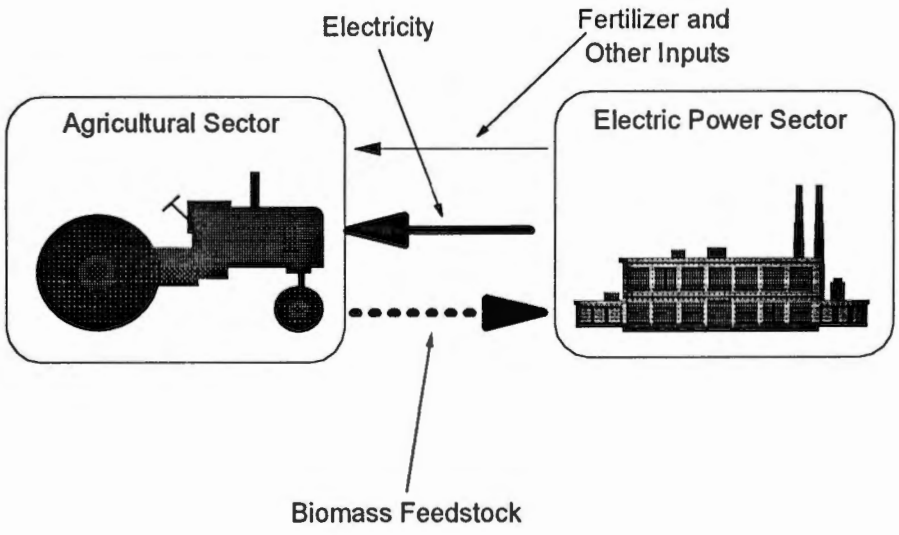


Figure 1.4 Agricultural and Power Sector Linkages

Need for this Study

While there have been numerous studies done about the production and supply of bioenergy crops, no studies of switchgrass production and utilization incorporating the use of a geographical information system (GIS) currently exist. One reason for this is that until recently, the cost of producing switchgrass was too high to justify its use beyond the research, development and demonstration (RD&D) stage. The emergence of new techniques of switchgrass production and harvesting have reduced costs. The production and harvesting of switchgrass is now competitive with traditional row cropping production and harvesting systems. Because of the lower production and harvesting costs of switchgrass and the elimination of government price supports, farmers may consider switchgrass a viable crop that requires little additional capital investment from them.

Another reason for the lack of studies incorporating a geographical information system is that until recently, the development of a geographical information system was too costly to justify its widespread use as a technique of analysis. Current increase in computer processing sophistication allows the use of a GIS to be cost effective.

One of the major stumbling blocks in widespread adoption of switchgrass production and utilization systems is the lack of a market. The farmers, who would like to produce switchgrass, see no market to sell their crop. Farmers will not produce a crop that they cannot sell. So they choose not to produce the crop. The power producers, on the other hand, may use switchgrass in electrical power generation. Because power producers do not see an adequate supply of switchgrass available, they are reluctant to

take the risk of building a switchgrass fueled electrical generation plants. Furthermore, the electric power regulation authority, is reluctant to allow investment in facilities without adequate feedstock supply.

Purpose and Hypotheses

The purpose of this study is to examine the economic feasibility of switchgrass production and utilization for electrical power generation in Tennessee. The primary hypothesis of this study is that switchgrass production and utilization is economically feasible in Tennessee. The supporting hypotheses of this study are:

1. Economic feasibility of switchgrass relates to the following activities: location, production, harvesting, storage and transportation.
2. Because of large transport costs, the location of switchgrass needs to be within a fixed geographic distance from an electrical conversion facility.
3. Switchgrass is an economically feasible crop to agricultural producers in Tennessee, and
4. A reduction in harvesting costs of switchgrass through reorganization will result in switchgrass becoming economically feasible.

The techniques used to test both the main and supporting hypotheses are developed from the economic analysis of farm budgets and the use of Geographical Information Systems (GIS).

Chapter 2 THEORY AND LITERATURE REVIEW

Overview

Switchgrass is a grass native to the Great Plains of North America. Switchgrass production and harvesting practices are similar to hay. Like many other agricultural products, switchgrass is bulky relative to its Btu content. In general, the bulkier the product, the larger the transportation cost. Transportation over large distances becomes too costly. Subsequently, consumption facilities that use switchgrass as an input (electrical power plants) need to be located near production areas.

Economic location theory examines the allocation of economic resources necessary for both efficient production location and efficient distribution networks. The economic basis for the geographical information system used in this study is based on location theory. Economic location theories relevant to the production and utilization of switchgrass in Tennessee are examined in this chapter. Both the initial and modern adaptations of location theories are presented in this chapter. The major limitations of the location theories as well as the use of a geographical information system (GIS) to overcome the limitations of location theory are also presented.

The cost studies of biomass, specifically switchgrass, are examined in the second part of this chapter. Biomass cost studies are divided into two types. The first type is single site cost studies. These studies examine development of production techniques of biomass at a farm level. The second type of cost studies examines potential costs and

benefits of biomass production and utilization at a regional level. This chapter concludes with an examination of the environmental benefits of biomass.

Location Theory

Agriculture location theory typically deals with the use and location of agricultural land. Because agricultural crops are mainly sold to urban areas, the location of rural land uses has to be studied not only in terms of absolute location of each crop and interrelations with other crops, but also with respect to market locations. Products will have a larger transport cost the greater the distance between the production areas and the consumption areas. Agriculture location theory has emphasized two levels of locational process and pattern: one relating to the individual decision maker utilizing land and the other relating to regional patterns of agricultural land use (Kellerman 1983).

This section will discuss several areas of location theory. The earliest theory is that of economic rent attributed to David Ricardo. This theory was quickly abandoned due to the lack of consideration of transport costs. Von Thünen's crop location theory is then presented. Von Thünen stressed that transport cost should be the sole determinant of location. Von Thünen's theory as well as extensions and adaptations of his theories are discussed. Limitations of these extensions are also discussed.

Economic Rent

Current economic location theory evolved from basic concepts developed simultaneously but separately by Von Thünen and Ricardo in the late 18th and early 19th

centuries. Both Von Thünen and Ricardo claimed, separately, that economic rent or land rent determines the spatial allocation of crops among units of land. Ricardo defined rent as the payment for the original and indestructible powers of the soil. Ricardo assumed that economic rent is the result of the comparative advantage of land determined by its physical quality. Rent does not exist at the margin (the worst cultivation) and arises on better lands only when poorer lands are brought into use (Ekelund and Hebert 1990). In addition, growth in demand for agricultural products would put qualitatively marginal land into use and increase the economic rent of the better land already cultivated (Kellerman 1983).

Ricardo's theory of economic rent from land is typical of the classical school of economists who did not consider distance and transport costs among the factors of resource allocation. It is because of these two reasons that agricultural location theory has emphasized Von Thünen's approach to location (Kellerman 1983).

Von Thünen's Crop Theory

Von Thünen's theory was originally drafted in German, over a century ago. In 1966, it was fully translated into English. It is considered to be the cornerstone of location theory and a major tenet of economic thought (Richardson 1978). Von Thünen's primary interest was in the analysis of agricultural land allocation. Given that agricultural products have to be transported from the point of production to the point of consumption (a city), how should land be allocated between competing agricultural uses (Greenhut, Norman and Hung 1987)?

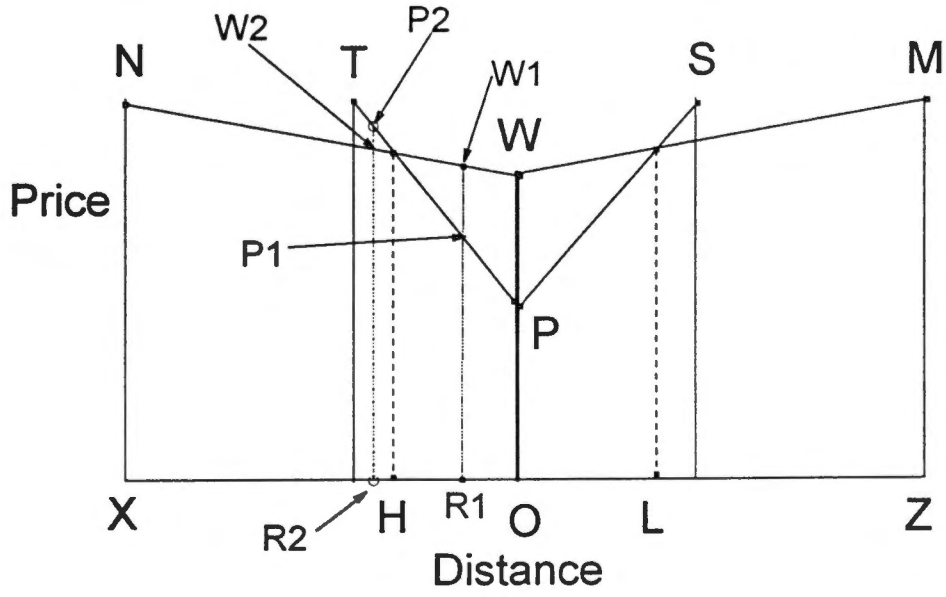
Von Thünen's model begins with the following assumptions:

1. The surface area is a uniform, homogenous plane.
2. Productivity of labor and capital inputs are identical at all locations.
3. The cost of production for a given crop is identical at all locations.
4. There is a single isolated city at the center of the plane.

The solution to a two product allocation problem is given in Figure 2.1. Assume that the city is located at O. Unit production costs are given at OW for wheat and OP for potatoes. Unit transport costs are given by the slopes of WN and PT or WM and PS for wheat and potatoes, respectively. Wheat is assumed to be more costly to produce, but cheaper to transport than potatoes. The total cost of producing and delivering wheat to the city from any location is represented by the height of the line NWM and, for potatoes by the height of the line TPS.

Consider agricultural land at distance OR1 from the city. The average costs of production and transportation are R1P1 for potatoes and R1W1 for wheat, with R1P1 < R1W1. In contrast, land located at distance R2 from the city has relative average costs such that R2P2 >R2W2. Assume that wheat and potatoes sell at identical prices in the city.

Then potato producers can outbid wheat producers for land at R1 and wheat producers can outbid potato producers for land at R2. In general, all of the land between H and L will be used for potato production and the land in regions XH and LZ will be used for wheat production. Giving Von Thünen's theory a two dimensional plane



Source: Kellerman, A. *Agricultural Location Theory: A Review and Bibliography of Theory and Applications.* Peace Dale: Regional Science Resource Institute, 1983.

Figure 2.1 Von Thünen Model

market, it predicts a pattern of land use characterized by concentric rings each devoted to the type of production that can offer the highest land rent within that ring area.

Weber's Theory

Weber argued that the optimal location was uniquely determined at the site that minimized transport costs. Consider a firm using a single raw material produced at location M and converting it via a single stage production process to a final product sold at a single market at location C. The firm will locate along a straight line between point M and point C. If production costs are identical at all locations, the site location of maximum profit occurs where total transport costs are minimized. Let this unknown location be Z. Then total transport cost (TC_{trans});

(1)
$$TC_{trans} = t_m MZ + t_c CZ$$
$$CZ = MC - MZ$$
$$TC_{trans} = t_m MZ + t_c (MC - MZ)$$
$$TC_{trans} = (t_m - t_c)MZ + t_c MC$$

where:

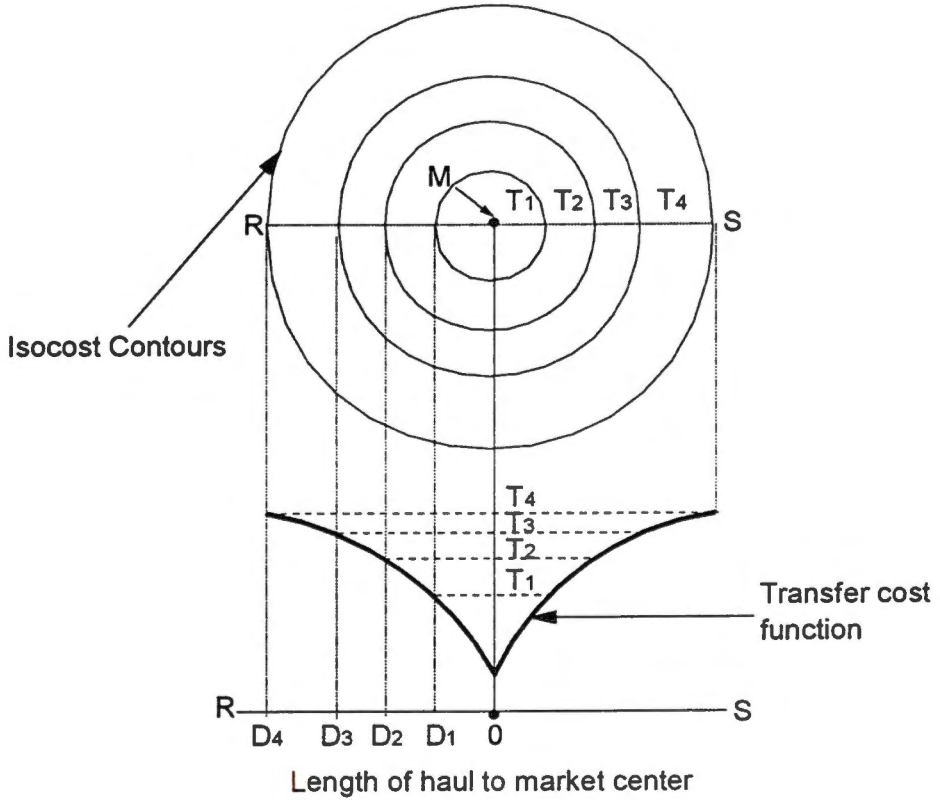
t_m = cost per mile of transporting enough raw material to make one unit of final product,
t_c = freight cost per mile per unit of product
and:
Z is chosen so as to minimize $TC_{trans.}$

If $t_m > t_c$, the firm will minimize MZ and will locate at the production region, where MZ=0. If $t_m < t_c$, then the firm will locate at C, the market, where CZ=0 and MZ=MC. If $t_m = t_c$ the transport costs are t_c MC regardless of where the firm locates. This is the case of locational indifference (Richardson 1978).

Modern Adaptations of Location Theory

With production and consumption carried on at spatially separated locations, the transfer of products provides a necessary and essential connection. For biomass, these transfer activities may include assembly or collection from small producing sites, loading and other terminal activities, storage, or transportation to the electrical generation facility. Some of these activities may not be directly related to space or length of the haul, but the costs of performing the service are clearly a function of the distance involved. Transfer costs are all of the costs involved with the movement of the product (Bressler and King 1970).

Consider one localized market with product supplies scattered over a completely uniform and flat geographic area. Travel in any direction within the plain is equally feasible. The resulting pattern of transport costs from every point on this plain to the market is called a transfer cost surface (Bressler and King 1970). A transfer cost surface can be described in either section or plane view (Figure 2.2). An isocost contour line represents the locus of points on a plain where equal transfer cost will be incurred when shipping a given product to a given market center. If the transfer cost function takes the shape of the type in Figure 2.2, the resulting isocost contours are concentric circles but with radii that increase at an increasing rate. With this type of cost function, the distance between D1 and D2, D2 and D3, etc. becomes greater and greater because the cost surface rises at a decreasing rate.



Source: Bressler, R.G. and R.A. King. *Markets, Prices and Interregional Trade*. New York: John Wiley & Sons, 1970.

Figure 2.2 Curvilinear Transfer Cost Surface

Any real geographic area will be characterized by a complex of non-uniform typography- hills and valleys, mountain ranges, rivers and streams. These topographical influences, interacting with the nonuniform spatial distribution of resources, will give rise to particular spatial distributions of human populations- a complex of major cities and urban areas, secondary cities, towns, villages and rural districts. Interconnecting these population distributions and developing with them will be particular networks of transportation routes - major and secondary highways, rural roads, rail lines, and water transport (where applicable) by canals, major rivers, lakes and coastal ocean routes (Bressler and King 1970). The obvious impact of the real-word rail and road networks is to distort the transfer costs and isocost contours.

Topographical features may significantly change cost relations. In some circumstances, the distortion may be slight. In others where natural barriers are more formidable, the location of mountain passes and bridges over major rivers will represent "gateways" that may seriously affect point-to-point transport distances and costs. This suggests that equal-cost contours will be irregular instead of forming concentric circles. The type of terrain may affect the cost of transport per kilometer ton (km). A higher cost per kilometer ton would occur in mountainous areas while a lower cost per kilometer ton may occur in flat plain areas. Population and production densities will also effect transport costs due to their influence of the utilization of the available capacity of existing transport systems. These distance and cost distortions can be expected to destroy the smoothness and symmetry of locational solutions suggested by theory.

Agricultural economists have developed techniques to define appropriate transport cost contours for materials and products, given an irregular pattern of transport costs. English, (1993) developed a square or diamond shaped pattern of transport routes for analysis in Iowa. This was appropriate due to Iowa's road network and terrain. Due to the terrain of Tennessee and a road network that does not run east-west or north-south, the square or diamond shaped patterns are not appropriate.

Summary of Location Theory

All theory relies upon a foundation of assumptions or axioms. It can usually be shown that the restrictiveness or invalidity of these axioms will restrict the application of the theory to the empirical state of nature. Location theory is no different from any other economic theory.

Ricardo's theory of comparative advantage and rent did not consider distance and transport costs among the factors of resource allocation. Both of these factors are essential in any modern theory of location. Von Thünen's model is an improvement from Ricardo, but Von Thünen's assumptions are too restrictive for empirical analysis. For example, cities are not isolated and there is no uniform homogenous surface area on earth.

What is needed is a modification of location theory that accounts for the differences in topographic features land and variations in road networks. These modification must also incorporate these features in the cost of product transportation. These modifications typically are available in a Geographical Information System (GIS).

Site Location Literature

Optimization Literature

A large body of literature exists for optimal location of industries. Most of this literature deals with analysis of the regional promotion of industries. There is also literature on specific plant locations. This literature is a much smaller body of knowledge addressing two major concerns: optimization models and decision maker models.

The most common site location optimization model is the spatial model. Spatial models have been used in agricultural economics literature for decades, and several books have been written on their use (Takayama and Judge 1971; Heady and Srivastava 1975; Hazell and Norton 1986). In this study, spatial analysis assumes the "Weber Model" as its theoretical basis but removes the restrictiveness of Weber's assumptions. The objective when using Weber models is to determine the locational patterns which minimize the cost of transportation (Takayama and Judge 1971).

Kilmer, Spreen and Tilley (1983) use a spatial model to determine the dynamic adjustments required in number, size and location of East Florida citrus packinghouses over time when the volume and location of production is changing. They state that static models are not appropriate when the spatial pattern of supply or demand is changing, and the cost of closing plants and opening new ones is a significant portion of total citrus industry costs. Kilmer, Spreen and Tilley suggest using a dynamic programming model which allows the incorporation of short and long run adjustment in the plant location model. Their results indicate that new large packinghouses are not competitive with

existing small packinghouses because existing plants can forgo a return on investment for a finite period.

Faminow and Sarahn (1983) adapt a mixed integer plant location model for fed cattle slaughtering plants in the United States. Their model is formulated to locate the optimal number, size and location of large scale fed cattle slaughtering plants in the United States. In general, large scale slaughtering plants are to be located near the production areas.

A severe limitation of spatial models is their rigidness. Many parameters such as: input prices, transport rates, quantity demanded, price of output and a given technology are fixed. A new analysis is required for every change made to the parameters (Hurter and Martinich 1989).

Decision-Maker Characteristics

The severe limitation of the spatial models has led to a different approach toward location theory. This new approach relies upon a direct sampling of the decision makers within an organization, who make plant location decisions. The decision maker literature uses qualitative dependent variable choice statistical models, most notably the multinomial logit.

An early attempt to statistically analyze the determinants of industrial location in rural communities was conducted by Smith, Deaton and Kelch, (1978). Using a linear probability model, their major goal was to generate appropriate policy recommendations for the rural communities in the Kentucky - Tennessee area. These data consisted of 565

nonmetro communities, 179 of which had one or more plants each having at least 20 employees. Their results suggested that community size, and a location of a higher education establishment in the community did not appear to be factors in the location of manufacturing industries. Plant size and location were based on the accessibility of transportation and cost-related considerations. The implication for communities who seek new facilities to be located in their region is that they should promote information that addresses the transport and cost concerns for these companies.

Schmenner, Huber and Cook (1987) claim that the decision of manufacturing plant location within the United States should divided into two stages. The first stage of the decision process is expected to capture state characteristics that are most important to firms. Some of these manufacturing characteristics are: access to interstate highways, availability of input materials, and an adequate labor force in terms of both quality and quantity. The second stage is to use site specific characteristics to either magnify or diminish factors defined by the first stage..

A Fortune 500 study of plants that opened in the 1970's is used to derive plant specific siting characteristics. The relationships derived from characteristics of site selection and expected profitability were tested through a series of multinomial logit models. The results of Schmenner, Huber and Cook confirm that the location decision can be approached from a two staged process and that geographic differences, by themselves are not enough to explain why some states are better than others at attracting new plants.

A study by Walker and Calzonetti (1988), analyzes the decision process by managers for manufacturing location in Central Appalachia. A hierarchical decision making model that incorporated imperfect information was developed. The data was collected from interviews of surveys of plant managers involved in regional and local site selection processes. Results indicated that factors of site location are different both at the regional and at the local level. Also, branch plant search behavior may be based solely by cost minimization of single-plant site location.

Kriesel and McNamara (1991) use hedonic price theory to examine the price of industrial sites. The price of an industrial site can be explained by its quality characteristics. Data from 158 Georgia counties were used in their empirical model. Their results suggest that community leaders should take three kinds of actions to influence the community's probability of attracting a manufacturing plant. Based on this study, these community leaders need to improve the community's fire protection rating, increase community's involvement in state policies concerning unemployment, infrastructure and labor quality, and reduce community's industrial taxes.

GIS Literature

The function of an information system is to efficiently organize information to improve the ability to make decisions. An information system is a chain of operations that proceeds from planning the observation and the collection of data to the storage and the analysis of data (Star and Estes 1990). A geographical information system (GIS) model provides additional information which may lead to more complete decisions than previous

location models. A GIS is model incorporates specific spatial and non-spatial characteristics of both the land and the road network.

The lack of formal markets coupled with the lack of location, size, and specification of both facility and production areas creates models that are subject to variations in both costs of production and pricing of switchgrass. The GIS model incorporates distinct characteristics of particular regions in an attempt to define the location, plant size and specification of using switchgrass as a fuel source in electrical generation plants. This GIS model incorporates data on facility siting requirements and location of roads, power transmission lines, existing power plants and projected population growth, as well as specific information on the potential supply and cost of switchgrass (English et al. 1993). A GIS analysis of this type would have been prohibitively costly five years ago, but due to technology advancements, most of this analysis can be performed on personal computers (Noon 1996).

Two models, BRAVO and RIBA have been recently developed for the analysis of biomass. BRAVO is currently used by the Tennessee Valley Authority (TVA) to determine the cost of including biomass as part of its fuel mix for existing fossil plants. BRAVO provided information to TVA decision makers allowing them to quickly conduct a knowledgeable and targeted assessment in using biomass as a potential fuel source for current electrical power plants (Noon 1996).

The Regional Integrated Biomass Assessment Model (RIBA) has been used by the Department of Energy to help identify promising areas for locating switchgrass-based

production facilities in the Midwest and Southeast United States. RIBA integrates the following: farmgate prices, available quantities, road network, transport costs, and simulated plant location into a combined flexible GIS. RIBA's output is a series of maps showing least cost locations of biomass plants and production regions (Noon 1996).

Economics of Biomass Literature

Most of the biomass production literature in the United States has been published by the National Laboratory at Oak Ridge (ORNL). After the energy crisis of 1973, the US Department of Energy (DOE), through ORNL, began to study the management of short rotation woody crops. In 1992, the National Biofuels Roundtable (NBR) was established by a collaboration of the Electric Power Research Institute (EPRI) and the National Audubon Society with ORNL playing the major role. NBR was developed to address the environmental and economic issues resulting from the widespread use of biomass. The major biomass issues that were addressed by NBR were: (1) the absence of established markets, (2) the potential for improving the environment, (3) the low alternative fuel prices, and (4) the landowner attitudes opposing biomass crop establishment (Lothner 1990).

Several goals were developed by the NBR. Microeconomic models, utilizing a unit cost and least cost pattern of supply, were needed to analyze biomass systems. Other models utilizing linear programming were needed for economic evaluation and scheduling of traditional agricultural production and biomass activities at the same time. The need to

integrate both biomass production and harvesting systems into a total system framework received the highest priority from NBR. (National Biofuels Roundtable 1994)

The economic literature of biomass can be broken into two distinct areas: those studies that focus on cost of feedstock production and those studies evaluating environmental impacts. Within the cost of feedstock production, there are single site (test plot) studies and regional analysis.

Cost Studies

Single Site

English et al. (1991) uses a farm level modeling system to evaluate the impacts of adopting biomass production techniques on three types of farm firms. The Farm Level Agricultural, Resource and Environmental Modeling System (FLARE) was used on representative farms in Southwest Georgia and West Tennessee to model farm profitability and erosion control. The financial variables examined include net farm income, net worth, net cash income, and government deficiency and diversion payments. The results indicate that under current agricultural policy consideration, Tennessee farms, which are characterized by more erosive and less productive soils will benefit more by adopting biomass production techniques than Georgia farms.

In the analysis, English et al. (1991) incorporated biomass with a traditional crop mix. Four management systems were simulated for each farm, with each simulation depicting a different crop mix or using different technology and production methods. The first system was a base farm scenario with no biomass participation. The second system

prevented the use of any CRP or price support programs but included biomass participation. In the third simulation, biomass participation, price support and CRP were included. The fourth simulation allowed the use of biomass on CRP land and price support program participation. The results indicate that either CRP land or biomass production land will reduce erosion. Both CRP and biomass production resulted in decreased net returns from the base model. Government intervention can be reduced if participants in CRP are allowed to use that land for biomass production.

Another English et al. study (1995) determined the feasibility of supplying switchgrass and hybrid popular to potential biomass conversion facilities at three specific Midwest locations. The analysis uses a linear programming model which maximizes net returns under various biomass price levels subject to several resource constraints. The biomass supply curves generated were based upon the perfect competition structure at the farm level.

A study by Graham et al. (1995) derived a supply curve for delivered wood chips from short rotation woody crops (SRWC) for 21 regularly spaced locations spanning the state of Tennessee. The supply curves were developed using BRAVO, a GIS based decision support system that calculates marginal cost of delivering wood chips to a specific location using given road network maps and maps of farmgate prices and supplies of wood chip from SRWC. Marginal cost varied by facility location. Marginal costs were lowest in West Tennessee until facility demand fell to less than 3 million dry tons per year. Below that figure, Middle Tennessee was the least cost region. Between 18 and 29

percent of delivered cost was due to transportation. Delivered cost ranged between $7 and $16 per dry ton. Reducing the expected farmer participation rate from 100 percent to 50 or 25 percent dramatically raised the marginal costs of feedstock supply in the east and central portions of Tennessee.

Bhat and English (1993) examined a staggered harvesting strategy for switchgrass. They state that most feedstock cost estimates are based upon a harvesting system where farmers are expected to undertake the harvesting operation. Such a system requires the farmers to have the harvest machinery at the time when it pays them the most to harvest, i.e. when the crop attains maximum yield. If all farmers decide to harvest at the same time, a huge inventory of harvesting machinery will be required to complete the harvest. The individual farmer harvesting system contributes 30 percent to 50 percent of total feedstock costs for switchgrass.

Bhat and English (1993) state that this type of harvesting system causes an overinvestment in agriculture and a social cost to society. They propose a least cost, time-distributed (staggered) harvesting system for switchgrass. This system requires a coordination between farmers, processing plant and a single, third-party custom harvester. Their linear programming model used accounts for the trade-off between yield loss and the benefit of reduced machinery overhead cost.

Data for the switchgrass yields was obtained from the Erosion Productivity Impact Calculator (EPIC). EPIC is a plant growth simulator that incorporates specific crops, soil,

weather, crop inputs and management characteristics. West Tennessee was analyzed using the EPIC simulator.

Results indicate that the total cost of producing and harvesting is estimated to be 17.94 percent less in staggered harvesting than that of non-staggered harvesting. Along with the decrease in cost was a 9 percent decrease in switchgrass yields. Using the staggered harvest method, harvesting machinery cost were reduced by 39.68 percent. The net return to farmers increased by 160.40 percent.

Walsh and Graham (1995) develop a supply analysis of biomass feedstock. A full economic cost accounting approach was used and variable costs included costs of seeds, fertilizers and chemicals applied. Fixed costs included general farm overhead, taxes, insurance and loan payments. Owned resource costs included capital replacement costs of machinery and equipment, other non-land capital costs (opportunity cost of machinery and equipment), and the value of the farmer's labor. Farmers are assumed to own all of the necessary equipment used for production. The costs of producing biomass feedstock are estimated separately, so whole farm synergies are not included in this analysis. Transportation costs are also not included in this analysis. Production costs are obtained from estimates of per hour equipment costs and hours required to complete each operation.

Regional Analysis

English and Bhat (1991) examine the major constraint to a biomass feedstock development program, namely, the cost of production and transportation. In 1991,

biofuels production was not attractive to producers nor to consumers when compared to traditional alternatives. Current available estimates of unit switchgrass cost were based upon a fixed feedstock price assumption without accounting for species variation and feedstock production costs. English and Bhat (1991) developed a reliable regional resource base for switchgrass feedstock. Their results indicate that sorghum is the most efficient biomass energy crops for the Midwest region of the United States and energy cane is the best biomass crop for the Southeast region of the United States.

Bhat and English (1995) examine biofuels from energy crops in the midwest region of the United States. They point out that biofuels can be a potential alternative for conventional fossil fuels. Their study identifies the comparative advantage among biomass species and locations in terms of costs of producing biomass, transporting feedstocks, and conversion into biofuels. Their results indicate that the costs of feedstocks varies widely with the type of biomass crop and production region. They also point out that transportation cost for feedstock could become a sizable component of total cost in the future. Sorghum grown in the Midwest appears to be the most economical crop for the production of methanol and reformulated gasoline. Hybrid popular from the Midwest seems to yield ethanol at minimum cost.

Graham and Downing (1995) examine the potential supply and cost of biomass production in the Tennessee Valley Authority (TVA) region. Their results indicate that if all of the current farmland within the TVA region is used for bioenergy crops, it can

support 18 GW (gigawatts[10]) of energy if wood is the sole fuel and 30 GW if switchgrass is the sole fuel. They assumes an efficiency of 10,000 BTU per kilowatt hour for both bioenergy crops. Farm gate prices range between $40 and $50 per ton of wood fuel and between $35 and $45 for switchgrass are needed to ensure landowners' profits commensurate with current land use. From a regional perspective, energy crop supplies are projected to be the greatest in the West Tennessee due to the combination of low land rent and high agricultural use.

Walsh and Graham (1995) discusses the evolution and future goals of the Biofuels Feedstock Development Program (BFDP). The BFDP was a leader in the development of siviculture production technologies. The program has screened more than 25 grass species, leading to the selection of switchgrasss as a model herbaceous energy crop (HEC). The current challenges of the program are to increase the range of conditions and locations where cost competitive, dedicated energy crops can be grown, and to develop adequate plant materials and techniques to assure sustainability of supplies in those areas which appear to be cost competitive now. BFDP's long term goal is to be able to provide farmers with the technology and techniques to supply up to 15 percent of the nation's energy feedstock .

Graham et. al (1996) presents estimates of potential biomass production in the United States under a wide range of assumptions. Biomass - based electricity generation is a niche market where electricity is expensive and fuel is cheap or incurs a disposal cost,

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[10] A gigawatt is one billion watts.

e.g. waste wood, sawdust etc. If biomass production and usage systems demonstrate themselves workable at DOE's projected cost, biomass crops might become competitive for electricity production and other uses. Estimates of potential biomass crop yields and production cost from ORNL are combined with measures from land rents from USDA's conservation resource program (CRP) to estimate a competitive supply of biomass wood and grass crops. Biomass crops could be produced on some of the land idled by farm programs in recent years. If biomass crop production exceeds 30 million acres, the interaction between biomass and traditional agricultural crops, markets and programs becomes important.

Environmental Impacts

The use of biomass as an input to generate electricity is less intrusive to the environment than using coal or other fossil fuels. An economic approach used to assess the environmental impacts of fuels is evaluate the benefits and the costs of changes in environmental quality that may result from using different fuelstocks in electrical power generation (Downing and Graham 1993). To evaluate the costs effectively, both market and non-market costs must be utilized. The extraction and transportation of coal to the conversion facility is reflected in the current coal price. A non-market cost would be the value of damage to the environment caused by emissions that occur when coal is burned.

The burning of coal in electrical power generation emits carbon dioxide (CO_2) and sulfur dioxide (SO_2) gases into the atmosphere. Sulfur dioxide gas is the major contributor to acid rain formulation. Increases in atmospheric levels of carbon dioxide

production have been attributed to global warming of the earth (Downing and Graham 1993). Several programs were enacted in an attempt to make utilities accountable for the emissions of coal plants. Title IV of the 1990 amendments to the Clean Air Act (CAA), created a trade allowance system for sulfur dioxide (SO_2) emissions. These SO_2 permits are currently traded on The Chicago Board of Trade (CBOT).

Another program developed by individual states is the use of social cost pricing for coal fired electric power plants. Social cost pricing is a method that assigns the non-observable cost of coal to the electric power plant that uses coal for electrical production. Palmer et al. (1994) discusses techniques of social costing that is already in use by many states. Many public utility commissions require electric utilities to consider the environmental social cost in the electric generating process. Currently social costing has been evaluated only at new energy facilities, such as biomass burning facilities. Palmer et al. (1994) examines three comprehensive social costing approaches. The first approach is to require consumers to pay a price for electricity that reflects its true social cost. The second approach is to require the utility to include social cost estimates in the cost structure of constructing new generation facilities. The last approach is to include social cost estimates in the operating cost structure of existing generating facilities.

Using estimates of external costs taken from the literature, Palmer et al. contrasts the implication of these approaches in the decision making and pricing of electricity for a Maryland utility. Results indicate that incorporating social costing in the cost structure for the development of new electrical generation facilities will lead to fewer new facilities

constructed and increased use of current electrical generation facilities and higher levels of pollutants. By incorporating social costing to the cost structure of existing electrical generating facilities leads to increased investment in clean technologies (pollution scrubbers), lower levels of emissions and price increases of electricity.

Burtraw (1996) points out that low sulfur coal has provided electric utilities with short term solution to environmental restrictions. Using low sulfur coal instead of high sulfur coal as an input for electrical power generation has allowed electric generating facilities to meet current environmental restrictions. As environmental restrictions get more stringent, low sulfur coal may not be the cost effective alternative for compliance with these standards. Firms will turn to other more cost effective alternatives. Biomass may be one of them.

Switchgrass is a source of energy that has no sulfur dioxide emissions when burned. Switchgrass has less ash content than coal and offers zero net CO_2 emission[11]. Switchgrass use as a feedstock to electrical production avoids the safety and disposal issues related to nuclear power and the fishery and permanent land loss issues related to hydroelectric power (Graham, Dowling and Walsh 1996). In addition, Section 404(f) of the Title IV Clean Air Amendments Act (CAAA) includes provisions for earning credits from SO_2 emissions avoided through energy conservation measures or use of renewable energy (Robinson and Shapouri 1993).

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[11] Biomass also has a lower heat content than coal. Switchgrass generates 15.6 Mbtu per metric ton when burned, coal generates 22.13 Mbtu per metric ton. (Energy Information Administration, State Coal Profiles - Kentucky 1997).

Robinson and Shapouri (1993) state that before the rise of the internal combustion engine, most of society's energy was from agriculture. By the end of the 1960's, the land used to produce for food for animal power became so insignificant that it was dropped from *Agricultural Statistics*. The decline in the use of animal power resulted in the production and harvesting of fewer acres of close grown crops - hay, oats, rye and barley. Acreage once used for the production of forage were shifted into row crops, which use more fertilizer and allow more soil erosion. A shift back to close grown crops, such as switchgrass, would provide habitat for wildlife, reduce erosion, reduce sediment loadings, and reduce agricultural chemical loading to ground and surface waters. This would help promote a more sustainable agricultural resource base.

Graham and Dowling (1993) present an approach for projecting the probable impacts of biomass production at the regional (sub-county level) scale. Using EPIC Graham and Dowling analyze the impact of switchgrass production on two multi- county subregions within the Tennessee Valley Authority (TVA) region. Results indicate that adoption to switchgrass production from traditional row crops results in a decreases of erosion, evotanspiration and nitrate runoff in both sub-regions. Phosphorous fertilizer applications increased in one region and decreased in the other due to the initial differences in the type of conventional crops grown in each region. Overall, these changes resulted in the improvement of water quality with the increasing adoption of switchgrass.

Chapter 3 METHODS AND PROCEDURES

Overview

This chapter contains the development of the components necessary for the analysis of the economic feasibility of switchgrass in Tennessee. The Regional Integrated Biomass Assessment Model (RIBA) is a geographical information system developed by Noon et.al (1996) (Figure 3.1). The first section of this chapter explains the development of information needed for the RIBA model and the interpretation of the RIBA output. The derivation of specific criteria used in this study to determine the economic feasibility

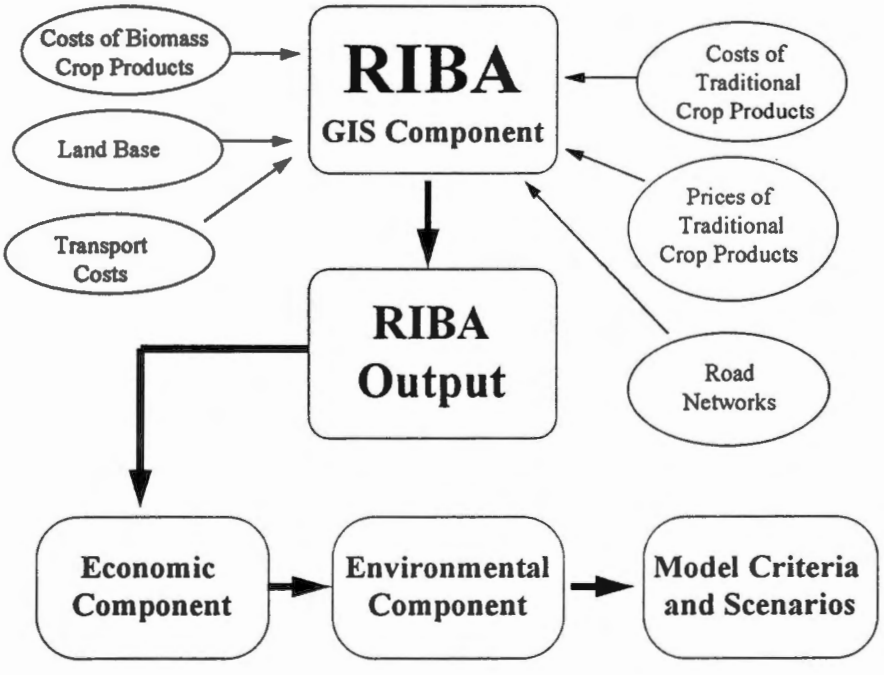


Figure 3.1 Method Overview

for the production and utilization of switchgrass in Tennessee is developed in the second section of this chapter.

Geographical Information System

A map is an information system. To be useful, a map must be able to convey information to its intended users in a clear and unambiguous fashion. A geographical information system is a type of mapping system designed to work both spatial data and non-spatial data. A GIS is both a database system as well as a set of operations for working with the data. In this sense, a GIS may be thought as higher order map (Star and Estes 1993).

As shown in Figure 3.2, various different techniques and types of data are brought together to develop a geographical information system. The GIS used in this study (the RIBA model) is composed of three sub-components. The spatial sub-component contains the information about the costs of transportation of switchgrass along Tennessee's road network. The yield sub-component contains the estimated switchgrass yields for Tennessee. Switchgrass yields are estimated due to the lack of switchgrass production in Tennessee. The economic sub-component contains the results derived from the break-even analysis evaluating the production of switchgrass instead of other traditional row crops.

The data used by the GIS in this study is developed from different reference sources. The source of spatial data is geographical map reference coordinates. The pixel is the initial mapping reference coordinate for this GIS (Figure 3.3). Each pixel, defined as a one square kilometer, has certain attributes. In this study, each pixel contains a percent

land type and spatial map coordinates. The pixel land types are: cropland, pasture, forest, urban or water. This land type is defined through the Anderson code. The Anderson code does not provide any information on what type of crop is planted, crop prices, crop yields, or soil quality.

The next level of mapping coordinates is the map unit identifier (MUID) (Figure 3.4). A MUID is an aggregation of pixels with similar soil types. A Major Land Resource Area (MLRA) is an aggregation of MUID's. A MUID is confined to a MLRA boundary.

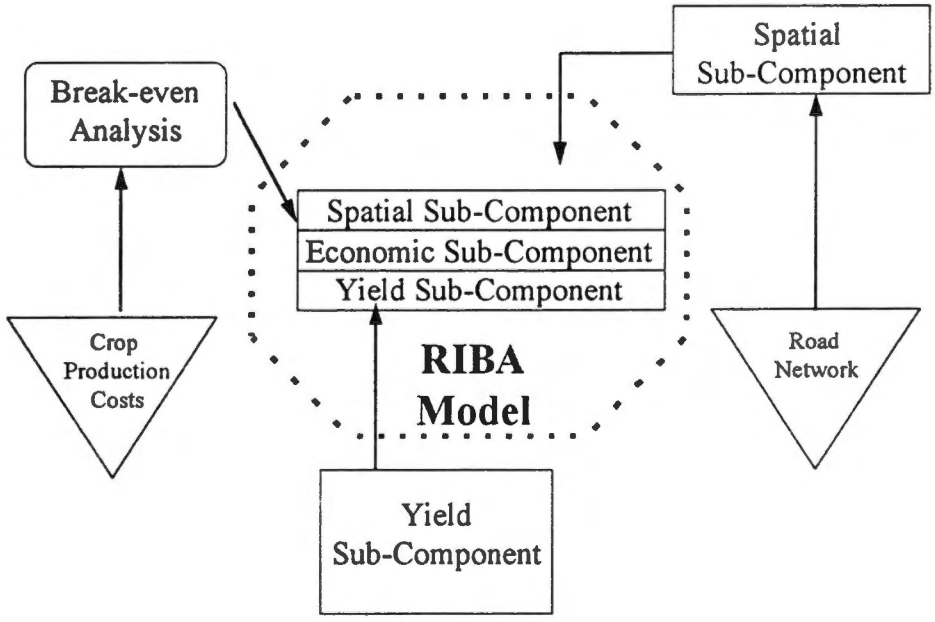
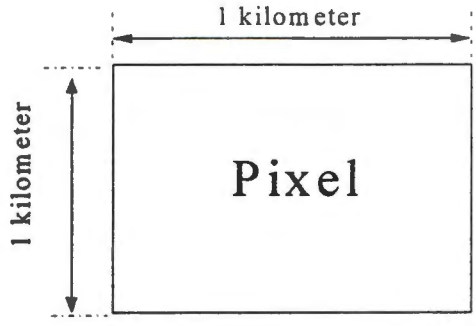


Figure 3.2 Conceptual Map of GIS Components



A pixel is equal to 1 square kilometer of area

Figure 3.3 Initial Mapping Unit in GIS

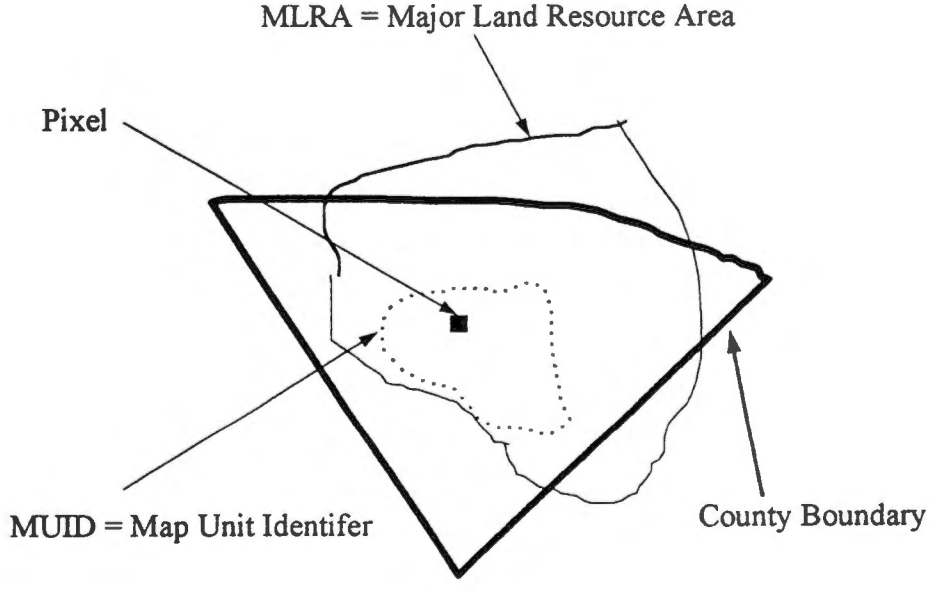


Figure 3.4 Geographical References

Another reference source of data for the GIS is based upon political boundaries. Here the initial unit is the county. Most of the economic data needed for the GIS in this study is organized by counties. Crop types and prices are reported at the county level. Counties are aggregated to the state level where production costs are defined.

To complete the yield sub-component of the RIBA model, both data classifications must be integrated. Problems arise when integrating the two data classifications within the GIS. Counties do not necessarily coincide with MLRA's (Figure 3.4). Hence, a county can lie within or partially outside of a MLRA.

For this study, political boundaries are used. To integrate the two data structures, each MLRA is identified to the particular county it is located in. MLRAs located between two counties were assigned to the county which has the largest percentage of land area in that MLRA.

Development Of RIBA Variables

Study Selection

The analytical procedure used to develop the GIS was obtained from English et al., 1996. Because of the lack of a switchgrass market prices, a break-even price for switchgrass was developed. The break-even price was developed by examining the profits and costs of major crops by soil type and by estimating a price for switchgrass that would result in similar profit margins. The break-even switchgrass price developed from English et. al (1996) is used as the base case for this study. This break-even switchgrass price is responsive to changes in land quality, traditional crop mix and current or projected

government commodity policy. This price responsiveness developed by English et al. (1996) is ideal for use with the detailed analysis of the RIBA model.

Base Case

The lack of an established market for switchgrass requires a proxy price to be developed for switchgrass. A proxy price for switchgrass can be generated by using the break-even analysis technique. In using break-even analysis, the assumption is made that farmers will be indifferent to what crop they grow if the profit of current crops is equal to the profit generated by switchgrass (English et al. 1996). Due to the precision of the GIS, a single break-even biomass price for each pixel is desired. For traditional crops,

(3.1) $$\Pi c = Pc * Yc - Cc$$

and for biomass

(3.2) $$\Pi b = Pb * Yb - Cb$$

where:

Πc is the profit for composite crop (c) expressed in terms of dollars per hectare;

Πb is the profit for biomass crop (b) expressed in terms of dollars per hectare;

Pc is the price of composite crop (c) expressed in terms of dollars per metric ton;

Pb is the price of biomass crop (b) expressed in terms of dollars per metric ton;

Yc is the yield of composite crop (c) expressed in metric tons per hectare;

Yb is the yield of biomass crop (b) expressed in metric tons per hectare;

Cc is the variable production cost of composite crop (c) expressed in dollars per hectare; and Cb is the variable production cost of biomass crop (b) expressed in dollars per hectare.

By setting equations (3.1) and (3.2) equal and solving for the unknown, Pb, we obtain:

$$\frac{[Pc * Yc - Cc + Cb]}{Yb} = Pb \tag{3.3}$$

To determine the composite price, Pc, the crop data are weighted by acres of that crop in a given county (i) divided by total acres.

$$Pc = \frac{\{[\sum_m (P_{i,m} * Y_{i,m} - C_{i,m}) * A_{i,m}] [\sum_m Ai]^{-1}\} + Cc}{Yc} \tag{3.4}$$

where:

i is the county that the pixel is in;

m is the major crop in Tennessee (m = 1 to 4);

P_i is the price of crop m in county i;

Y_i is the yield of crop m in county i;

C_i is the production cost of crop m in county i ;

A_i is acres planted of crop m in county i; and

A_T is total acres planted in county i.

Traditional crop selection

The major crops selected for Tennessee are: corn, hay, soybeans and wheat (English et al. 1996). These crops were selected by the following criteria:

1. The crop must account for no less than 3 percent of total harvested area within Tennessee.
2. The crop must account for at least 3 percent of the Agricultural Statistical District's (ASD's) harvested acres.
3. The crop must account for at least 5 percent of the total harvested acres in any Agricultural Statistical District.

Composite crop price (Pc)

Determining the price of crop c by county is achieved using national prices and commodity loan rate for each of the traditional crops. The county loan rate is constructed to reflect local price differentials. The county loan rate is divided by the national loan rate to form a county index.

National prices for selected crops are converted into dollars per metric ton (Table 3.1). The local crop price is obtained by taking the national price multiplied by a county level price index that represents a differential from the national price (Table 3.2). This index was developed by the Agricultural Policy Analysis Center (APAC), Department of Agricultural Economics and Rural Sociology, The University of Tennessee from data on loan rates for program crops (English et al. 1996).

Table 3.1 National Prices for Selected Crops

Crop	Units	National Price	Conversion Factor
		dollars per unit	
Corn	bushels	2.05	39.35
Soybeans	bushels	5.40	36.73
Wheat	bushels	3.30	36.73

Source: English, B.C., K.D. Dillivan, R.L. Graham, V. Witcher, and J. Velasquez. "Evaluation of Agricultural Producers Willingness to Produce Biomass: An Assessment and Methodology to Developing the Data Necessary for a Geographical Information System," University of Tennessee, Department of Agricultural Economics and Rural Sociology, 1996. Photocopied.

Table 3.2 Index for Crop Prices in Agricultural Statistical Districts in Tennessee

Agricultural Statistical District	Corn	Soybeans	Wheat
44	1.102	1.028	1.100
45	1.083	1.028	1.050
46	1.066	1.020	1.040
47	1.064	1.020	1.050
48	1.069	1.019	1.050
49	1.054	1.012	1.020

Source: English, B.C., K.D. Dillivan, R.L. Graham, V. Witcher, and J. Velasquez. "Evaluation of Agricultural Producers Willingness to Produce Biomass: An Assessment and Methodology to Developing the Data Necessary for a Geographical Information System," University of Tennessee, Department of Agricultural Economics and Rural Sociology, 1996. Photocopied.

Crop production cost data (Cc, Cb)

Production costs are estimated for each of the selected crops. Because of the similarities between hay and switchgrass production practices, hay cost of production are used as a proxies for switchgrass production costs (Table 3.3). The costs for traditional crops are estimated using a budget generator developed by the Agricultural Policy Analysis Center (APAC), Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville (Slinsky 1996). Production practices are based

Table 3.3 Cost of Production for 300,000 Tons of Switchgrass in Tennessee, 1992

Item	Establishment Cost ($/acre)	Annual Maintenance Cost ($/acre)
Total Variable Cost	51.90	37.01
Labor Cost	10.91	8.03
Machine Cost	8.86	12.85
Interest Cost	2.94	2.09
Fertilizer Cost	0.00	8.40
Chemical Cost	5.64	5.64
Seed Cost	23.55	0.00

Source: English, B.C., K.D. Dillivan, R.L. Graham, V. Witcher, and J. Velasquez. "Evaluation of Agricultural Producers Willingness to Produce Biomass: An Assessment and Methodology to Developing the Data Necessary for a Geographical Information System," University of Tennessee, Department of Agricultural Economics and Rural Sociology, 1996. Photocopied.

upon information from the National Crop Practices Survey. Both crop dominant practices and input application rates are identified in this survey. These data are placed into the APAC budget generator and estimates of total costs are determined (English et al. 1996).

Yield data (Yc, Yb)

Figure 3.5 illustrates the yield sub-component of the GIS. The yield sub-component is one of the most intricate layers of data in the GIS. The smallest geographical breakdown of yields available from secondary sources is the county level. These yields are reported annually by the National Agricultural Statistics Service (NASS). In a GIS attempting to evaluate the agricultural potential at the pixel (one square kilometer) level, soils, weather, management practices etc. are likely to impact the yield estimate.

A methodology that captures variations within a county would be more desirable than secondary sources. The Environmental Productivity Impact Calculator (EPIC) has been developed to estimate yield differentials and environmental parameters. EPIC

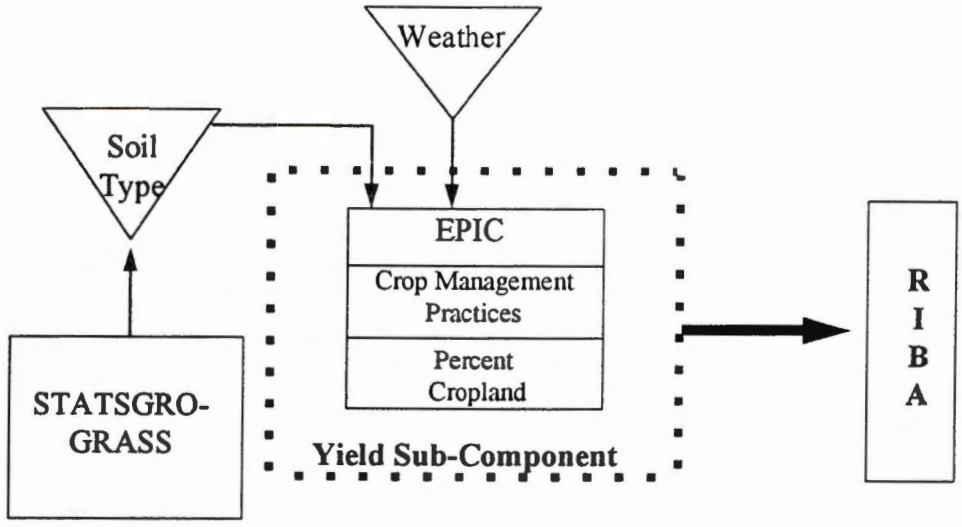


Figure 3.5 Yield Sub-Component Concept Map

requires information on management practices, soils and weather to calculate yield differences resulting from a change in environmental parameters (English et al. 1996).

The management practices for a given crop were established from the Crop Practices Survey and Extension Service publications. The soil selection was based upon a Natural Resources Conservation Service (NRCS) established methodology. This methodology required the interface of a soils database (STATSGO) with a GIS (GRASS). The STATSGO-GRASS database contains the geographical locations of soils within the continental United States. Using the STATSGO-GRASS database, dominant soils for each MLRA are selected. The soil type with the largest percentage (in terms of area) in the MLRA is the MLRA dominant soil (English et al. 1996).

The weather component for EPIC was developed from a database developed by the University of Tennessee Geology Department. This database contains longitude, latitude, and elevation coordinates for the geographic center of each county in the United States. These coordinates were used to select the national weather station closest to each county. Average annual weather patterns from those stations were inputted into the EPIC model.

Data was placed into an EPIC simulator and EPIC runs simulating 100 years under a constant technology assumption were made. Average annual estimates for yield and other selected environmental variables were then placed into the EPIC database. These yields estimated for EPIC represent yields for a dominant soil and weather pattern over a region that uses a "typical" management practice (English et al. 1996)

Similar methodology was employed for biomass crops as was used in traditional crop analysis. However the yield indices are based upon hay yields since there is no commercial biomass production (English et al. 1996).

Percent cropland

Because each pixel is not 100 percent cropland, the percentages for each pixel within a county were adjusted uniformly to reflect the county cropland acreage expressed in the 1992 Agricultural Census. Cropland available for switchgrass production was determined by establishing two levels of adoption: infant and mature. The infant level uses the remainder of the percent of active cropland after the acreage of the top two crops are subtracted from total active cropland. The mature adoption level is the greater of the

amount of acreage of the top crop or the infant technology adoption rate (English et al. 1996). These values were inputted into the GIS database. With both levels of adoption available, this analysis assumes a mature level.

Development of Alternative Model

In the traditional farmer-operated harvesting system, all farmers need access to the required harvesting machinery when a crop attains maximum yield. If all of the farmers in the switchgrass production area decide to harvest switchgrass at the same time, each farmer must own harvesting machines to accomplish their harvesting operation. Another result from all farmers harvesting at the same time (peak yield) is that either the farmer or the processing plant has to incur additional costs of feedstock storage and higher storage loss. The use of a traditional harvesting system is estimated to contribute 30 to 50 percent of total feedstock cost (Bhat and English 1993).

The alternative model developed from the analysis done by Bhat and English (1993). Their study examines the harvesting aspect of switchgrass feedstock cost. They develop a least cost staggered harvesting system for biomass. Bhat and English (1993) use a linear programming model to explicitly account for the trade-off between yield loss and benefit of reduced machinery overhead cost associated with the staggered harvesting system. The yield loss is a result of harvesting some of the crop before or after the peak yield time.

The costs of staggered harvesting are 37 percent less than the traditional harvest plan (Table 3.4). Two values of particular interest are the percent change in production area and per acre cost (9.10 percent and -24.78 percent, respectively).

The break-even analysis is modified by using the increase in yield and decrease in per acre cost values developed by Bhat and English. The switchgrass profit equation is now modified to include the values from the staggered harvest study.

(3.5) $$\Pi b = Pb * Yb - Cb$$

The modified equation is

(3.6) $$\Pi b = Pb * [Yb * 0.91] - [Cb * 0.76]$$

Setting 3.6 equal to 3.1 and solving for Pb, the unknown, we obtain

(3.7) $$\frac{[Pc * Yc - Cc + [Cb * 0.76]}{[Yb * 0.91]} = Pb$$

Table 3.4 Cost and Returns of Production for 300,000 Tons of Switchgrass for Staggered and Traditional Harvesting Techniques for Switchgrass

Relative Measures	Unit	Traditional Harvesting	Staggered Harvesting	Percent Change
Total area required	acres	30,334	33,093	**9.10**
Total farm-gate costs	dollars	6,413,686	5,263,120	-17.94
Net return	dollars	717,314	1,867,880	160.40
Total biomass produced	tons	300,000	300,000	0.0
Per ton cost	$/ton	21.38	17.54	-17.94
Per acre cost	$/acre	211.44	159.04	**-24.78**
Per acre harvesting cost	$/acre	140.05	87.66	-37.41

Source: Bhat, M., G. and B.C. English. "An Optimal Staggered Harvesting Strategy for Herbaceous Biomass Energy Crops," *In the Proceedings of the First Biomass Conference of the Americas: Energy, Environment, Agriculture and Industry* held in Golden, CO: NREL, 1993.

Equation 3.7 is now used in the calculations for the price of biomass (Pb), and inputted into the RIBA database. The modifications of the equations and subsequent database were necessary to account for the adoption of the staggered harvesting system.

Bhat and English (1993) examined one switchgrass fueled electric power plant size, that of a 300,000 ton yearly capacity. By the use of a linearity assumption, this study examines switchgrass fueled electrical power plants of several different sizes: 100,000 tons per year, 600,000 tons per year and 1,100,000 tons per year. The other plant sizes were extrapolated from the Bhat and English study. Table 3.5 examines the machinery requirements necessary for the subsequent plant size.

Environmental Analysis

The environmental component in this study examines the difference in air pollutants produced by potential biomass facilities and current coal facilities. Coal as a fuel source for electrical power generation produces undesired emissions. These

Table 3.5 Plant Size and Machinery Requirements for Switchgrass

Plant Size Annual Tonnage	Mower-conditioner	Number of Balers	Hay stackers	Tractors (80HP)
100,000	11	9	10	40
300,000	34	28	31	121
600,000	68	56	62	242
1,100,000	136	112	124	484

Source: Bhat, M., G. and B.C. English. "An Optimal Staggered Harvesting Strategy for Herbaceous Biomass Energy Crops," *In the Proceedings of the First Biomass Conference of the Americas: Energy, Environment, Agriculture and Industry* held in Golden, CO: NREL, 1993.

emissions are mainly sulfur dioxide (SO_2) and carbon dioxide (CO_2). Sulfur dioxide is the main contributor to acid rain, while carbon dioxide is linked to global warming.

Kentucky bituminous coal was chosen as the current source for electrical power generation plants for two reasons: the majority of electricity produced in Tennessee is by coal burning steam generation power plants (Electric Power Annual 1996) and Tennessee is the largest importer of Kentucky coal (State Coal Profiles - Kentucky 1997).

Bituminous coal is a dense, soft coal used primarily for generating electricity, making coke and space heating. Bituminous coal is the most mined coal in Kentucky. This coal can be found in the Appalachian coal basin of Eastern Kentucky. This coal has a low water content (20 percent), but a higher sulfur content (between 1 percent and 3 percent) than other types of coal (State Coal Profiles - Kentucky 1997).

The use of switchgrass as a feedstock in electrical power plants does not have the undesired emissions that the use of coal as a feedstock in electrical power plants. There is a no net carbon dioxide gain in burning biomass. The amount of carbon conversion during switchgrass's crop life offsets its burning as a fuel. Further, switchgrass does not emit any sulfur dioxide when burned (Downing and Graham 1993).

The burning of coal generates environmental damage to society in the form of sulfur dioxide and carbon dioxide emissions. These damages to the environment are not reflected in the current price of coal. Abatement costs were used to incorporate the environmental damage to society (the social cost) of using coal as a fuel source in electrical power generation. This study uses estimated abatement costs as proxy prices for

carbon dioxide (CO_2) and sulfur dioxide (SO_2) emissions by electrical facilities that use coal as a fuel source. The abatement costs for this study were obtained from Palmer et.al. (1994). The environmental component of this study is incorporated into the economic feasibility criteria for switchgrass fueled electric generation plants in Tennessee.

Model Result Interpretation

Because of RIBA's flexibility, there are several types of file outputs. Many of these are related to producing maps of specific criteria. The output for economic analysis consists of a file that lists all the pixels used to supply each plant location. An example of this output is displayed in Figure 3.6. Interpreted, the data indicate that at plant 1, node 672, receives 90.45 dry tons from pixel 101981 at a cost of $23.32 plus $3.04 shipping, for a total delivered cost of $26.37 per dry ton.

The plant number is based upon the location of the biomass conversion facilities as they are established in Tennessee. Plant 1 is the plant that initially receives biomass with the least delivered cost for the last ton received. Plant 1 receives biomass until its demand is met. At this point, the delivered cost of biomass is equaled to the delivered cost of the last ton of biomass to the plant, giving the plant full capacity. If the plant size is a 100,000 ton facility, then the delivered cost of the 100,000th ton delivered would be the maximum delivered cost for Plant 1. Plant 2 is the plant with the next highest delivered cost. The farmgate price is the price to produce biomass plus the opportunity cost lost not producing traditional crops. The transportation cost is taken from Noon, Daly, Graham

1 672 101981 23.32 3.04 26.37 90.45

Plant #	= 1
Network Node #	= 672
Pixel ID #	= 101981
Farmgate Price	= $23.32
Transport Cost	= $3.04
Delivered Cost	= $26.37
Tons Shipped	= 90.45

Figure 3.6 RIBA Model Output

and Zahn (1996) and varies due to road type . The delivered cost is the farmgate price plus the transportation cost. Finally, the tons shipped is the quantity supplied.

Supplying the State

A supply curve for Tennessee, according to plant size is generated from the RIBA output. Delivered cost and tons produced are the data needed to generate a supply curve. Both delivered cost and tons produced are first sorted by price (delivered cost). Tonnage is then aggregated by price to obtain quantity supplied. This price-quantity schedule is then plotted.

Total tonnage produced by plant size for each model was also provided by the RIBA output. State unit production and transportation cost by plant size for each model were developed by an average of farm production cost and transportation cost for each pixel.

Analysis of Components

The analysis of components examines the breakdown of costs and economic rent for three different sectors: the agricultural, the transportation and the utility plant.

Supply for each plant

A procedure similar to the state supply analysis was performed at the plant level. Supply curves, cost of production, cost of transportation and economic rents were developed for both the base and staggered harvest models and for each plant size: 100,000 tons per year, 600,000 tons per year and 1,100,000 tons per year.

Economic rent

In this study, total cost per unit is the delivered cost of each ith unit where i is equal to the pixel. Economic rent is the price one recieves for the product minus the cost of producing the product. Expressed in equation 3.8, the price, P, is the value of the ith unit of switchgrass supplied to the electric power plant.

(3.8) Economic rent $= \sum_{i=1}^{n} (P - C_i) q_i$

where:
n = number of pixels required for a given plant size;
i = pixel;
P = the delivered cost of switchgrass from the final pixel delivered;
C_i = the delivered cost for each pixel; and
q_i = the quantity of switchgrass delivered for each pixel.

There is an anticipated economic rent, but the distribution of this rent is not known. This study does not examine the distribution of the economic rent. The rent

could be captured by the utility, the farmers, the transportation sector or a combination of all these sectors.

Production cost and transport cost were obtained by plant from the RIBA output. Economic rent is calculated based upon the formula defined in equation 3.8. Production costs, transport costs and economic rents are tabulated for the initial switchgrass fueled electrical power plant of each plant size (100,000 tons per year, 600,000 tons per year and 1,100,000 tons per year) for both the base model and the staggered harvest model.

Locational Analysis

For this study, Tennessee is divided into three major regions: East, Middle and West. The division of these regions is based upon the natural physical geography of the land in Tennessee. The Tennessee River provides the regional boundary between Middle Tennessee and West Tennessee. The eastern edge of the Cumberland Plateau provides the regional boundary between Middle Tennessee and East Tennessee. County classification is based upon regional location. Table 3.6 shows the county classification used for this analysis.

For each model, the base model and the staggered harvest model, and each plant size (100,000 tons per year, 600,000 tons per year, and 1,100,000 tons per year) both the cost structure and quantity of switchgrass delivered by each region will be compared at both a regional level and a plant level.

Table 3.6 Tennessee County Classification

Location	Counties
East Tennessee	Anderson, Blount, Bradley, Campbell, Carter, Claiborne, Cocke, Grainger, Greene, Hamblen, Hamilton, Hancock, Hawkins, Jefferson, Johnson, Knox, Loudon, McMinn, Meigs, Monroe, Polk, Roane, Scott, Sevier, Sullivan, Unicoi, Union, Washington
Middle Tennessee	Bedford, Benton, Bledsoe, Cannon, Cheatham, Clay, Coffee, Cumberland, Davidson, De Kalb, Dickson, Fentress, Franklin, Grundy, Hardin, Hickman, Houston, Humphreys, Jackson, Lawrence, Lewis, Lincoln, Macon, Marion, Marshall, Montgomery, Moore, Morgan, Perry, Pickett, Putnam, Rhea, Robertson, Rutherford, Sequatchie, Smith, Stewart, Sumner, Trousdale, Van Buren, Warren, Wayne, White, Williamson, Wilson, Maury
West Tennessee	Carroll, Chester, Crockett, Decatur, Dyer, Fayette, Gibson, Giles, Hardeman, Haywood, Henderson, Henry, Lake, Lauderdale, Madison, McNairy, Obion, Overton, Shelby, Tipton, Weakley

Economic Scenario Development

Five scenarios were developed for establishing the economic feasibility of switchgrass production and utilization in Tennessee. These scenarios are used to examine the use of switchgrass instead of coal as an input to electrical power generation. Table 3.7 contains a summary of all of the characteristics needed for the development of the analysis. A price required for switchgrass utilization is determined by each of the five scenarios. This price is then compared to the break-even price developed by the RIBA model.

This is a marginal cost analysis procedure was developed to establish a base price for switchgrass (Pb). The price paid by the electrical power generation facility of last ton required by the plant (where n = plant size) is used to determine the price paid for all of the other tons received by the plant. In the case of the 100,000 ton plant size, the delivered

Table 3.7 Coal and Switchgrass Characteristics

Characteristic	Units	Value
Delivered Cost of Coal	$ per million Btu	1.48
Coal Heat Content	millions of Btu per metric ton	22.13
Sulfur Content of Coal	kilogram of SO_2 per million Btu	3.13
Coal Carbon Dioxide Content	kilogram of CO_2 per million Btu	449.6
Percentage of Sulfur	per metric ton of coal	1.73
Percentage of Carbon Dioxide Emitted	per metric ton of coal	0.418
Carbon Dioxide Abatement Cost	$ per kilogram	0.026
Sulfur Dioxide Abatement Cost	$ per kilogram	25.99
Switchgrass Heat Content	millions of Btu per metric ton	15.6
1 Metric Ton	pounds	2,204.62
1 Metric Ton	kilograms	1000
1 kilowatt hour	Btu	10,200

Sources: Graham, 1996; Energy Information Administration, State Coal Profiles - Kentucky 1997; Energy Information Administration, Electric Power Annual, 1996; Palmer et al., RFF Discussion Paper 94-39 1994; Hart and Hart 1990.

cost of the 100,000th ton would determine the price of switchgrass for all of the tons delivered.

A typical coal-fired electric facility produces electricity by using a steam driven turbine. The steam is created by heating water in a boiler. The input for the heat may be switchgrass or coal, *ceteris paribus*. In general, the decision makers of the electrical generation facility are indifferent to which fuel they use as long as the fuel generates enough heat energy or BTUs, to accomplish the generation of electrical power. Coal is the dominant fuel source used for electric power generation because of the high Btu content relative to coal's market price.

Coal also generates pollution into the environment in the form of sulfur dioxide (SO_2) and carbon dioxide (CO_2). These negative externalities distort coal's market price in favor of using more coal. The accurate economic price of an input (I) to society includes the market price as well as any externailty values generated by using the good.

(3.9) $P_I = P_M + P_e$

where P_I is the accurate price that incorporates the costs of the externality, P_M is the current market price, and P_e is the price of the externality. For coal the externailty price (P_e) is \$1.40 per million Btu $(Mbtu)^{-1}$ for SO_2 and \$0.05 $(Mbtu)^{-1}$ for CO_2.

The SO_2 externality value is obtained by multiplying the abatement cost of SO_2 by the coal sulfur content to get a Mbtu SO_2 value. This SO_2 value is converted into a metric ton (t) coal value by multiplying the percentage of sulfur found in Kentucky coal.

(3.10) \$25.90 $(kg)^{-1}$ SO_2 * 3.13 kg $(Mbtu)^{-1}$ * 1.73 percent = \$1.48 $(t)^{-1}$ of coal. The procedure is similar for the CO_2 value:

(3.11) 0.026 $(kg)^{-1}$ * 449.6 kg $(Mbtu)^{-1}$ * 0.418 percent = \$0.05 $(t)^{-1}$ of coal.

Unlike coal, switchgrass produces no SO_2 or CO_2 negative externalities to society. Therefore, switchgrass economic price (Pb) is equal to the price of input (I):

(3.12) $P_I = Pb$

For each scenario used to evaluate economic feasibility in Tennessee, there are five levels of P_I:

(3.13) P_I^a = Price of coal in \$ per Mbtu ;

(3.14) P_I^b = Price of coal + sulfur tax for burning coal;

(3.15) $P_I{}^c$ = Price of coal + carbon tax for burning coal;

(3.16) $P_I{}^d$ = Price of coal + carbon tax + sulfur tax; and

(3.17) $P_I{}^e$ = Price of coal + electric subsidy.

These conditions (3.13 - 3.17) form the basis for scenario evaluation. For ease of analysis, scenarios are presented in terms of dollars per metric ton of switchgrass.

Scenario I: Switchgrass Base Indifference Price

All of the five scenarios use a common switchgrass indifference price. This indifference price is the price that could cause an electrical power facility to be indifferent to purchasing either switchgrass or coal as an input, *ceteris paribus*. The development of this price is as follows:

(3.18) 15.6 Mbtu $(t)^{-1}$ * \$1.48 $(Mbtu)^{-1}$ = \$23.09 (t)

Verbally, the heat content of switchgrass (in millions of BTUs per ton) times the cost per Mbtu of coal equals the switchgrass per ton indifference price. A plant could purchase switchgrass at \$23.09 per ton and be indifferent between using coal or switchgrass, *ceteris paribus*.

Scenario II: SO_2 Subsidy

Scenario II examines the environmental benefits of using switchgrass for electrical production. Using abatement costs developed by Plamer et al. (1994) as a subsidy price for sulfur dioxide (SO_2), the indifference price is obtained by converting the coal sulfur content into dollars per Mbtu by multiplying the coal sulfur content by the SO_2 abatement price.

(3.19) 3.13 kg $(Mbtu)^{-1}$ * \$25.90 = \$81.07 $(Mbtu)^{-1}$ of SO_2

This Btu abatement value is converted into a per metric ton SO_2 value.

(3.20) \$81.07 $(Mbtu)^{-1}$ of SO_2 * 22.13 Mbtu $(t)^{-1}$ = \$1,794.01 $(t)^{-1}$ of SO_2

The metric ton SO_2 value is converted into a metric ton coal value by multiplying the percentage of sulfur in Kentucky coal.

(3.21) \$1,794.01 $(t)^{-1}$ of SO_2 * 1.73 percent $(t)^{-1}$ of SO_2 per ton of coal = \$31.04 of SO_2 per ton of coal.

The Scenario II switchgrass indifference price is:

(3.22) \$31.04 $(t)^{-1}$ + \$23.09 $(t)^{-1}$ = \$54.13 $(t)^{-1}$

Using the SO_2 abatement cost as a subsidy, a plant can now pay up to \$54.13 per ton for switchgrass and be indifferent between coal and switchgrass, *ceteris paribus*.

Scenario III CO_2 Subsidy

Scenario III also examines the environmental benefits of using switchgrass for electrical production. Using abatement costs developed by Palmer et al. (1994) as a subsidy price for carbon dioxide (CO_2), the indifference price is obtained by converting the coal CO_2 emission into dollars per Mbtu by multiplying the coal CO_2 emission by the CO_2 abatement price.

(3.23) 449.6 kg $(Mbtu)^{-1}$ * \$0.026 = \$11.89 $(Mbtu)^{-1}$ of CO_2

This Btu abatement value is converted into a per metric ton CO_2 value.

(3.24) \$11.89 $(Mbtu)^{-1}$ of CO_2 * 22.13 Mbtu $(t)^{-1}$ = \$263.12 $(t)^{-1}$ of CO_2

The metric ton CO_2 value is converted into a metric ton coal value by multiplying the percentage of CO_2 emission in Kentucky coal.

(3.25) \$263.12 $(t)^{-1}$ of CO_2 * 0.418percent $(t)^{-1}$ of CO_2 emission per ton of coal = \$1.10 of CO_2 per ton of coal.

The Scenario III switchgrass indifference price is:

(3.26) \$1.10 $(t)^{-1}$ + \$23.09 $(t)^{-1}$ = \$24.19 $(t)^{-1}$

Using the CO_2 abatement cost as a subsidy, a plant can now pay up to \$24.19 per ton for switchgrass and be indifferent between coal and switchgrass, *ceteris paribus.*

Scenario IV Combined Subsidy

Scenario IV is an aggregation of the three previous scenarios. The switchgrass indifference price is:

(3.27) \$23.09 $(t)^{-1}$ + \$31.04 $(t)^{-1}$ + \$1.10 $(t)^{-1}$ = \$55.23 $(t)^{-1}$

A plant can now pay up to \$55.23 per ton for switchgrass and be indifferent between coal and switchgrass, *ceteris paribus.*

Scenario V Electric Power Tax Credit

In 1992, the National Energy Renewable Act established a tax rebate price of \$.015 per kwh for using bioenergy based inputs in energy production processes (Renewing Our Energy Future 1994). To date this subsidy has not been used or claimed by any electric generating authority (Downing 1997). The use of this subsidy offsets the higher switchgrass delivered costs. This subsidy is calculated by the following procedure: Converting switchgrass heat content into kilowatt hours (kwh).

(3.28) 15.6 Mbtu $(t)^{-1}$ * 1 kwh (.0102 Mbtu)$^{-1}$ = 1529.70 kwh $(t)^{-1}$

Converting a kilowatt subsidy to get dollars per ton value.

(3.29) 1529.70 kwh $(t)^{-1}$ * \$0.015 $(kwh)^{-1}$ = \$22.95 $(t)^{-1}$

Add the kilowatt subsidy to the switchgrass indifference price to obtain the subsidy price.

(3.30) 23.09 $(t)^{-1}$ + 22.95 $(t)^{-1}$ = 46.04 $(t)^{-1}$

With a \$0.015 $(kwh)^{-1}$ subsidy, a plant can now pay \$46.04 $(t)^{-1}$ for switchgrass and still be indifferent between coal and switchgrass, *ceteris paribus*. Table 3.8 summarizes the five economic feasibility scenarios used in this study.

Environmental Benefits Development

The purpose to include the environmental benefits in this study is to compare the costs and benefits to society for the use of switchgrass as a feedstock to generate electricity instead of coal. For ease of calculation, the costs and savings to society values

Table 3.8 Economic Feasibility Scenarios

Economic Feasibility Scenario	Description	Base Indifference Price	Subsidy Value	Scenario Indifference Price
			dollars per ton	
Scenario I	Switchgrass Base	23.09	0.00	23.09
Scenario II	Sulfur Dioxide (SO_2) Subsidy	23.09	31.04	54.13
Scenario III	Carbon Dioxide (CO_2) Subsidy	23.09	1.10	24.19
Scenario IV	Combined Subsidy	23.09	32.14	55.23
Scenario V	Electric Power Tax Credit	23.09	22.95	46.04

were calculated in dollars per ton as opposed to dollars per Mbtu.

Burning switchgrass generates less heat than burning coal. Because of these differing heat contents, a heat conversion efficiency ratio is needed to directly compare the tonnage of coal to the tonnage of switchgrass. This heat efficiency ratio was used to determine the amount of coal needed to generate the same amount of electricity that switchgrass generates as a fuel source for electrical power generation for scenario V. The heat efficiency ratio is calculated by taking the heat output of switchgrass (in Mbtu) divided by the heat output of coal (in Mbtu) (equation 3.29).

(3.29) $$\frac{15.60 \text{ Mbtu per ton of switchgrass}}{22.13 \text{ Mbtu per ton of coal}} = .699551 \text{ heat efficiency ratio}$$

The societal benefits of using switchgrass as a feedstock for electrical power production were calculated by using estimates for SO_2 and CO_2 emission values for coal ($31.04 per ton of coal for SO_2 emission and $1.10 per ton of coal for CO_2 emission). Societal costs of using switchgrass as a feedstock for electrical power production were obtained by calculating the total amount of the $0.015 per kwh subsidy for switchgrass production for scenario V using the conversions in Table 3.7.

Chapter 4 RESULTS AND INTERPRETATION

Overview

In order to assess the economic feasibility of switchgrass as an input for electrical power generation, the results and interpretation of the Regional Integrated Switchgrass Assessment (RIBA) model output ran a total of six times using the two different harvesting models (the base model and the staggered harvest model) along with the three plant sizes: 100,000 metric tons (t), 600,000 metric tons (t) and 1,100,000 metric tons (t) (Table 4.1).

The economic feasibility scenarios developed in chapter 3 are used to analyze the economic feasibility of switchgrass production and utilization in Tennessee. An analysis at both the state and plant levels comparing both harvesting models is conducted. The locational comparison of the economic feasibility of both harvesting models within Tennessee is discussed next. Finally, an analysis of environmental cost and benefits related to the electric tax rebate (scenario V) is presented.

Table 4.1 Terminology Used in Analysis as Defined in Chapter 3

Term	Type
Models (2)	Base (Traditional Harvest)
	Staggered Harvest
Plant Sizes (3)	100,000 Ton
	600,000 Ton
	1,100,000 Ton
Scenarios (5)	I,II,III,IV,V

Statewide Comparison

Supply Curves

Figure 4.1 illustrates the switchgrass supply curves for Tennessee at the 100,000 tons per year plant size. These curves follow a textbook supply curve, as price increases, output increases. Within the same model, the supply curves have similar shape and are identical for all plant sizes.

The comparison across the models within the same plant size reveals two different supply curves. The supply curves for the staggered harvest models begin at a lower price and have a larger elastic portion than the respective base model. Reduction of production costs through the staggered harvest model allows the increase in tons produced and a more elastic supply curve than the base model.

Figure 4.1 also shows the price and output combination for scenario V. Scenario V is the electric power tax credit scenario. The switchgrass indifference price for scenarios II, V and IV was sufficient to generate switchgrass production in Tennessee. The switchgrass indifference prices in Scenario I and Scenario II, $22.95 per ton and $24.19 per ton, respectively, are too low to initiate switchgrass production in Tennessee. Scenario V is the scenario whose indifference price was sufficient to allow switchgrass production and utilization to be economically feasible in Tennessee.

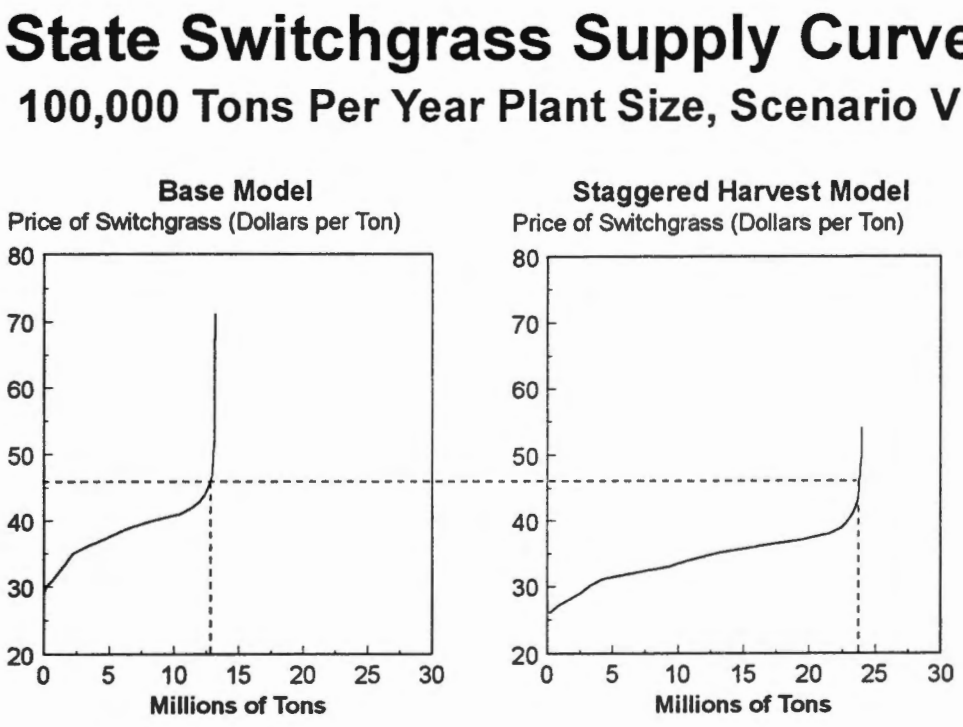


Figure 4.1 Tennessee Switchgrass Supply Curves, 100,000 Tons Per Year Plant Size, Scenario V

Number of Plants

Table 4.2 lists the total number of switchgrass plants for each plant size in Tennessee. The staggered harvest model has approximately twice the number of plants as its base counterparts. This is due to the greater output efficiency of the staggered harvest model.

100,000 Tons per Year Plant Size

Total costs

Table 4.3 displays the unit production and unit transport cost for both models. Compared to the base model, unit production cost was 12.78 percent lower and unit transport cost was 9.6 percent lower. Table 4.4 shows the unassigned economic rent for the 100,000 tons per year plant size. The differences in economic rent between the base and staggered harvest models are 27.09 percent and 29.62 percent, respectively. The highest increase in total economic rent was in scenario V with a $ 6,587,950 increase from the base model.

Table 4.2 Total Number of Switchgrass Fueled Electric Generation Plants in Tennessee

Maximum Plant Size	Base Model	Staggered Harvest Model
100,000 Tons Per Year	132	240
600,000 Tons Per Year	22	40
1,100,000 Tons Per Year	12	21

Table 4.3 Minimum Per Unit Cost Comparison: 100,000 Tons Per Year Plant Size

	Base Model	Staggered Harvest Model	Percent Difference From Base
Production Cost	$26.43 $(t)^{-1}$	$ 23.05 $(t)^{-1}$	-12.78
Transport Cost	$ 3.84 $(t)^{-1}$	$ 3.47 $(t)^{-1}$	- 9.60

Table 4.4 Total Unassigned Economic Rent: 100,000 Tons Per Year Plant Size

Scenario	Base Model	Staggered Harvest Model	Change in Economic Rent	Percent Difference From Base
I	$ 0.00	$ 0.00	$ 0.00	0.00
II	$ 16,586,489	$ 22,760,109	$ 6,173,619	27.12
III	$ 0.00	$ 0.00	$ 0.00	0.00
IV	$ 16,594,119	$ 22,760,165	$ 6,166,046	27.09
V	$ 12,782,541	$ 22,242,876	$ 6,587,950	29.62

Total output

The state total output for switchgrass at a 100,000 tons per year plant size is shown in Table 4.5 and Figure 4.2. On average, the staggered harvest method produced approximately 80 percent more total tons of switchgrass than the base model. Switchgrass output using the base model ranged between 12.9 and 13.19 million tons. Switchgrass staggered harvest output ranged between 23.7 and 24 million tons.

An increase of 86 percent of switchgrass output was obtained by the staggered harvest model instead of the base model for scenario V. The staggered harvest model produced gains (at least 80 percent) in switchgrass output from the base model for both scenario II and scenario IV. Maximum output at the 100,000 tons per year plant level was reached with scenario IV for the both the staggered harvest and base models.

600,000 Tons per Year Plant Size

Total costs

As shown in Table 4.6 unit production costs are 11.52 percent lower in the staggered harvest model than the base model. Unit transport costs are 10.2 percent less in

Table 4.5 Total Tons of Switchgrass Produced: 100,000 Tons Per Year Plant Size, Tennessee

Scenario	Base Model	Staggered Harvest Model	Percent Difference From Base
I	0.0	0.0	0.0
II	13,141,135	23,999,171	82.26
III	0.0	0.0	0.0
IV	13,141,600	24,000,002	82.63
V	12,782,541	23,785,478	86.08

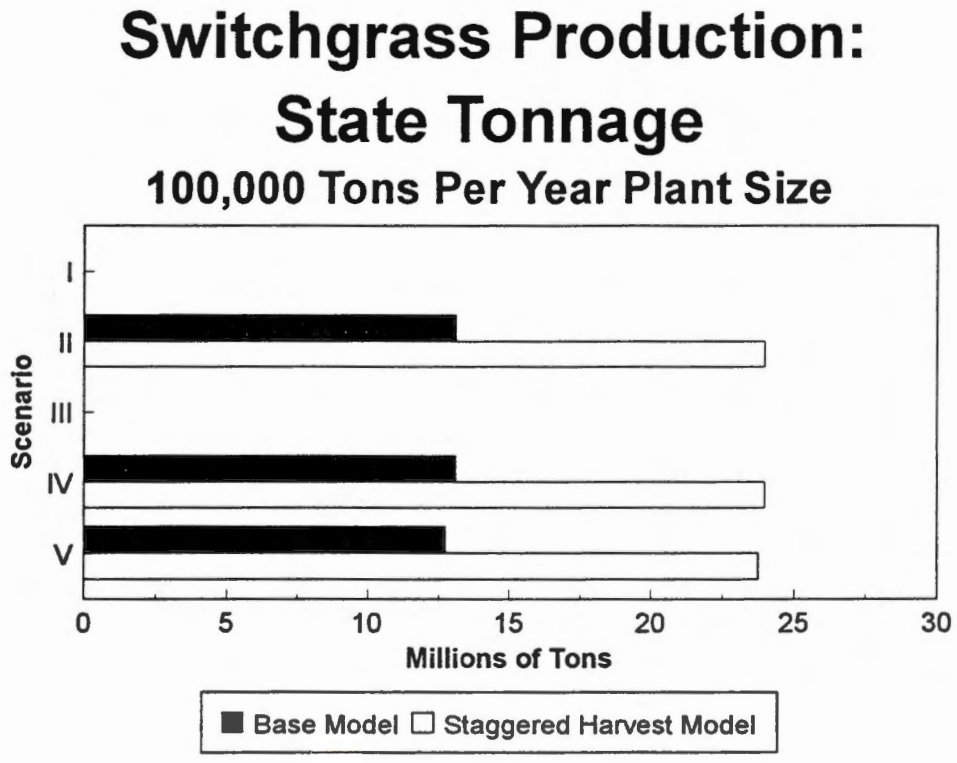


Figure 4.2 Switchgrass Production: 100,000 Tons Per Year Plant Size

Table 4.6 Minimum Unit Cost Comparison: 600,000 Tons Per Year Plant Size

	Base Model	Staggered Harvest Model	Percent Difference From Base
Production Cost	$ 27.33 $(t)^{-1}$	$ 24.18 $(t)^{-1}$	-11.52
Transport Cost	$ 5.48 $(t)^{-1}$	$ 4.88 $(t)^{-1}$	-10.20

the staggered harvest model than the base model. Switchgrass production costs are 3.4 percent higher for the 600,000 tons per year plant size than the 100,000 tons per year plant size for the base model. For the staggered harvest model, switchgrass production costs are 4.9 percent higher in the 600,000 tons plant size than in the 100,000 tons plant size.

The state economic rent total for the 600,000 tons plant size in Table 4.7, shows an increase in economic rent for the staggered harvest model over the base model. Scenario V shows the largest increase in terms of dollar amount and percentage. Scenario V shows a $20,987,767 and a 42.87 percent increase in economic rent.

Total output

Table 4.8 and Figure 4.3 illustrate the amount of switchgrass produced. Scenario V (switchgrass base with electric subsidy) shows a 106.95 percent increase in output in using the staggered harvest model over the base model.

Table 4.7 State Total of Economic Rent: 600,000 Tons Per Year Plant Size

Scenario	Base Model	Staggered Harvest Model	Change in Economic Rent	Percent Difference From Base
I	$ 0.00	$ 0.00	$ 0.00	0.00
II	$ 34,761,065	$ 52,460,423	$ 17,699,358	33.74
III	$ 0.00	$ 0.00	$ 0.00	0.00
IV	$ 35,126,275	$ 52,773,649	$ 17,647,373	33.44
V	$ 27,958,732	$ 48,937,499	$ 20,978,767	42.87

Table 4.8 State Total Tons of Switchgrass Produced: 600,000 Tons Per Year Plant Size

Scenario	Base Model	Staggered Harvest Model	Percent Difference From Base
I	0.0	0.0	0.0
II	12,659,836	23,704,984	87.25
III	0.0	0.0	0.0
IV	12,739,273	23,731,562	86.29
V	11,253,730	23,289,656	106.95

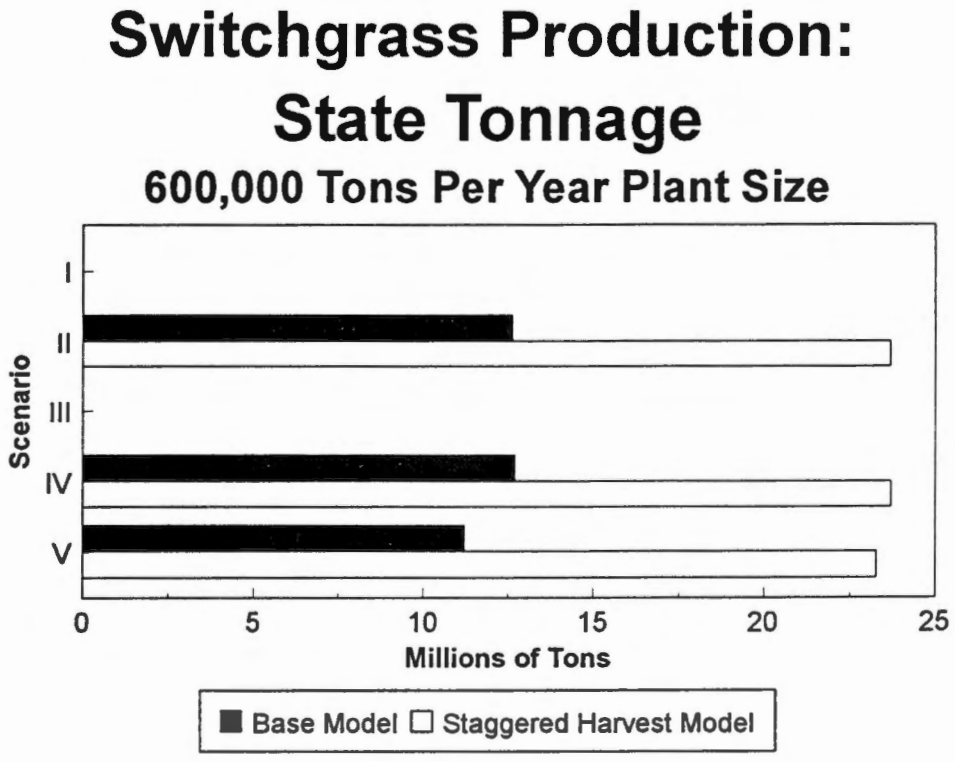


Figure 4.3 Switchgrass Production: 600,000 Tons Per Year Plant Size

1.1 Million Tons per Year Plant Size

Total costs

Unit costs for the 1.1 million tons per year switchgrass plant sizes are in Table 4.9. Production costs are 11.64 percent lower and transport cost are 19.76 percent lower in the staggered harvest model than the base model. Comparing across plant sizes for the base model, the 1.1 million tons per year plant has a 2.6 percent higher minimum unit production cost than the 100,000 tons per year plant size. The staggered harvest model 1.1 million tons per year plant size has a 4.18 percent higher minimum unit production cost than the 100,000 tons per year plant size. There is only a slight difference in switchgrass production cost between the 600,000 tons per year plant size and the 1.1 million tons per year plant size.

Total economic rent at the 1,100,000 tons per year plant size experienced a 46.78 percent increase in using the staggered harvest model over the base model for scenario V. Scenario IV (SO_2 subsidy) produced the smallest gain in economic rent from using the staggered harvest model over the base model. Table 4.10 summarizes these results.

Total output

Table 4.11 summarizes the total production of switchgrass at the 1,100,000 tons per year plant size. Scenario V showed and increase of 126.49 percent in using the

Table 4.9 Minimum Unit Cost Comparison: 1,100,000 Tons Per Year Plant Size

	Base Model	Staggered Harvest Model	Percent Difference From Base
Production Cost	\$ 27.21 $(t)^{-1}$	\$ 24.04 $(t)^{-1}$	- 11.64
Transport Cost	\$ 7.59 $(t)^{-1}$	\$ 6.09 $(t)^{-1}$	-19.76

Table 4.10 State Total of Economic Rent: 1,100,000 Tons Per Year Plant Size

Scenario	Base Model	Staggered Harvest Model	Change in Economic Rent	Percent Difference
I	$ 0.00	$ 0.00	$ 0.00	0.00
II	$ 35,941,182	$ 54,431,179	$ 18,499,996	33.97
III	$ 0.00	$ 0.00	$ 0.00	0.00
IV	$ 37,980,068	$ 54,431,235	$ 16,451,167	30.22
V	$ 27,599,918	$ 51,861,729	$ 24,261,810	46.78

Table 4.11 State Total Tons of Switchgrass Produced: 1,100,000 Tons Per Year Plant Size

Scenario	Base Model	Staggered Harvest Model	Percent Difference
I	0.0	0.0	0.0
II	12,236,178	23,100,059	88.78
III	0.0	0.0	0.0
IV	12,321,479	23,100,890	87.48
V	9,785,002	22,161,969	126.49

staggered harvest method over the base model.

Economic Interpretation

Upon examination of the overall state level for three different plant sizes and two models, it can be stated that the production and utilization of switchgrass for electrical power generation is economically feasible in Tennessee given a scenario V indifference price of $46.04 per ton. The scenario I and scenario III switchgrass indifference prices are not adequate for switchgrass production in Tennessee.

The staggered harvest model produces substantially more output at a lower cost than the base model. The staggered harvest model also produces between 30 and 40 percent more in economic rent than the base model regardless of plant size.

Switchgrass Costs and Economic Rents

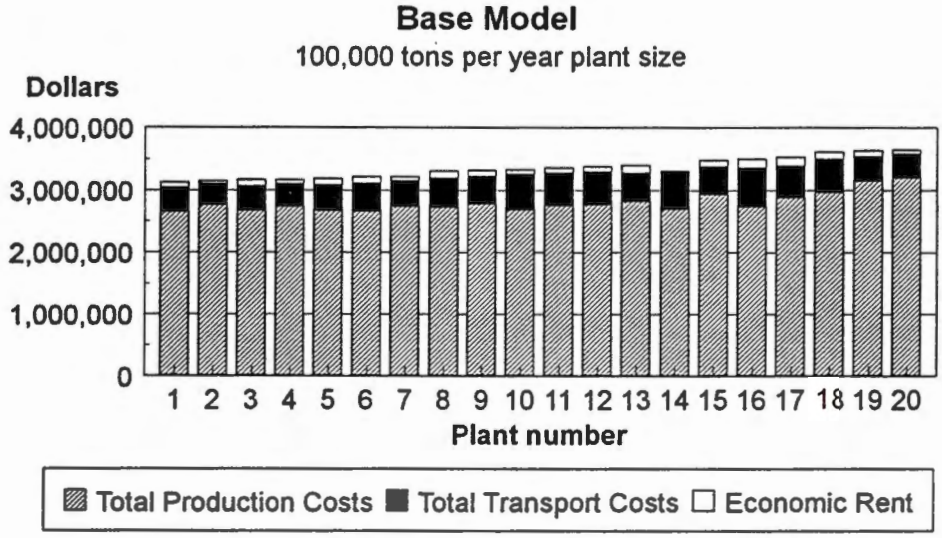


Figure 4.4 Switchgrass Costs and Economic Rents: Base Model, 100,000 Tons Per Year Plant Size

Switchgrass Costs and Economic Rents

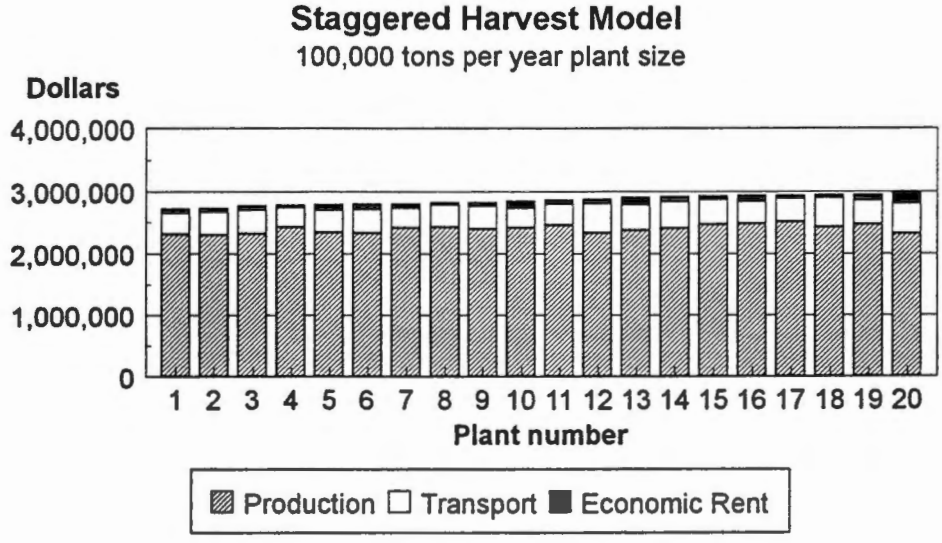


Figure 4.5 Switchgrass Costs and Economic Rents: Staggered Harvest Model, 100,000 Tons Per Year Plant Size

Plant Comparison

100,000 Tons per Year Plant Size

The bulk of switchgrass costs are production costs in both the base model (Figure 4.4) and the staggered harvest model (Figure 4.5). Production costs, transport costs and economic rents vary slightly plant by plant. There is a reduction in overall cost under the staggered harvest model as compared to the base model.

Figure 4.6 and Figure 4.7 show the supply curve for the initial 100,000 tons per year switchgrass plant for both the base model(Figure 4.6) and the staggered harvest (Figure 4.7) model. Table 4.12 shows both the minimum and maximum delivered cost of switchgrass for the initial 100,000 tons per year plant. Using the staggered harvest method produced an 11.4 percent decrease in minimum delivered cost and a 12.82 percent decrease in maximum delivered cost from the base model. For the initial 100,000 tons per year plant size, production cost fell 12.7 percent and transport cost fell 9.6 percent in the staggered harvest model when compared to the base model (Table 4.13). Economic rent decreased by 27 percent from the base model to the staggered harvest model .

600,000 Tons per Year Plant Size

Both the minimum and maximum delivered cost for both the base model and the staggered cost model are less for the 600,000 tons per year plant size than the 100,000

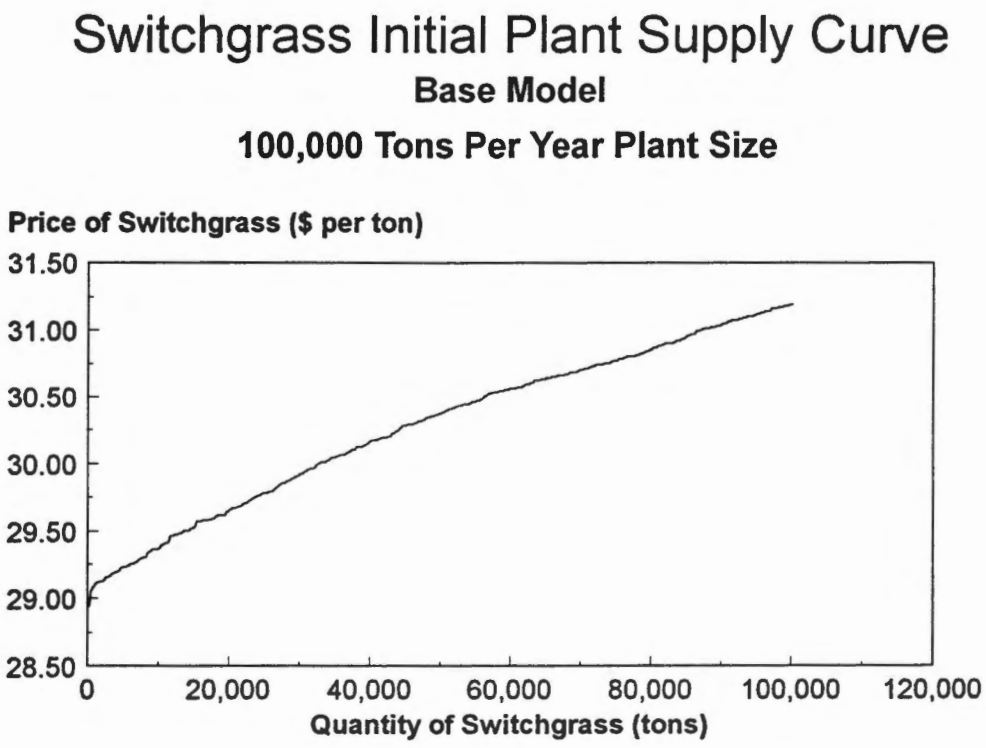


Figure 4.6 Switchgrass Initial Plant Supply Curve: 100,000 Tons Per Year Plant Size, Base Model

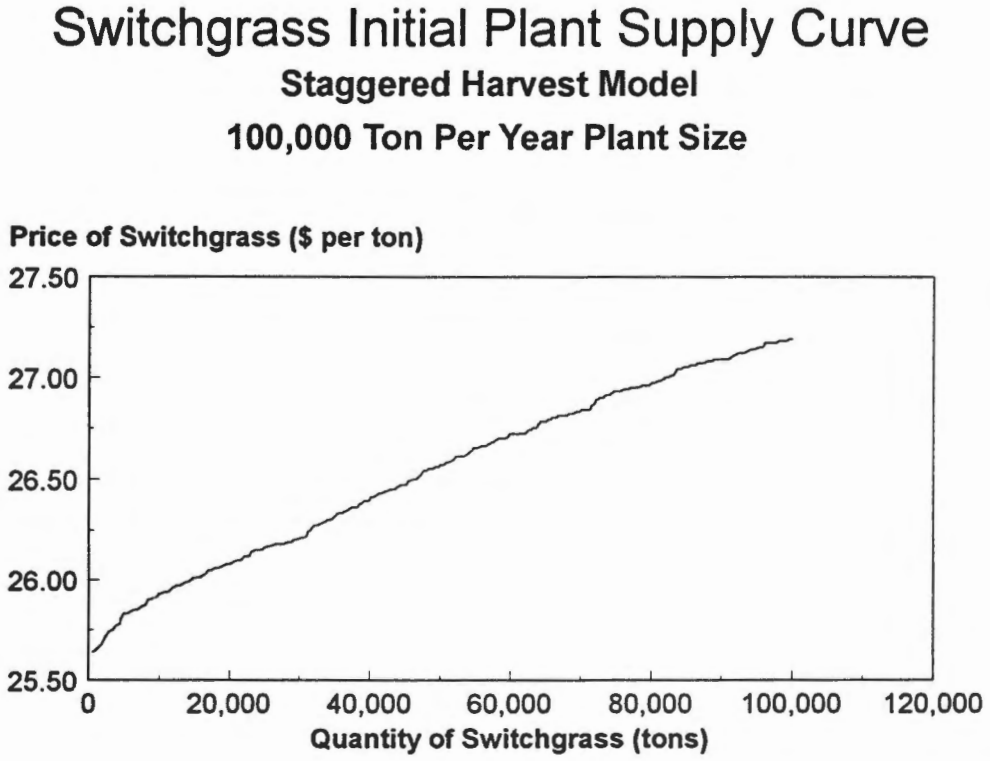


Figure 4.7 Switchgrass Initial Plant Supply Curve: 100,000 Tons Per Year Plant Size, Staggered Harvest Model

Table 4.12 Delivered Cost Range, 100,000 Tons Per Year Plant Size, Initial Plant

	Base Model	Staggered Harvest Model	Percent Difference From Base
Minimum Delivered Cost	$ 28.94 $(t)^{-1}$	$ 25.64 $(t)^{-1}$	- 11.40
Maximum Delivered Cost	$ 31.19 $(t)^{-1}$	$ 27.19 $(t)^{-1}$	- 12.82

Table 4.13 Total Plant Costs: 100,000 Tons Per Year Plant Size, Initial Plant

Value	Base Model	Staggered Harvest Model
Economic Rent	$ 91,081	$ 66,106
Production Cost	$ 2,643,396	$ 2,305,253
Transport Cost	$ 384,465	$ 347,548

tons per year plant size (Table 4.14). Switchgrass minimum delivered costs are 11.3 percent less for the staggered harvest model than the base model. Maximum costs are 13 percent less for the staggered harvest model than for the base model.

The initial 600,000 tons per year plant total production costs are 11.6 percent lower under the staggered harvest model than under the base model (Table 4.15). Total transport costs are 15 percent lower under the staggered harvest model than the base model. Economic rent is also 26.6 percent lower under the staggered harvest model than under the base model.

1.1 Million Tons per Year Plant Size

Table 4.16 lists the delivered cost range for the initial 1,100,000 tons per year plant size. There is a 10.53 percent lower minimum delivered cost and a 14.67 percent lower maximum delivered cost for the staggered harvest model than the base model. Table 4.17 lists the total plant cost for the 1,100,000 tons per year plant. Total

Table 4.14 Delivered Cost Range, 600,000 Tons Per Year Plant Size Initial Plant

	Base Model	Staggered Harvest Model	Percent Difference From Base
Minimum Delivered Cost	\$ 29.50 $(t)^{-1}$	\$ 26.17 $(t)^{-1}$	- 11.29
Maximum Delivered Cost	\$ 35.09 $(t)^{-1}$	\$ 30.52 $(t)^{-1}$	- 13.02

Table 4.15 Total Plant Costs: 600,000 Tons Per Year Plant Size, Initial Plant

Value	Base Model	Staggered Harvest Model
Economic Rent	\$ 1,202,448	\$ 882,455
Production Cost	\$ 16,403,315	\$ 14,500,856
Transport Cost	\$ 3,447,768	\$ 2,928,148

Table 4.16 Delivered Cost Range, 1,100,000 Tons Per Year Plant Size, Initial Plant

	Base Model	Staggered Harvest Model	Percent Difference From Base
Minimum Delivered Cost	\$ 29.25 $(t)^{-1}$	\$ 26.17 $(t)^{-1}$	- 10.53
Maximum Delivered Cost	\$ 37.76 $(t)^{-1}$	\$ 32.22 $(t)^{-1}$	- 14.67

production costs are 3.5 million dollars less under the staggered harvest model. Transport cost were 1.3 million dollars less for the staggered cost model than the base model.

Economic Interpretation

The plant level analysis supports the hypothesis that switchgrass is economically feasible in Tennessee under the scenario V indifference price level (Table 4.18). Because scenarios II and IV have a higher per unit switchgrass indifference price than scenario V, they are also feasible. Both the indifference prices in scenario I (base scenario) and scenario III (carbon subsidy scenario) are not sufficient to generate production of switchgrass in Tennessee.

The plant cost analysis showed substantial reductions in production cost and transport cost by using the staggered harvest model as opposed to using the base model.

Table 4.17 Total Plant Costs: 1,100,000 Tons Per Year Plant Size, Initial Plant

Value	Base Model	Staggered Harvest Model
Economic Rent	$ 3,252,559	$ 2,298,412
Production Cost	$ 29,931,867	$ 26,447,581
Transport Cost	$ 8,352,401	$ 6,695,729

Table 4.18 RIBA Solutions With The Scenario Criteria Satisfied

Scenario	100,000 Tons Per Year Plant Size	600,000 Tons Per Year Plant Size	1,100,000 Tons Per Year Plant Size
I			
II	✓	✓	✓
III			
IV	✓	✓	✓
V	✓	✓	✓

The total economic rent obtained by using the staggered harvest model varied by plant size. At all plant levels, economic rent decreased in using the staggered harvest model as compared to the base model. The decrease in economic rent in using the staggered harvest model is an indication of a flatter supply curve than the base model.

Locational Analysis

Regional Output

Chapter 3, Table 3.6 shows the county classification used in the regional analysis and Table 4.19 lists the regional output for switchgrass production in Tennessee. Overall, East Tennessee has the lowest percentage (24 percent) of switchgrass output. This is followed by West Tennessee with 25 percent of total state switchgrass output. Middle Tennessee has the largest percentage of state switchgrass output with 48 percent of the total state level of switchgrass production. The large Middle Tennessee percentage of

Table 4.19 Regional Tons of Switchgrass Produced, Scenario V

Location	Base Model	Staggered Harvest Model
	(Tons of Switchgrass)	
100,000 Tons Plant Size		
East	3,105,425	5,778,508
Middle	6,191,750	11,521,475
West	3,282,449	6,107,911
600,000 Tons Plant Size		
East	2,724,867	5,543,181
Middle	5,469,234	11,429,854
West	2,881,653	5,946,654
1,100,000 Tons Plant Size		
East	2,344,703	5,310,499
Middle	4,780,466	10,827,237
West	2,505,062	5,673,693

output is primarily due to the definition of the geographical regions used in this study. Middle Tennessee is the largest region in Tennessee in terms of land area. In this study, Middle Tennessee constitutes about 50 percent of the state's total land area, with the remaining 50 percent of land area divided equally between East Tennessee and West Tennessee.

The staggered harvest model regional production for all regions and plant sizes by approximately 80 percent, except the 600,000 tons per year plant size for Middle Tennessee. For that plant size, the staggered harvest method increased output by 108 percent. There was decrease in switchgrass output between the 600,000 tons per year facility and the 1,100,000 tons per year facility within the same harvest model. There was a slight decrease in switchgrass output utilizing the staggered harvest model, from the 100,000 tons plant size to the 600,000 tons plant size.

Tables 4.20 to 4.22 show the regional breakdown of total production costs, transport costs and economic rent. Compared with the base model, total production costs increased under the staggered harvest model for all regions. This is due to the increase in output under the staggered harvest model. As with the production output, regions break along the following percentages: East Tennessee 25 percent, West Tennessee 25 percent, and Middle Tennessee 50 percent. Transport costs are the highest (regionally) in Middle Tennessee. Compared to the other two regions, total economic rent is the largest in Middle Tennessee,.

Regional Initial Facility Location

Figures 4.8 to 4.10 show the county location of switchgrass supply points for the initial plants in each of the three Tennessee regions for each of the three plant sizes. The locational supply maps were nearly identical for both the base model and the staggered harvest model. For East Tennessee, the initial 100,000 tons per year switchgrass fueled

Table 4.20 Regional Total Production Cost, Scenario V

Location	Base Model	Staggered Harvest Model
	(in dollars)	
100,000 Tons Plant Size		
East	104,509,675	174,327,121
Middle	430,182,461	347,582,057
West	110,467,236	184,264,616
600,000 Tons Plant Size		
East	91,390,848	167,031,669
Middle	183,435,703	344,416,682
West	96,649,366	179,189,440
1,100,000 Tons Plant Size		
East	78,835,577	160,143,883
Middle	160,732,826	326,507,141
West	84,227,283	171,096,410

Table 4.21 Regional Total Transport Cost, Scenario V

Location	Base Model	Staggered Harvest Model
	(dollars)	
100,000 Tons Plant Size		
East	15,165,151	25,107,440
Middle	30,237,029	50,060,459
West	16,029,638	26,538,687
600,000 Tons Plant Size		
East	18,911,335	35,333,409
Middle	37,958,002	72,856,300
West	19,999,470	37,905,229
1,100,000 Tons Plant Size		
East	17,771,962	39,792,972
Middle	36,234,119	81,131,350
West	18,987,418	42,514,484

Table 4.22 Regional Total Economic Rent, Scenario V

Location	Base Model	Staggered Harvest Model
	(dollars)	
100,000 Tons Plant Size		
East	3,105,425	5,403,744
Middle	6,191,750	10,774,252
West	3,282,448	5,711,783
600,000 Tons Plant Size		
East	6,769,652	11,647,636
Middle	13,587,748	24,017,033
West	7,159,169	12,495,435
1,100,000 Tons Plant Size		
East	6,613,552	12,427,219
Middle	13,483,949	25,337,064
West	7,065,865	13,277,139

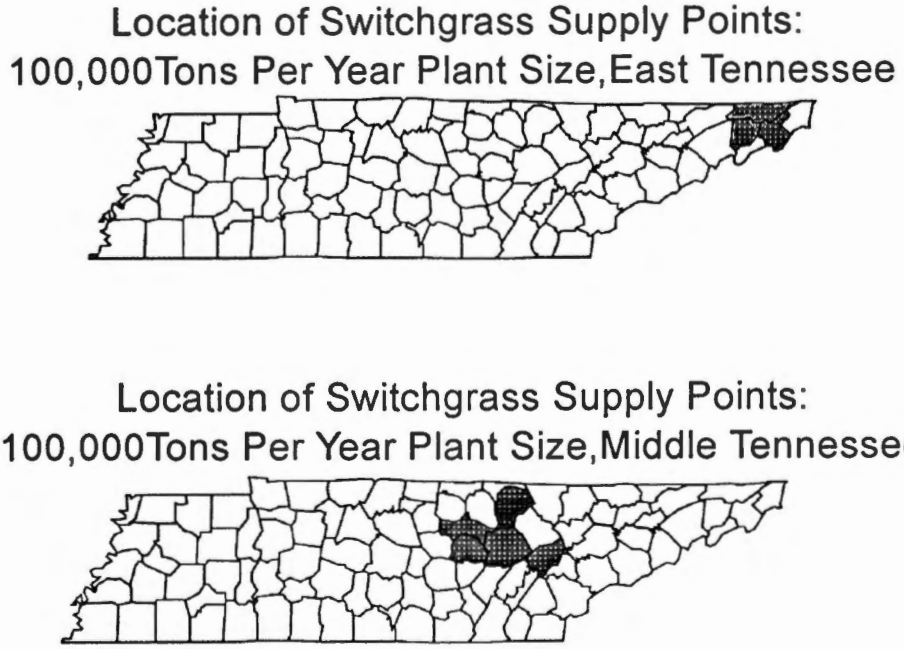


Figure 4.8 Switchgrass Supply Points, 100,000 Tons Per Year Plant Size

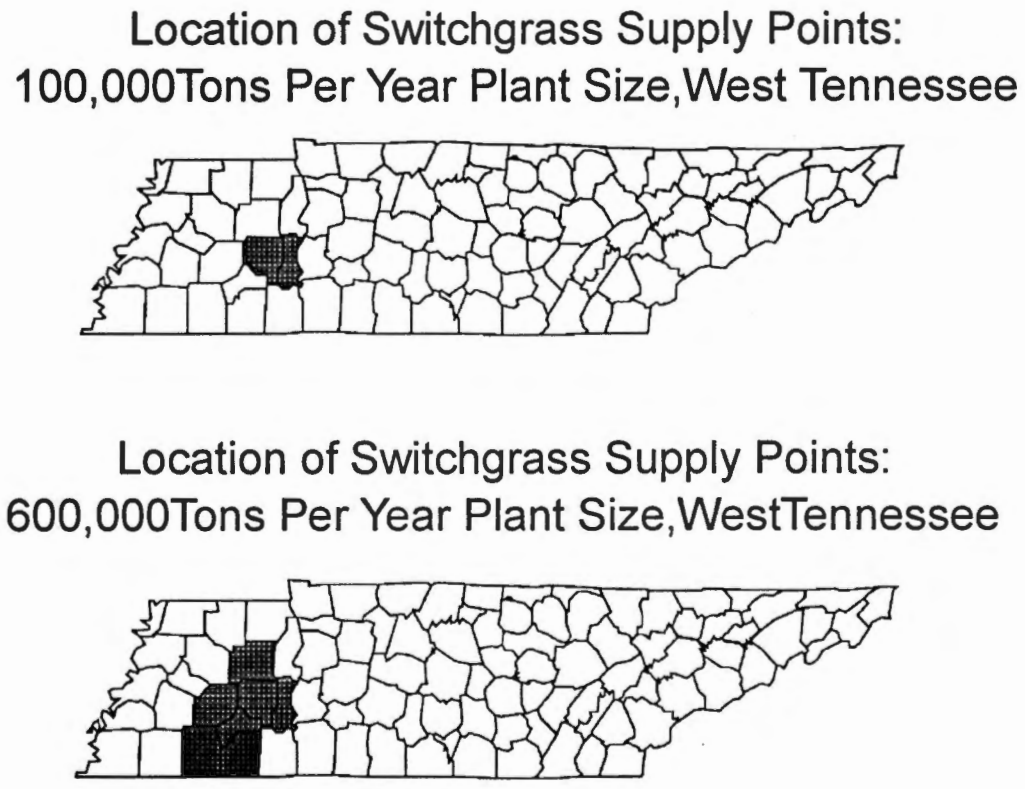


Figure 4.9 West Tennessee Switchgrass Supply Points

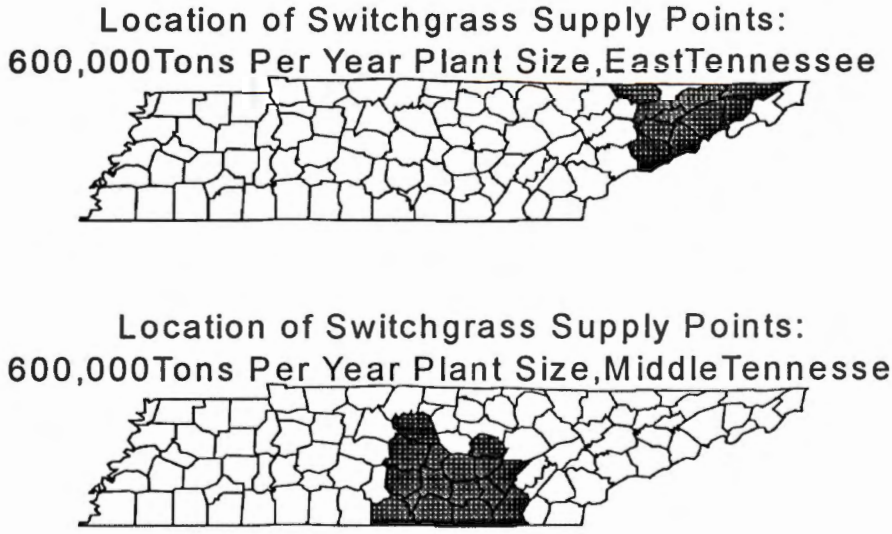


Figure 4.10 Switchgrass Supply Points, 600,000 Tons Per Year Plant Size

electric generation plant is located in Carter County and draws its switchgrass supply from Carter, Sullivan and Washington Counties. For Middle Tennessee, the initial switchgrass fueled electric generation plant switchgrass plant is located in Cumberland County and draws its supply from Cumberland, Fentress, Putnam, Rhone, and White Counties. West Tennessee's initial 100,000 tons per year switchgrass fueled electric generation plant is located in Decatur County. It draws switchgrass from Decatur and Henderson Counties.

The initial 600,000 tons per year switchgrass fueled electric generation plant for East Tennessee is located in Clairborne County and is supplied switchgrass by Clairborne, Cocke, Grainger, Green Hamblin, Hancock, Hawkins, Jefferson, Sevier, Sullivan and Washington Counties. The initial 600,000 tons per year switchgrass fueled electric generation plant for Middle Tennessee is located in Hamilton County and draws its switchgrass supply from Hamilton, Bedford, Bledsoe, Cannon, Coffee, Franklin, Grundy,

Lincoln, Marion, Moore, Rutherford, Sequatchie, Van Buren, Warren, White, and Wilson Counties. The initial 600,000 tons per year switchgrass fueled electric generation plant in West Tennessee is located in Carroll County and receives switchgrass from Carroll, Chester, Decatur, Gibson, Hardeman, Henderson, Madison and McNairy Counties.

Given the same yield per acre and the same amount of available land, a larger size plant must draw its supply of switchgrass from a greater distance. This is true for plants located in both East and Middle Tennessee.

West Tennessee has a greater switchgrass yield per acre than either Middle or East Tennessee. Because of this greater yield per acre and higher cropland to land density, a larger plant located in West Tennessee will draw its supply of switchgrass from a smaller distance than plants of similar size located in East or Middle Tennessee.

Graphical representations of delivered cost maps of switchgrass for Tennessee are located in the Appendix. These maps plot the delivered cost of switchgrass for the eachsize plant for both the base and staggered harvest models. The East Tennessee region has the lowest delivered cost for switchgrass, regardless of plant size or model. This is followed by the Middle Tennessee region. West Tennessee is the region with the highest plant delivered cost. West Tennessee also has the smallest dispersion of delivered costs according to distance. East Tennessee has the largest dispersion of delivered costs due to distance. While the pattern of distribution remained the same, the delivered costs were significantly reduced by utilization of the staggered harvest method.

Environmental Analysis

The environmental gains are determined from the societal costs incurred when burning switchgrass instead of coal These gains are estimated by determining the decrease in sulfur dioxide and carbon dioxide when the substitution by switchgrass for coal as a fuel source is made and multiplying the result by the abatement costs. These benefits are derived from the sulfur dioxide and carbon dioxide emission values developed in chapter three.

The largest environmental benefit values occur when emissions of sulfur dioxide into the atmosphere are reduced. SO_2 emission values account for 96 percent of the total environmental benefit value calculated. CO_2 values accounted for the remaining 4 percent. Benefits varied by both plant size and harvest model used.

The total societal environmental value of using switchgrass as a fuel source for electrical power generation at 100,000 tons per year plant size base model is 287.58 million dollars for the state of Tennessee. The utilization of the staggered harvest model increases this value to 535.12 million dollars (Table 4.23). This increase in value is due to a larger quantity of switchgrass produced and used as a fuel source for electrical generation under the staggered harvest model instead of the base model. Total benefits range between 253.18 and 523.97 million dollars (Table 4.24) for the 600,000 tons per year plant size and between 220.14 and 498.99 million dollars for the 1,100,000 tons per year plant size (Table 4.25).

Table 4.23 Total Environmental Benefits: 100,000 Tons Per Year Plant Size

Model	SO_2 Value	CO_2 Value	Total
		(dollars)	
Base	277,739,050	9,842,556	287,581,606
Staggered Harvest	516,810,866	18,314,818	535,125,684

Table 4.24 Total Environmental Benefits: 600,000 Tons Per Year Plant Size

Model	SO_2 Value	CO_2 Value	Total
		(dollars)	
Base	244,521,480	8,665,372	253,186,852
Staggered Harvest	506,037,645	17,933,035	523,970,680

Table 4.25 Total Environmental Benefits: 1,100,000 Tons Per Year Plant Size

Model	SO_2 Value	CO_2 Value	Total
		(dollars)	
Base	212,608,523	7,534,451	220,142,974
Staggered Harvest	481,535,265	17,064,716	498,599,981

If it is assumed that the $0.015 per kwh subsidy was established in part to reduce the societal costs of burning coal for electrical generation, then a comparison of the cost of this subsidy to the societal benefits realized when using switchgrass as a feedstock to electrical power generation should be conducted. Overall, society spends more under the $0.015 per kwh subsidy than if an abatement cost rebate for SO_2 and CO_2 reduction were used (Table 4.26). These losses range between 4.33 million dollars for the 1,100,000 tons per year plant size, base model and 10.54 million dollars for the 100,000 tons per year plant size, staggered harvest model. Within the same model, societal losses decreased as plant size increased.

Table 4.26 Societal Costs and Benefits for Switchgrass Utilization

Plant Size	Model	Benefits of SO_2 and CO_2 Reduction	Subsidy Cost	Difference
(tons per year)			(dollars)	
100,000	Base	287,581,606	293,246,528	- 5,664,922
	Staggered Harvest	535,125,684	545,666,848	- 10,541,163
600,000	Base	253,186,852	258,173,805	- 4,986,953
	Staggered Harvest	523,970,680	534,292,108	- 10,321,428
1,100,000	Base	220,142,974	224,479,457	- 4,336,483
	Staggered Harvest	498,599,981	508,421,641	- 9,821,660

Model Conclusions

The overall conclusions of this chapter are that switchgrass production is economically feasible in Tennessee if environmental impacts are included in the costs of competing fuels. The scenario V electric subsidy provides the lowest economically feasible indifference price for switchgrass to be produced in Tennessee.

At the state level, the staggered harvest model provided substantial gains in switchgrass output and unassigned economic rent. The staggered harvest model also had lower per unit production and transport cost when compared to the base model. The staggered harvest model produced a more elastic supply curve for all plant sizes than the base model.

There were substantial reductions in production cost and transport cost by using the staggered harvest model as opposed to the base model at the plant level. The total economic rent obtained by using the staggered harvest model varied by plant size. At all

plant levels, economic rent decreased using the staggered harvest model instead of the base model. This decrease in economic rent is an indication of the staggered harvest model's more elastic supply curve than the supply curve of the base model.

The regional analysis results indicated that Middle Tennessee had the largest total output of the three regions. Middle Tennessee's total production cost, total transport cost and total economic rent are 48 percent of the state's total. East and West Tennessee maintained approximately 25 percent of the state's total in each of the above categories.

The lowest delivered cost of switchgrass was in the East Tennessee Region, regardless of harvesting model or plant size. Based on this analysis, the East Tennessee Region would be the first to build a switchgrass fueled electrical generation plant. Depending upon the plant size, this facility would be located in either Carter County (100,000 tons per year switchgrass plant) or Claiborne County (600,000 tons per year switchgrass plant). After East Tennessee, Middle Tennessee would be the next region to build a switchgrass facility. The West Tennessee region would be the last region to build a switchgrass facility in Tennessee. Adoption of the staggered harvest model would reduce delivered cost, but cause little locational changes.

The results of the societal environmental costs and benefits analysis suggest that the one and one-half cent per kilowatt hour subsidy is more costly to society than the combined sulfur dioxide and carbon dioxide subsidy.

Chapter 5 SUMMARY AND CONCLUSIONS

Summary

The development of reliable and renewable sources of energy has been a major goal of the national energy strategy of the United States (National Biofuels Roundtable, 1994). One type of renewable resource is bioenergy crops. Bioenergy crops are crops produced and harvested specifically for their energy content. Switchgrass, a bioenergy crop, is a grass that is native to the prairie region of the United States. Switchgrass has a high energy content and low establishment and maintenance costs compared to other energy crops. Switchgrass also has deep root patterns which benefit the environment through control of soil erosion. Buffers of switchgrass around other traditional crops can be used to filter out chemical residues used in traditional crop production.

This study examined the economic feasibility of switchgrass production and utilization for electrical power production in Tennessee. This economic feasibility analysis was enhanced by employing a geographical information system. To date, virtually no literature exists on integrating bioenergy crops, environmental degradation caused by fossil fuels, and geographical information systems. The methodology developed for this study was based on the use of break-even analysis to determine a production cost for switchgrass. The Regional Integrated Biomass Assessment (RIBA) model, a geographical information system, established a link between soil types, anticipated yields, political

boundary data, natural boundary data, harvesting techniques and the costs of production of switchgrass as well as the costs of production of traditional crops.

Burning coal for electrical power production emits both sulfur dioxide and carbon dioxide. The emission of these gases imposes a negative external cost on society currently not accounted for in the price of coal. Because of this externality, the price of coal does not reflect its economic cost to society.

This study established scenarios that allow switchgrass to effectively compete with coal as a feedstock to electric power production. Switchgrass indifference prices for five scenarios were developed. One scenario was a base scenario developing the indifference price of switchgrass for use as a fuel source instead of coal for electrical power generation in Tennessee. Three scenarios were developed by using abatement cost values of both sulfur dioxide and carbon dioxide emissions from burning coal as subsidies for using switchgrass as a fuel source for electrical power plants instead of coal. The fifth scenario used the one and one-half cent per kilowatt hour subsidy for switchgrass as established by the 1992 National Energy Renewable Act. Four of these subsidies provided an estimated price of switchgrass that reflected its environmental benefits to society.

Economic feasibility of switchgrass production and utilization as a feedstock for electrical generation in Tennessee was examined at the state level, the plant level and the regional level. The overall conclusions are that switchgrass is economically feasible in Tennessee if environmental impacts are included in the costs of competing fuels. Switchgrass is not feasible given the current distortions in the energy market.

At the state level, utilization of the staggered harvest model produced between 80 and 126 percent more output than the base model. There were considerable reductions in production cost and transport cost by using the staggered harvest model as opposed to the base model at the plant level. When compared with a base model, the staggered harvest model also reduced unit production and unit transport costs between 9 and 12 percent. Finally, economic rent decreased for each individual plant size when comparing the staggered harvest model to the base (traditional harvest) model.

The locational analysis revealed the breakdown of output, economic rent, and production and transport cost along the traditional regional definitions of Tennessee: East, Middle, and West. Middle Tennessee had the largest output, production cost, transport cost, and economic rent with 48 percent of the state's total. East and West Tennessee were equally divided with approximately 25 percent of the state total in each of the above categories.

The lowest delivered cost of switchgrass was in the East Tennessee Region, regardless of harvesting model or plant size. Based on this analysis, the East Tennessee Region would be the first to build a switchgrass plant. Depending upon the plant size, this facility would be located in either Carter (100,000 ton per year switchgrass fueled power plant) or Claiborne (600,000 ton per year switchgrass fueled power plant) County. The next region in which switchgrass facilities would located is Middle Tennessee. West Tennessee would be the last region to have a switchgrass facility. Adoption of the staggered harvest model would reduce delivered cost, but cause little locational changes.

Depending upon the plant size and harvesting model chosen, society would gain between 4.33 and 10.13 million dollars if the current $0.015 per kWh subsidy was defined in terms of value of emission reduction of SO_2 and CO_2. The same amounts of switchgrass would be used as a feedstock for electrical power generation at a lower price under the emission reduction value of SO_2 and CO_2 than under the $0.015 per kWh subsidy.

Conclusions

The overall conclusion of this study is that switchgrass production, harvesting, and transport for use in electric power generation is economically feasible in Tennessee if environmental impacts are included in the costs of competing fuels. Compared to traditional farming methods, the staggered harvest method provided an opportunity to greatly reduce costs and increase output of switchgrass in Tennessee.

Burning coal emits sulfur dioxide and carbon dioxide. Burning switchgrass produces no sulfur dioxide and no additional carbon dioxide. For every Mbtu of heat generated by Kentucky coal, 3.13 kg of sulfur dioxide and 449.6 kg of carbon dioxide are produced. Emission of these two gases into the atmosphere may contribute to acid rain and global warming, respectively. The emission of these gases have a negative impact on society. The cost of this negative impact is not reflected in the current price of coal..

This study modeled the subsidization of switchgrass prices in order to allow switchgrass to competitively compete with coal as a fuel source for electrical power generation in Tennessee. Currently, the delivered price of coal is $1.48 per Mbtu. Based

on this study, the scenario I delivered price of switchgrass is $1.66 per Mbtu. Allowing coal prices to reflect its damage of sulfur dioxide emissions to society ($1.40 per Mbtu of coal), the delivered price of coal increases by $1.40 per Mbtu to a delivered price of $2.88 per Mbtu of coal. At this level, switchgrass becomes an economically feasible and competitive fuel source for electric generation in Tennessee. The current costs of carbon dioxide emissions are so small that they are insignificant in determining the economic feasibility of switchgrass production and utilization as a feedstock for electric power generation in Tennessee. Society benefited more by the combined carbon dioxide and sulfur dioxide subsidy then by the one and one-half cent per kilowatt hour electric subsidy for switchgrass production and utilization in Tennessee.

The location of marginal land in East Tennessee allowed the initial opportunity for switchgrass production and utilization within Tennessee. Land is needed in Middle Tennessee and West Tennessee for switchgrass usage as a feedstock for electric power generation in Tennessee to approach its full potential for producing large amounts of electrical power.

Limitations And Further Research

There are several limitations to this research. The largest limitation is the problem of "edge effects". This analysis was conducted using the political boundaries of Tennessee. Switchgrass is not assumed to cross state borders. In reality, switchgrass would very likely cross state borders. Switchgrass may be produced and transported in from various states around Tennessee. Switchgrass may be produced in Tennessee and

shipped to the surrounding states. The current design of the RIBA model was not flexible enough to accommodate these edge effects.

Another limitation is the static nature of the data used in the analysis. The static nature of production costs, current switchgrass costs, etc. requires the analysis to be updated every several years to be effective. Also, the static nature of this study does not take into account the reactions of the coal market caused by the increased usage of switchgrass as a fuel source for electric power production. There is a decline in the quantity demanded of coal because of the increase use of switchgrass, *ceteris paribus*. A decrease in the price of coal would result from less coal being demanded. The combined effects of a decrease in both the price and quantity of coal would reduce the marginal damage of coal to society. The potential of dynamic market interaction between the switchgrass and coal markets was not addressed in this study.

This study compared two types of harvesting methods: the traditional method and the staggered harvest method. There was only one alternative harvesting method selected to differ from traditional agriculture. No analysis was conducted on the organization and management required to efficiently operate a staggered harvesting system. Also, this study compared only two feedstocks, coal and switchgrass, for electrical power generation. Other feedstocks for electrical power, such as natural gas, were not compared.

An important issue for further research is the development of models to analyze which market participant, the power plant, the transport sector, farmers, or some

combination of them, will receive the unassigned economic rent. Possibly a contracting market arrangement may develop.

Another area for future research is the examination of the cost and capital investment necessary for a the construction of a switchgrass fueled electrical generation plant. These facilities do not produce electric power in the order of magnitude familiar to electric companies. Switchgrass fueled power plant outputs are small; a 100,000 ton per year plant produces only 40 MW of electricity per year (Graham 1996). In comparison, the TVA Kingston Coal Facility produces a 2 billion watt output per year (TVA, 1996). Given the low generation capacity, current investment in switchgrass facilities by electrical companies may be unlikely. A switchgrass fueled electrical generation facility may need to seek funding from private or government investors. Investment in switchgrass facilities may be too risky due to the lack of an established market for switchgrass. Before investment can be accomplished, an accurate cost estimate of a switchgrass electric power facility needs to be developed.

Another area for future research is the further development and standardization of abatement costing techniques. While the abatement cost estimates selected for this study were the best available, these costs are taken as exogenous in this analysis. There is a large degree of ambiguity in the literature about the definition, design, and usage of abatement costs. Further development on abatement cost to reflect the economic price of fossil fuels needs to be addressed.

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APPENDIX

This appendix contains the map output generated from the RIBA analysis. The locational pattern of delivered costs was identical for both the traditional (base) harvest model and the staggered harvest model. Maps were generated for the traditional harvest (base) model only. In terms of both output per acre and total output, the West Tennessee Region is the largest producer of switchgrass in Tennessee (A1). Only pixels in West Tennessee produce at least 500 tons per year. Switchgrass production between 200 and 499 tons per pixel per year are located throughout Tennessee.

The East Tennessee Region has the lowest delivered cost (less than $35 per ton) of switchgrass at the 100,000 tons per year plant size (A2). Delivered costs of switchgrass are greater in both the Middle and West Tennessee Regions. There exists a large number of switchgrass fueled electric power facilities at the 100,000 ton per year plant size (132 plants). A large number of facilities with delivered costs ranging between $35.00 and $39.99 per ton of switchgrass are located in West Tennessee.

As plant size increases, the total number of switchgrass fueled electric power facilities declines. The geographic pattern of delivered costs for both the 600,000 tons per year plant size (A3) and the 1,100,000 tons per year plant size (A4) are the same as the 100,000 tons per year plant size.

A1. Total Switchgrass Production: Tennessee

TENNESSEE

Switchgrass Supply
(tonnes/sq. kilometer/year)

TENNESSEE

Switchgrass Conversion Facility Locations

Facility Size = 100,000 dry tonnes / year

A2. Switchgrass Fueled Electric Generation Facility Locations: 100,000 Tons Per Year Plant Size

A3. Switchgrass Fueled Electric Generation Facility Locations: 600,000 Tons Per Year Plant Size

A4. Switchgrass Fueled Electric Generation Facility Locations: 1,100,000 Tons Per Year Plant Size

VITA

William Joseph Hewitt was born in Philadelphia, Pennsylvania on March 8, 1967 to his mother, Kathleen A. Hewitt, and his father, William E. Hewitt, a railroad lineman. On January, 1983, William obtained one of his most notable achievements, the rank of Eagle in The Boy Scouts of America. While working full time at the Philadelphia Stock Exchange, Mr. Hewitt attended night school at Philadelphia Community College. He enrolled in Widener University on September, 1986. Widener University's quality education and concerned faculty provided him with the opportunity of obtaining a Bachelor of Science Degree in Business Economics with a minor in Political Science on June, 1990. Upon graduation, Widener University unanimously awarded him the Geoffrey Nearing Prize for student contribution to economics.

William Hewitt entered The Pennsylvania State University's Economics program in Fall, 1990. After one semester, Mr. Hewitt realized that he needed a more applied degree than theoretical economics. He transferred to the Department of Agricultural Economics at Penn State and received a Master of Science Degree in August, 1992. Mr. Hewitt enrolled in the University of Tennessee's Doctoral program in Agricultural Economics in August, 1992. With the encouragement of his wife, Jane, Mr. Hewitt also embarked on obtaining a Master of Science Degree in Educational Psychology, with a concentration in Adult Education in Fall, 1994. The education degree enhanced and refined Mr. Hewitt's communication skills. He received his doctorate degree in Agricultural Economics in August, 1997.

With several publications to his name, William Hewitt continues to serve his two intellectual passions, agricultural economics and education. Within agricultural economics, he has authored articles with a variety of diverse issues including: international trade, agricultural production, economic development and resource economics. Mr. Hewitt's publications in education are devoted to the enhancement of teaching and program planning within agricultural economics. His long term goal is to obtain a dean position at a university. He currently is a professor at Pellisippi State Technical Community College in Knoxville, Tennessee. He resides in Louisville, Tennessee with his wife Jane, dog Khaki, and nine Guinea Pigs.

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