

**EXPLORING THE POTENTIAL TO PENETRATE THE
ENERGY MARKET FOR TENNESSEE-PRODUCED
SWITCHGRASS**

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ABSTRACT

The need for alternative sources of energy which are renewable and environmentally friendly has focused attention on the development of biomass-based energy sector. Lignocellulosic energy crops such as switchgrass are considered potential feedstock for biomass-based energy because of wide range adaptability in conjunction with lower input requirements. However, the costs of the collection, storage, and transportation of the low density feedstock from farm to conversion facilities in the switchgrass supply chain pose a major barrier to the development of bioenergy sector.

The objective of the present study is to determine the optimal logistics configuration for Tennessee-produced switchgrass to penetrate the energy market via a collection/distribution hub. A mathematical programming model in integration with the Geographic Information System (GIS) was used to maximize the net present value of the profit of a collection hub/depot serving both switchgrass producers as well as bioenergy markets. A total of seven logistics scenarios were evaluated: the Baseline scenario utilized a conventional baler harvest and storage system used in the study area, while the other six scenarios incorporated various preprocessing technologies to increase the density of feedstock before delivery to local or international markets.

The results showed the economic challenges of feedstock logistics: only one of the seven evaluated logistics configurations was found to be profitable for the collection hub/depot with the given assumptions. With an increase in fuel prices, it was even difficult to penetrate the energy markets for Tennessee produced switchgrass. However, if investment risk could be lower, two logistics configurations targeting international markets would become profitable. The results imply that government intervention in the bioenergy industry in the form of incentives, policies,

or carbon trading mechanism can reduce the risk of investment in this market and hence increase the profitability and prompt the development of advanced bioenergy industry.

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CHAPTER I INTRODUCTION

Greenhouse gas (GHG) emissions from fossil fuels have stimulated the demand for alternative sources of energy that are both renewable and eco-friendly. Bioenergy is expected to play a dominant role because biomass is an environment friendly energy source (Perlack et al 2005). Apart from reducing GHG emissions, utilizing biomass to produce bioenergy can also generate socio-economic benefits, such as regional economic gain, employment gains, and security of energy supply (Domac et al 2005). In the United States (US), biomass provided over four percent of total energy consumption in 2010, primarily for heat and electricity (Conti et al. 2011). Also, biomass is the only renewable source of liquid transportation fuel (Jensen et al. 2007). Currently, major source of biofuels comes from field grain crops, while second generation biofuels derived from lignocellulosic biomass (LCB), e.g. perennial grasses, crop residues, and woody residues; have gained increasing attention because of less impact on food production and is considered to be the future of the biofuels industry (Samson et al. 2005).

Realizing the importance of bioenergy, many countries have developed mandates, incentives, and policies to accelerate the implementation of biofuel/bioenergy systems (McCormick and Kåberger 2007). A series of policies to promote the use of renewable sources of energy including LCB has been employed by the US and the European Union (EU) (Zegada-Lizarazu et al 2013). In the US, the continued development of biomass as a renewable energy source is being driven in large part by the Energy Independence and Security Act of 2007 (EISA). The Renewable Fuel Standard (RFS), one of the key provisions of EISA, mandates that by 2022 at least 36 billion gallons of biofuel be available in the US, with at least 16 billion gallons derived from LCB (U.S. Congress 2007). The EU has targets for achieving 24% of transport fuel, 14% of bioelectricity, and 62% heat from biomass by 2020 (AEBIOM 2010).

Energy crops are the largest potential source of biomass feedstock (U.S. DOE, 2011). With a growth rate of 3-4% per year in productivity, energy crops are projected to account for over half of potential biomass, assuming \$60 per dry ton for biomass feedstock in US (U.S. DOE, 2011). Switchgrass (*Panicum virgatum*), a warm season perennial grass native to North America, is considered a potential lignocellulosic energy crop (Fike et al. 2006), owing to its very hardy nature and ability to grow well in a wide range of environments throughout the US with relatively low inputs compared to traditional field crops (Jensen et al. 2007). It not only grows well on soils not used for conventional crop production (Lewandowski et al. 2003), due to its deep fibrous root system, switchgrass also prevents soil erosion and increases carbon sequestration in soil, thereby increasing productivity of soil (Mitchell et al. 2008). The deep rooting system helps switchgrass to survive under adverse conditions (Ma et al. 2000). Once established it remains productive for 10 years or more but can be harvested annually using conventional hay equipment (Jensen et al 2007).

Energy can be produced from switchgrass in various forms. Switchgrass can be used to produce biofuel and is viewed as a potential long-term biofuel feedstock to replace corn (Keshwani and Cheng 2009). Heat or electricity can be produced using switchgrass through combustion, either alone or by co-firing with coal or other fossil fuels. While the major portion of electricity in the US is produced by burning coal and natural gas, the burning of coal produces 36% of the CO₂ emissions from energy use (Fraas and Johansson 2009); however, switchgrass co-fired with coal reduces the greenhouse gas emissions (Tillman 2000). Also, Boylan et al. (2000) showed that switchgrass co-firing in existing coal fired units was one of the low cost renewable energy options in the southeast United States.

The EU is an emerging market of switchgrass pellets for commercial heating applications (Grbovic 2010, Samson et al. 2008). Currently wood pellets hold the largest share in the international trade of biomass-based energy feedstock (Sikkema et al 2011). Switchgrass pellets have the potential to penetrate this market as they are next to wood pellets in terms of suitability to large heat and power generation plants. (Sultana et al 2010). Jannasch et al. (2001) have also found switchgrass pellets have equivalent energy content and matching conversion efficiency when compared to wood pellets.

Despite its potential for energy production, switchgrass is not currently produced commercially on a large scale for energy use in the US. One of the major barriers to the development of this bioenergy sector is the cost of the switchgrass supply chain, owing to the technical challenges associated with the handling and transport of the low density feedstock from farm to conversion facility. Due to high costs, market penetration becomes difficult and costs inhibit competition with the traditional energy sources like fossil fuels (Wee et al 2012). Apart from these individual components, an additional challenge is to design a logistics system that efficiently integrates each procedure (Zhu and Yao 2011). Optimization of all the logistical components along the entire supply chain of switchgrass is essential to minimize the total cost or maximize the total profit (de Lourdes Bravo et al 2012).

Several states in US created various incentive programs to develop local bioenergy industry. For example, the Iowa Switchgrass Project has been working to develop markets for switchgrass as an alternative energy crop in southern Iowa since 1996 (Duffy and Nanhou 2001). The Tennessee Biofuels Initiative (TBI), a state sponsored program, allocated \$70 million in 2007 to establish a switchgrass-based energy sector. Under the TBI, more than 5,000 acres of switchgrass was established. In addition, a pilot LCB-based ethanol plant with a capacity of

250,000 gallons of biofuel per year was constructed by DuPont Cellulosic Ethanol and Genera Energy Inc. (a for-profit company formed by The University of Tennessee under the Initiative) and has been in operation in Vonore, TN, since January 2010.

Genera Energy issued contracts with 61 local farmers to supply switchgrass in 2008 (Tiller 2011). All farms in contract were within a 50-mile radius of the pilot cellulosic biorefinery in Vonore, TN. These contracts expired at the end of harvesting season in 2013 as the state funded payment had been exhausted and markets for switchgrass had not developed. Thus, to continuously encourage farmer participation, maintain the operation of Genera Energy, and achieve the goal of developing a bioenergy sector in the state, it is timely and crucial to explore the potential to penetrate energy markets for Tennessee-produced switchgrass.

The objective of the study is to determine the optimum logistics pathway to penetrate bioenergy markets via a collection hub/depot with Genera Energy used as an example in this study. Genera Energy is responsible for managing the feedstock logistics to serve both feedstock producers and bioenergy markets. This study is expected to provide useful information for policy makers to expedite the development of the LCB-based energy industry and for investors to make decisions regarding investment in bioenergy.

CHAPTER II LITERATURE REVIEW

With the development of biomass energy as a focus of national energy and environmental plans, an array of studies has been conducted to analyze the potential of biomass for energy production as well as related opportunities and challenges. To establish a biomass energy sector in a particular region, knowing the potential of using local biomass feedstock for existing energy demand and the feasibility of producing energy from the biomass feedstock within the region is important. In addition, the efficiency of the feedstock supply chain which connects producers of the bulky biomass with bioenergy plants is a crucial factor. Thus, the present study focuses on the literature in three areas: the potential of using biomass for energy, the biomass supply chain costs, and the economic feasibility of biomass energy production.

2.1 Using biomass for energy

The use of biomass as a raw material for bioenergy has been encouraged both by the need for a secure energy supply and to reduce GHG emissions. Global trade in biomass feedstock is growing at a fast pace (Heinimö and Junginger 2009). Biomass is considered to be an attractive renewable fuel to supplement coal combustion in utility boilers (Hughes 1998). The co-firing of biomass and coal is a promising technology for efficiently converting biomass to electricity in existing coal-fired boilers without major capital investments (Nicholls and Zerbe 2012). Furthermore, better efficiency can be achieved in converting biomass into electric power in existing coal-fired power plants as compared to existing wood-fired power plants (Hughes 2000).

In the US, more than 40 coal plants have conducted test burns evaluating fuel types including wood chips, sawdust, switchgrass, and urban wood wastes (IEA 2010). Table 1 summarizes a few studies evaluating the economic and environmental advantages of using

biomass for energy production. Baxter (2005) showed that co-firing biomass with coal was a low-risk, low-cost, renewable energy option. English et al (2007) evaluated the co-firing of various biomass feedstocks (forest residues, primary mill waste, agricultural residues, switchgrass, and urban wood wastes) with coal in coal-fired plants in the southeastern US, finding that in some locations, using biomass at a co-fire rate of 2% (by weight) was feasible when compared to 100% coal combustion.

Switchgrass is more efficient in co-firing than wood because of the lower power requirement during particle reduction as compared to wood (Amos 2002). The co-firing test of switchgrass with coal conducted by Boylan et al (2000) at the Alabama Power Company's Gadsden plant suggested that a combination of 10% switchgrass and 90% coal mixtures (by weight) burned well in the pilot combustor. Amos (2002) carried out the Chariton Valley Biomass Project, a test burn of co-firing with switchgrass at the Ottumwa Generating Station (OGS) in Chillicothe, Iowa, showing that there was an overall reduction of sulfur dioxide emissions, and a reduction of particulate emissions by about 4% while the thermal efficiency of the power plant remained unchanged when burning with switchgrass compared to coal-only operation. Tillman (2000) also demonstrated that the co-firing of biomass with coal had little impact on the efficiency of the conversion facility.

Some studies have assessed the net energy production of switchgrass by comparing it with fossil fuels or other crops (e.g. corn, alfalfa). Schmer et al (2008) estimated the net energy, petroleum inputs to ethanol, and GHG emissions associated with switchgrass use. They found that switchgrass produced 540% more renewable energy than nonrenewable energy consumed in its production, and its GHG emissions were 94% lower than the GHG emissions estimated from gasoline use. Some studies indicated that switchgrass could produce 700% more output than

input energy with almost zero or slightly positive GHG emissions for ethanol derived from switchgrass (Wang, 2009; Mclaughlin et al., 2002). Similarly, the Life Cycle Assessment (LCA) study conducted by Cherubini and Jungmeier (2009) demonstrated that significant fossil energy savings were achieved when using switchgrass over fossil fuels.

Vadas et al. (2008) assessed energy conversion efficiency in Wisconsin by comparing cropping systems of continuous corn, an alfalfa–corn rotation, and continuous switchgrass, demonstrating that net energy produced by switchgrass was greatest, followed by continuous corn, and then alfalfa–corn. Samson et al. (2000) compared various biofuel production pathways such as the co-firing of switchgrass with coal, cellulosic ethanol production, corn ethanol production, and the pelletization of switchgrass. The results showed that pelletized switchgrass had the highest net energy balance and a higher energy conversion rate as compared to other energy options. When compared to wood pellets, switchgrass pellets have an equivalent energy content of 19.0 Giga Joules/tonne and the same conversion efficiency of 82% (Jannasch et al. 2001).

Currently, the EU is one of the leading markets in wood pellets. The main driving force boosting the demand of wood pellets in the EU is its support schemes aimed at achieving its energy objectives. The EU 2020 policy targets for renewable energy sources and GHG emissions reduction are the main drivers of a booming pellet market in the EU (Qian and McDow 2013). That said, although the wood pellets are considered to be the most economically efficient means to displace fossil fuels, large volumes of wood cannot be harvested because of ecological and supply constraints (Faaij and Domac 2006).

As switchgrass pellets have an energy content comparable to wood pellets (Jannasch et al 2001), switchgrass pellets have the potential to penetrate the EU's bioenergy market and meet

the increasing demand for pellets. Sultana and Kumar's study (2012), which evaluated and ranked biomass feedstock based pellets including wood, straw, switchgrass, alfalfa and poultry litter, found switchgrass pellets similar to wood pellets in terms of suitability for use in large heat and power generation plants. Pellets were assessed with a multi-criteria assessment model based on environmental, economical, and technical factors, both quantitative and qualitative. The quantitative criteria were: production cost, bulk density, nitrous oxides (NO_x) emissions, sulfur oxides (SO_x) emissions, methane (CH_4) emission, deposit formation, lower heating value, durability and storage time before degradation. The qualitative criteria assessed acceptability to user. Whereas the analysis results showed wood pellets as the best among the five alternatives evaluated, switchgrass pellets followed closely.

2.2 Determining the biomass supply chain cost

The biomass supply chain includes the processes from harvesting to transportation to the end user (e.g., conversion facility). It reflects biomass supply (single or multiple locations), storage sites (one or more intermediate sites), preprocessing in some cases, and transportation (using one or more modes). Figure 1 shows the biomass logistics system suggested by Miao et al (2012). Initially, various farms are involved in producing biomass. After harvest, biomass is delivered to a storage site and is stored, possibly after first being preprocessed. The preprocessed or unprocessed biomass is then delivered to domestic or international energy markets using different modes of transportation (e.g., truck, rail, ocean). At every step of supply chain, the cost and energy efficiency of biomass can be influenced, such as by the type of harvesting method used (e.g., bale or chop), choice of preprocessing operation (e.g., compression, pelletization), storage method used (e.g., open or closed), and mode of transportation (e.g., truck, rail, ocean).

A number of studies have been conducted to analyze the biomass supply chain from farm to bioenergy conversion facility with respect to logistical performance and challenges (Table 2). Various researchers used the GIS integrated with mathematical programming or the GIS-based environmental decision support system (EDSS) to meet their objectives. Some researchers evaluated the switchgrass supply chain specifically (Cundiff et al 1997; Zhu et al 2011; Zhang et al 2012) which involves planting, harvesting, preprocessing, storing, and transportation to conversion facilities.

Switchgrass was assumed to have production cycle of 10 years and can be harvested annually. The planting of switchgrass constituted establishment in the first year and annual maintenance in the following years (Larson et al 2010). Switchgrass growing season is from early spring to late fall and it can be harvested nearly year-round. Harvest time and harvest frequency affect quantity and quality of biomass production of switchgrass (Sanderson et al. 1996). While harvesting switchgrass twice per year increases biomass yields, it also increases the fertilizer requirement (Guretzky et al. 2011).

Larson et al. (2010) suggested switchgrass harvesting once per year after the killing frost since the harvest and replacement of nutrients would be minimized. Thus, switchgrass is generally harvested within a four month window. The suitable harvest window of switchgrass grown in Tennessee is from November to February (Larson et al 2010). The harvest window can be extended over many months, but it leads to dry matter loss as dry matter yield depends on the growth stage of the plant and the length of time mature stands are left in the fields before harvest (Haque and Epplin 2012). Switchgrass is mainly harvested as bale or chop form, and the objective of selecting a particular form is to increase the density of feedstock to minimize the cost of storage and transport or based on customer needs (Sokhansanj and Hess 2009).

Storage is important to supply feedstock to the bioenergy industry throughout the year. Storage costs mainly depend on three factors: storage location, storage system, and storage duration. Feedstock can be stored in an open field, an open field on crushed rock covered with a tarp, or an enclosed building (Duffy 2007). Many researchers have assumed on-field biomass storage to calculate the delivered cost of biomass (Allen et al. 1998, Sokhansanj et al. 2006). Some authors have proposed intermediate storage sites between the farm and the power plant, so-called satellite storage locations (SSLs) (Ravula et al. 2008, Tatsiopoulou and Tolis 2003) to serve as temporary storage locations.

Additionally, some researchers have studied feedstock storage in different forms, including square bales, round bales, and chips. Searcy and Hess (2010) discussed the storage of wood chips in the form of a pile. The idea of storing wood chips in a pile is not a recent concept, starting in the 1950s with the use of wood products residuals becoming a major source for pulp chips. Wood chips were stored to meet the demand of mills throughout the year (Fuller 1985). In some cases, wood chips were handled by a circular stacker reclaimer where a front-end loader was used to move woody material around the grounds, and the chips were queued in a large open storage pile by a circular stacker reclaimer (Searcy and Hess 2010).

Cundiff et al. (1996) examined both ambient and covered on-field storage of switchgrass in bale form. On-field storage offered a cost advantage but with significant dry matter loss whereas storage in an enclosed building is expensive but results in the least dry matter loss. Dry matter loss is also highly dependent on the length of time in storage and the baling option chosen (Kumar et al. 2006). Switchgrass can be stored as rectangular or round bales. Rectangular bales are cost efficient as they are easy to handle and transport (Larson et al. 2010) but have more dry matter loss as compared to round bales. Though round bales are hard to manage, they shed water

more easily as compared to rectangular bales and hence dry matter loss is less (Cundiff and Grisso 2008). Wang (2009) examined the dry matter loss of switchgrass during storage for large round bale and large square bale and two storage durations (0 day and 200 days) in Tennessee. Compared to West Tennessee, the average annual precipitation is higher in East Tennessee and consequently the dry matter loss was higher in East Tennessee than in West Tennessee.

The low bulk density of switchgrass also increases logistics costs. Feedstock density can be increased substantially through various preprocessing methods. The major preprocessing methods are drying, densifying, stretch-wrap bale, pelletization, pyrolysis, and torrefaction. The density of pelletized feedstock ranges from 30 to 40 lbs/ft³ (Mani et al. 2006), and the compact size of pellet is an advantage for long distance transportation (Selkimäki et al. 2010). In the case of international markets, Hamelinck et al. (2005) have emphasized the densification of biomass in the form of pellets as pellets are easy to handle and reduce transportation costs in comparison to less condensed chips or bales. Preprocessing can occur with harvesting operations or at separate preprocessing facilities known as preprocessing depots or hubs (Wright et al 2006; Carolan et al 2007; Eranki et al 2011; Bals and Dale 2012). Yu et al. (2011) evaluated the potential value of including preprocessing in the biomass feedstock supply chain for a biorefinery in East Tennessee using a spatial oriented mixed-integer mathematical programming model. The results showed that stretch-wrap bale preprocessing technology could reduce the total delivered cost of switchgrass for large scale biorefineries.

The transportation costs of biomass constitute one of the major cost components in the entire supply system. The higher transportation costs of lignocellulosic crops make it uncompetitive economically to deliver from farm to bioconversion facility. Transportation costs contribute 25-40% to the total delivery cost of biomass depending on the location of biomass

resource (Hamelinck et al. 2005). Biomass transportation costs vary with biomass form and transport distance. As the transportation cost of chopped switchgrass (with density of 4lb/ft³) is higher than the cost of baled switchgrass (with density of 8lb/ft³) (Kumar and Sokhansanj 2007), one of the solutions to reduce transportation cost is densification of biomass into pellets, cubes, or briquettes with bulk density of more than 25lb/ft³ (Sokhansanj and Turhollow 2004).

The two main components of transportation costs are fixed cost (FC) which is independent of distance, and variable cost (VC) which is directly dependent on the distance traveled (Alfonso et al. 2009; Searcy et al. 2007). The VC varies with the specific location and mode of transportation, and the FC depends on the type of biomass transported and the contractual agreements involved (e.g. includes the cost of loading and unloading of biomass) (Searcy et al. 2007).

Transportation modes can be roads, rails, and waterways. Truck transportation is appropriate for short distances of 100 miles but not for longer distances (Sokhansanj et al. 2009). Truck transport also causes congestion on roads and hence community resistance. For longer distances, rail transport is less costly and is a more efficient mode of transporting biomass compared to truck (Kang et al. 2010). That is, the FC is higher than the VC in the case of rail shipment (Mahmudi and Flynn 2006). Thus, it is advisable to use both modes of transport: truck as well as rail. The intermodal transportation has cost advantages over a single mode of transportation as, for longer distances, rail transport is less costly than transportation by truck (Gold and Seuring 2011). While water transportation is the cheapest of the three, it is vulnerable to weather and extreme water levels with the potential to delay shipment (Kang et al. 2010).

2.3 Assessing the economic feasibility of biomass for bioenergy

O'Mahoney et al (2013) carried out a cost-benefit analysis in Ireland to assess the feasibility of achieving the target of 30% co-firing of peat and biomass by 2015. The study considered biomass fuel costs, capital costs, and increased operations and maintenance costs at power stations associated with handling the biomass. The benefits included CO₂ and annual peat fuel cost savings. Different co-firing options (15%, 30%, and 45%) (by weight) and reduction in the use of peat equivalent to 30% (reduction was met by electricity generation through natural gas) were considered. The study showed a negative net present value (NPV) for all co-firing options except the reduced output option, which showed positive NPV. The negative NPV resulted from the unavailability of sufficient biomass resources in Ireland to meet the co-firing targets.

The impact of biomass availability on the NPV was also analyzed by Rentizelas et al (2009) in a case study for the district of Thessaly, Greece. The study was done with an objective of maximizing the NPV of an investment in co-generation plants. The results indicated that the interest rate had the highest impact on project costs, and biomass cost had little impact on the NPV because of cheap availability of biomass in the region.

Tembo et al (2003) established a conceptual mixed integer linear programming (MILP) model to do an investment appraisal of a LCB-to-ethanol industry and conducted a case study in Oklahoma. The objective of the study was to determine the most economical source of lignocellulosic biomass, timing of harvest and storage, inventory management, biorefinery size, and biorefinery location, as well as the breakeven price of ethanol, for a gasification-fermentation process. Based on the given assumptions, the results showed that gasification-

fermentation of lignocellulosic biomass to ethanol might be more economical than the fermentation of corn grain.

When Van Dam et al (2009) analyzed the economic feasibility of large-scale bioenergy production from soybeans and switchgrass in Argentina, the researchers estimated the land availability for bioenergy production from soybeans and switchgrass. The results showed that transportation costs, cultivation costs, preprocessing costs, and crop prices were the key parameters affecting economic performance. As switchgrass pellets for local use were not competitive, there was a need to encourage incentives and promote the marketing of switchgrass pellets to make it competitive. However, with the depletion of oil resources in Argentina, switchgrass has the potential as an alternative source for heat and electricity production.

An et al (2011) developed a case study of nine counties in central Texas with switchgrass as the biomass feedstock. A mathematical model was developed with an objective of maximizing the profit of the biofuel supply chain. The researchers studied the impact of switchgrass cost, switchgrass yield, ethanol price, and ethanol demand on the supply chain. The study suggested that the most significant cost factor affecting the economic viability of the biofuel supply chain was the ethanol price.

The environmental impact, cost, and net GHG emissions of replacing coal with switchgrass were assessed by Qin et al (2011). Different production methods and transportations methods were analyzed, showing that switchgrass for bioenergy was competitive with coal only in case of high coal prices, lower production costs, or with an emission price for CO₂. Similar results were found by Aravindhakshan et al (2010) when evaluating the economics of switchgrass and the miscanthus relative to coal for electricity generation in an experimental station in Oklahoma. The study determined the co-firing feasibility for each of the two energy

crops with coal for electricity generation. The researchers focused on determining the minimum carbon tax required to make switchgrass and miscanthus economically feasible for co-firing with coal as the technology for co-firing LCB is simple and can be carried out in existing plants with small investments and modifications. The results showed that a carbon emissions tax makes the feedstock competitive with coal.

Although biomass energy production and associated supply chains for feedstock have been studied previously, little attention has been given to exploring the optimum logistics pathway as managed by a collection/distribution hub in regard to energy market penetration for Tennessee-produced switchgrass. Therefore, the present study fills a gap in the literature by providing the systematic evaluation of different logistics configurations, including different harvest, storage, and preprocessing means, for a case study of switchgrass in Tennessee.

CHAPTER III CONCEPTUAL FRAMEWORK

The study explored to penetrate potential energy markets by evaluating the costs and revenue of delivering Tennessee-produced switchgrass to various markets via a collection/distribution hub. The structure of the feedstock supply system shown in Figure 2 presents the movement of feedstock (switchgrass) from producer (Tennessee farmers) to market (energy plants) via a collection/distribution hub.

The objective is to maximize the profit of the hub for selling the switchgrass to potential markets, which can be written as:

$$Max \pi_t = R_t - TC_t \quad (1)$$

where π_t is profit, R_t is revenue, and TC_t is the total cost. The revenue in year t can be written as:

$$R_t = P_t * Q_t \quad (2)$$

where P_t is the price of switchgrass in the energy market, and Q_t is the quantity sold in year t .

Total costs (TC_t) including the opportunity cost, production cost, storage cost, preprocessing cost, and transportation cost can be written as:

$$TC_t = OppCst_t + ProdCst_t + StrgCst_t + PPCst_t + TrnsCst_t \quad (3)$$

where $OppCst_t$, $ProdCst_t$, $StrgCst_t$, $PPCst_t$, and $TrnsCst_t$ represent the total opportunity, production, storage, preprocessing, and transportation costs in year t , respectively. Assuming the price of switchgrass and demand for switchgrass to be constant every year and the costs of opportunity, production, storage, preprocessing, and transportation to be constant, equations (2) and (3) can be rewritten as:

$$R = P * Q \quad (4)$$

$$TC = OppCst + ProdCst + StrgCst + PPCst + TrnsCst \quad (5)$$

Annual profit is estimated for each year as in equation (6):

$$\pi = P * Q - TC \quad (6)$$

To analyze the profitability of investment for t years, the NPV of the total profit is commonly evaluated (Walsh et al 2003; Rentizelas et al 2009; O'Mahoney et al 2003). When future profit is discounted back to the initial year (when $t = 1$), the NPV value can be written as:

$$\begin{aligned} NPV &= \frac{\pi_1}{1+r} + \frac{\pi_2}{(1+r)^2} + \frac{\pi_3}{(1+r)^3} + \dots + \frac{\pi_t}{(1+r)^t} \\ &= \frac{\pi}{1+r} + \frac{\pi}{(1+r)^2} + \frac{\pi}{(1+r)^3} + \dots + \frac{\pi}{(1+r)^T} \\ &= \pi * \left[\frac{1}{1+r} + \frac{1}{(1+r)^2} + \frac{1}{(1+r)^3} + \dots + \frac{1}{(1+r)^t} \right] \\ &= \pi * \frac{\frac{1}{1+r} \left[1 - \left(\frac{1}{1+r} \right)^t \right]}{1 - \left(\frac{1}{1+r} \right)} \\ &= \pi * \frac{(1+r)^t - 1}{r(1+r)^t} \quad (7) \end{aligned}$$

Thus, the net present value of future profit is a linear function of annual profit with a constant present value annuity factor ($PVAF$), which is given by:

$$PVAF = \frac{(1+r)^T - 1}{r(1+r)^T} \quad (8)$$

The initial investment costs are annualized using capital recovery factor (Thek and Obernberger 2004) and the NPV is formulated in equation (9):

$$NPV = \{(P * Q - TC)\} * PVAF \quad (9)$$

The NPV of the total profit is subject to change with change in interest rate (r). High interest rate is used in case of high risk associated with investment. Change in r impact the initial cost of investment in equipment or buildings used in the analysis, hence the profit. When r increases, the investment cost increases, hence the total profit decreases. In addition, the variations in fuel price affect the total operation cost. Fuel price also impact the production cost of crop as crop prices are correlated to fuel price (Tyner 2010). As the fuel price increases, the demand for biofuels increases, which, in turn, leads to increase in crop prices. With increase in fuel prices, the total logistics cost increases and the profit decreases.

CHAPTER IV METHOD AND DATA

A cost-minimization switchgrass logistics model developed by Gao (2011) was modified to maximize the profit for the collection/distribution hub for delivering Tennessee-produced switchgrass to energy markets. The present study was a case study assuming Genera Energy as the collection/distribution hub between the potential producers and markets. The model was used to determine the costs associated with various switchgrass supply systems and the revenue generated from targeted markets. The GIS was integrated with the mathematical programming model to select the optimal biomass supply region. Cases utilizing different harvesting, preprocessing, storage, and transportation methods were analyzed.

4.1 Case Study

Genera Energy Inc., a for-profit company originally formed by The University of Tennessee Research Foundation under the TBI, was located at Vonore, Tennessee. The feedstock supply region considered in the study consisted of 13 counties in Tennessee including Anderson, Blount, Graham, Knox, Loudon, McMinn, Meigs, Monroe, Morgan, Polk, Rhea, Roane, and Sevier. The feedstock supply region was determined given the geographical relationship with Genera Energy. Traditional croplands, e.g. corn, wheat, soybean, sorghum, cotton and hay, were considered for potential switchgrass production area. The study used existing biomass-energy producers as targeted local markets. Local markets were selected within 70 miles of Genera Energy (Table 3). It was assumed that the switchgrass would be delivered to local markets in bale or chopped form, and the quality of either form was assumed to be the same. Switchgrass pellets were assumed to be utility grade pellets, which can be used for industrial purposes. The industrial wood pellet market in The Netherlands and Belgium, which serve as the largest market for industrial use of wood pellets, was considered as the international market.

The region was divided into 1,138 five square-mile hexagons (i.e. crop zones) (Figure 3). The crop yield was obtained from the soil survey geographical (SSURGO) database at the sub-county level (USDA 2012). The area under each crop zone for each crop type was derived from the cropland layer database (USDA National Agricultural Statistics Service, 2011). The prices of traditional crops were obtained by taking a three year average (2010-2012) from the National Agricultural Statistics Service, USDA (2013). The POLYSYS model was used to obtain the production cost of traditional crops (Ugarte and Ray 2000). Budgets for the equipment, materials, and labor used for the establishment, annual maintenance, harvest, storage and transportation of switchgrass were obtained from the budgets produced by the University of Tennessee Department of Agricultural and Resource Economics and data from Larson et al (2010). The diesel price was assumed to \$3.5 per gallon when estimating machinery costs.

Following Larson et al (2010), cost of switchgrass production included opportunity costs on land, establishment costs incurred in the first year of production, and recurring annual costs for fertilizer, pest control, harvest, preprocessing, storage, and transportation of the feedstock. The establishment costs included the costs of seed, fertilizers, and machinery used for establishing switchgrass. It was amortized annually using a capital recovery factor at an interest rate of 10% over a 10 year time period.

The harvesting costs included labor, operating, and ownership costs for a mower, loader, baler, and tractor. For the transportation of bales (round or square) a semi-tractor trailer was used, while a tandem-axle truck was used for chopped feedstock. The fixed costs associated with each operation were also annualized using a capital recovery factor. All the machinery costs were calculated following American Society of Agricultural Engineers Standards (ASAE, 2006). In case of industrial machinery, like pelletizing equipment, stretch-wrap bale equipment, a

stacker-reclaimer, and silos, salvage value was assumed to be zero. Taxes, insurance, and housing (TIH) were calculated based on the property assessment ratio (0.4) and property rate (2.01) in Vonore, TN. The values were obtained from the Monroe County Trustee website (2014).

The ownership cost was calculated by estimating the capital recovery cost and property taxes on machinery. The operating cost included fuel cost, lubrication cost, and maintenance and repair costs. The annual capital recovery cost was generated by first multiplying the appropriate capital recovery factor by the total depreciation incorporating the interest rate and the salvage value. The cost component for each year was calculated by estimating machinery cost including ownership costs and operating costs associated with each operation and the cost of labor employed. Costs and revenue were estimated for each year for the period of 10 years. Profit was calculated for each year. To estimate the NPV, profit was discounted using PVAF.

The present study considered seven different logistic systems (one baseline and six alternative harvest and preprocessing options) for delivering switchgrass to potential energy markets. The definition of each scenario is listed as follows:

- Baseline: In this scenario, switchgrass was mowed, baled by a round baler or a square baler, and delivered to local markets.
- C_SWB: Switchgrass was harvested as chopped feedstock, preprocessed using stretch-wrap bale (SWB) technology, and delivered to local markets.
- C_SR: Switchgrass was harvested as chopped feedstock, stored at Genera Energy using a stacker-reclaimer (SR), and delivered to local markets.
- B_P: Switchgrass was harvested as bales and then pelletized. Pellets were delivered to international markets.

- C_SWB_P: Switchgrass was harvested as chopped feedstock. SWB technology and pelletization were used as preprocessing options. Switchgrass pellets were then delivered to international markets.
- C_SR_P: This scenario used a SR as a storage system during the off-harvest season and pelletization as preprocessing method. Pellets were then delivered to international markets.
- C_SWB_SLO_P: In this scenario, SWB technology and pelletization were used as preprocessing options. A silo (SLO) was used as a storage system during the off-harvest season. Switchgrass pellets were delivered to international markets.

Table 4 summarizes the operation sequences of supplying switchgrass to the potential markets in each logistics system.

4.2 Baseline scenario

This scenario assumed that one-third of the harvested switchgrass bales were loaded onto a semi-tractor trailer by a tractor with a front-end loader and transported to local markets directly during harvesting season. The remaining two-thirds of the harvested switchgrass bales were moved to the field edge by a tractor with a front-end loader for storage and delivered to the local markets during the off-harvest season. Genera Energy was assumed to be responsible for the collection and transportation of feedstock from farms to the markets. Farm machinery costs associated with this scenario are summarized in Tables 5-12.

4.2.1 Revenue and cost components

As local markets were considered in this scenario the price of delivered switchgrass was assumed to be \$60 per ton. This price is based on the estimate by U.S. Department of Energy

(2011), which suggested that a market price of \$60 per dry ton can attract a sufficient supply of biomass feedstock to replace 30% of transportation fuel use by 2030. The quantity delivered was based on the demand of local markets within 70 miles from Genera Energy, Inc. The price and quantity assumptions were made identical for other scenarios considering the local markets. The total logistics cost consisted of opportunity costs from land conversion, switchgrass production, harvest, storage, and transportation from field to markets (equation (10)).

$$TC_1 = C_{opp} + C_{Prod} + C_{Harv} + C_{Stor} + C_{TrnsFtoM} \quad (10)$$

The opportunity cost (C_{opp}) for switchgrass production was equal to the income from a traditional crop type grown on that land. If the profit from the traditional crop grown was less than the land rent, then the opportunity cost was equal to the land rent. The relationship is presented in equation (11):

$$C_{opp} = \begin{cases} \sum_{icb} \left(\frac{P_{ic} * Y_{ic} - PC_{ic}}{y_{ib}} * XC_{icb} \right), & \text{if } (P_{ic} * Y_{ic} - PC_{ic}) \geq LR_{ic} \\ \sum_{ic} \left(\frac{LR_{ic}}{y_{ib}} * XC_{icb} \right), & \text{if } (P_{ic} * Y_{ic} - PC_{ic}) < LR_{ic} \end{cases} \quad (11)$$

where P_{ic} , Y_{ic} , PC_{ic} , LR_{ic} represented price of the traditional crop, yield of the crop, production costs and land rent associated with each crop zone; XC_{icb} represented switchgrass production; and y_{ib} was the yield of switchgrass. To estimate the price of traditional crops, the average price of three years was taken from the years 2010-2012. The subscript i , c , and b represent crop zones, type of crop, and bale form respectively. The production cost (C_{prod}) for switchgrass produced (XC_{icb}) consisted of the establishment costs (Est) as well as the annual maintenance costs (AMC) (equation (12)). The method of calculation for the opportunity cost, production cost, and harvest cost was similar in each scenario.

$$C_{prod} = \sum_{icb} \left(\frac{Est + AMC}{y_{ib}} * XC_{icb} \right) \quad (12)$$

The harvest cost (C_{harv}) constituted labor, fuel and machinery costs for switchgrass harvest. Harvest technologies such as bale type influenced the cost since different machineries with different fuel consumption rates were used in equation (13).

$$C_{harv} = \sum_{icb} \left(\frac{\text{Sigma}_{ic}}{y_{ib}} \times XH_{icb} \right) \quad (13)$$

where Sigma_{ic} represents the cost of harvest per ton and XH_{icb} the tons of switchgrass harvested. The breakeven price (BEP_{icb}) was the price at which farmers were willing to switch from traditional crops to switchgrass production. It consisted of three components: the opportunity cost of land use change, the production cost of switchgrass and the harvest cost of switchgrass. The BEP_{ic} of switchgrass was calculated by combining equations (11)-(13), and was given by equation (14).

$$BEP_{ic} = \begin{cases} \frac{\text{Price}_{ic} * \text{Yield}_{ic} - PC_{ic} + \text{Est} + \text{AM} + \text{Sigma}_{ib}}{y_{ib}}, & \text{if } (P_{ic} * Y_{ic} - PC_{ic}) \geq LR_{ic} \\ \frac{LR_{ic} + \text{Est} + \text{AM} + \text{Sigma}_{ib}}{y_{ib}}, & \text{if } (P_{ic} * Y_{ic} - PC_{ic}) < LR_{ic} \end{cases} \quad (14)$$

The switchgrass yield varied across the state with an average of 7.26 tons/acre and 6.56 tons/acre for round and square bales, respectively. The average yield for square bales was lower than the round bales because of higher dry matter loss during storage in the case of square bales as compared to round bales. The annual dry matter loss was incorporated into the yield of switchgrass used in the study. Storage cost for switchgrass (γ_{ibt}) consisted of the costs of materials used and the cost from equipment, such as bale stack and tarp, and labor used in storage operations. Square bales were stored using pallet and tarp, while in the case of round bales, only tarp was used. The storage cost (C_{stor}) was given by equation (15).

$$C_{stor} = \sum_{icbs} \gamma_{ibs} * XS_{icbs} \quad (15)$$

where s represents the storage method used, and XS_{icbs} is tons of switchgrass stored.

Semi-tractor trailer was used for transporting switchgrass from farm to markets. The loading capacity of the trailer was assumed to be different for both types of bales, i.e., 16.01 tons/load for square bales and 13.18 tons/load for round bales. The speed of the trailer was assumed to be 50 miles per hour. The transportation time was estimated by considering the speed and distance between two points. Tonnage loss during transportation (2%) was also incorporated in the transportation cost (Kumar and Sokhansanj 2007).

The transportation cost consisted of loading and unloading costs, labor costs, and machinery costs. Following Duffy (2007), loading and unloading times for round and square bales were different, with round bales assumed to consume more time as compared to square bales. The transportation cost from farm to market ($C_{transFtoM}$) was calculated using equation (16).

$$C_{transFtoM} = \sum_{ibz} \theta_{ibz} * \frac{\sum_{ct} XT_{icbsz}}{1 - DML_{trans}} \quad (16)$$

where XT_{icbsz} is the total tons of switchgrass transported, θ_{ibz} represents transportation costs per ton, DML_{trans} is the dry matter loss during transportation, and z represents the type of market.

4.2.2 Constraints

For the marketing of switchgrass, the availability of feedstock and inventory flow needed to be maintained. Feedstock flow was constrained at each step. Switchgrass production was constrained by the availability of land and yield of switchgrass. Equation (17) limited the number of acres under switchgrass production (A_{icb}) to be less than or equal to potential acres ($acre_{ic}$) available. Equation (18) limited the amount of switchgrass produced (XC_{icb}) to be less than or equal the maximum potential production amount. y_{ib} represents the yield of switchgrass.

$$\sum_b A_{icb} \leq acre_{ic} \quad (17)$$

$$XC_{icb} \leq y_{ib} \times A_{icb} \quad (18)$$

Tons of switchgrass harvested (XH_{icb}) was constrained to no more than the amount of switchgrass produced and was given by equation (19), with DML_{har} representing dry matter loss during harvest. Equation (20) ensured that the switchgrass stored (XS_{icbt}) equaled the amount of switchgrass harvested (XH_{icb}), deducting the amount of switchgrass delivered to the market (XTM_{icbz}) directly.

$$XC_{ipb} - \frac{XH_{icb}}{1 - DML_{har}} \geq 0 \quad (19)$$

$$\sum_t XS_{icbs} = XH_{icb} - \frac{XTM_{icbz}}{1 - DML_{trans}} \quad (20)$$

Equation (21) gave the amount of switchgrass transported (XTO_{icbsz}) to markets during the off-harvest season. The demand ($DMkt_z$) and supply of switchgrass was balanced by the equation (22).

$$XS_{icbs} \geq \frac{\sum_z XTO_{icbsz}}{1 - DML_{trans}} \quad (21)$$

$$(\sum_{i,c,b,z} XTO_{icbsz} + \sum_{i,c,b,s} XTM_{icbz}) = DMkt_z \quad (22)$$

4.3 C_SWB scenario

In this scenario, the switchgrass was harvested using self-propelled forage chopper without prior mowing. The chopper was equipped with a rotary header and had a throughput

capacity of 20 tons per hour. The harvest dry matter loss was assumed to be zero in this scenario. As chopped feedstock cannot be stored at the farm, the preprocessing option was incorporated which could handle the chopped feedstock and store it to use in the off-harvest season. One-third of the chopped switchgrass was delivered directly to the market, and two-third was delivered to the preprocessing facilities using a tandem-axle truck. The capacity of the truck was assumed to be 3.37 tons/ load. The speed of the andem-axle truck used in this study was 25 miles/hour.

The preprocessing analysis was based on stretch-wrap bale technology originally developed in Europe for garbage which has since been marketed in the US by TLA BaleTech LLC (Larson et al. 2010). After the chopped feedstock is dumped into a holding area of the preprocessing facility, the feedstock is been loaded by a front-end loader onto a conveyor belt, and is compressed into compact bales wrapped in mesh net. The compactor was assumed to preprocess 63,360 tons of chopped material during harvesting, with a throughput of 45 dtons per hour (16 h/day for 22 days for 4 months). Assuming 90% of the utilization rate of machinery, one preprocessing facility would preprocess 57,000 dtons of switchgrass during the harvesting season. The land required for a compactor baler and the storage of stretch-wrap bales was assumed to be 15 acres.

The stretch-wrap bales were assumed to be stored at the preprocessing facility and delivered to market during off-harvest season. The stretch-wrap bales were loaded onto a semi-tractor trailer by a tractor with a front-end loader and transported to market during the off-harvest season. The capacity of the semi-tractor trailer was assumed to be 25 tons per load. The speed of semi-tractor trailer used in this study was 50 miles/hour (Brechbill and Tyner 2008). The potential preprocessing facilities were selected based on the least logistics costs. Seven facilities were selected based on the total amount preprocessed annually.

4.3.1 Revenue and cost components

The assumptions for the price and quantity of switchgrass delivered to the local market were discussed previously. The total logistics cost for this scenario consisted of the opportunity costs from land conversion, switchgrass production, harvest, preprocessing, and transportation from field to market, from field to preprocessing facilities and from preprocessing facilities to market.

$$TC_2 = C_{opp} + C_{Prod} + C_{Harv} + C_{TrnsFtoM} + C_{TrnsFtoPPF} + C_{Prepro} + C_{TrnsPPFtoM} \quad (23)$$

Harvesting cost constituted the machinery costs, maintenance costs of machinery used, the energy used, and the labor used to do all the operations. Harvest cost (C_{harv}) was given by equation (24) :

$$C_{harv} = \sum_{ic} \left(\frac{\text{Sigma}_{ic}}{y_i} \times XH_{ic} \right) \quad (24)$$

where XH_{ic} is the total tons harvested and Sigma_{ic} represents harvest cost per ton. The transportation cost is comprised of machinery, labor, and energy used. Chopped switchgrass was transported to market or preprocessing facilities using a tandem-axle truck. The transportation cost ($C_{TrnsFtoM}$) from farm to market and transportation cost ($C_{TrnsFtoPPF}$) from farm to preprocessing facility was given by equation (25) and (26), respectively.

$$C_{TrnsFtoM} = \sum_z \theta_{1iz} \times \frac{(\sum_c XTO_{ictz})}{1 - DML_{trans}} \quad (25)$$

$$C_{TrnsFtoPPF} = \sum_j \theta_{2iz} \times \frac{(\sum_c XTP_{icj})}{1 - DML_{trans}} \quad (26)$$

XTO_{ictz} , represents tons of switchgrass transported from farm to market and tonnage delivered from farm to preprocessing facility is represented by XTP_{icj} . The subscript j represents the location of the preprocessing facility. Transportation cost per ton from farm to market and

from farm to preprocessing facility was represented by $\theta 1_{iz}$ and $\theta 2_{iz}$ respectively. The transportation time was calculated based on the distance and speed of the tandem-axle truck used. The preprocessing cost (C_{Prepro}) was given by equation (27)

$$C_{Prepro} = \sum_j (FCP_j \times PF_j) + \sum_{icj} (VCP_j \times XTP_{icj}) \quad (27)$$

It constituted the fixed cost (FCP_j) and the variable cost (VCP_j) of tons of switchgrass (XTP_{icj}) to be preprocessed (equation (27)). Fixed costs included the costs of land and building where the preprocessing facility was located. The variable cost consisted of total cost of film, net, and belt used to wrap the compact bales. The cost of storing the chopped switchgrass (before preprocessing treatment) and stretch-wrap bales (after preprocessing treatment) in preprocessing facilities (PF_j) was included. The estimated machinery costs of compactor and a building to house the compactor was summarized in Tables 13 and 14 respectively. The preprocessed switchgrass was transported to market (XTM_{icjz}) using a semi-tractor trailer. The transportation cost ($C_{TrnsPPFtoM}$) of preprocessed switchgrass from preprocessing facility to market was given by equation (28):

$$C_{TrnsPPFtoM} = \sum_{icjz} \theta 3_{jz} \times XTM_{icjz} \quad (28)$$

where $\theta 3_{jz}$ represents the transportation cost per ton from preprocessing facility to market and XTM_{icjz} represents the preprocessed switchgrass delivered to market from the preprocessing facility.

4.3.2 Constraints

Equation (29) showed that the switchgrass delivered to preprocessing facilities (XP_{icj}) equaled the amount of switchgrass harvested minus the amount of switchgrass delivered to the

market directly without preprocessing (chopped) after adjusting dry matter loss during transportation (DML_{trans}).

$$\sum_j XP_{icj} = XH_{ic} - \frac{XTM_{icz}}{1 - DML_{trans}} \quad (29)$$

Equation (30) put a constraint on maximum feedstock to be preprocessed (XP_{icj}) depending upon the capacity of preprocessing facility (Cap_j), or in other words, put a limit on the number of preprocessing facilities used depending upon the amount of feedstock preprocessed.

$$Cap_j \times PF_j \geq \sum_{ic} XP_{icj} \quad (30)$$

Equation (31) limited the transportation of preprocessed switchgrass delivered to markets (XTP_{icjz}) to be less than or equal to the amount preprocessed at preprocessing facilities (XP_{icj}). The demand ($DMkt_z$) and supply of switchgrass was balanced by the equation (32).

$$XP_{icj} \geq \sum_z XTP_{icjz} \quad (31)$$

$$XTM_{icz} + \sum_j^7 XTP_{icjz} = DMkt_z \quad (32)$$

4.4 C_SR scenario

In this scenario, the hub acted as a satellite storage facility. Genera Energy was assumed to be a storage facility between farm and market. Switchgrass was assumed to be harvested in the form of chopped material. One-third of the chopped feedstock was delivered to market during harvesting season and two-thirds was delivered to Genera Energy during the off-harvest season using a tandem-axle truck. The capacity of the truck was assumed to be 3.37 tons/ load. The switchgrass at Genera Energy was stored using a stacker-reclaimer. The stored switchgrass was

transported to market from Genera Energy using a semi-tractor trailer. The capacity of the semi-tractor trailer was assumed to be 25 tons per load. The speed of a semi- tractor trailer used in this study was 50 miles/hour (Brechtbill and Tyner 2008). The data for a stacker-reclaimer was received from the vice-president of Genera Energy Inc. (Jackson 2014).

In this scenario, it was assumed that 371,173 tons of switchgrass were handled by a stacker-reclaimer at the Genera Energy site. The whole system constituted a receiving station, conveyance, a dust collection system, and a stacking and reclaiming unit. The assumptions followed in the calculation of machinery costs and total cost of handling switchgrass with a stacker-reclaimer are shown in Tables 15 to 18.

A stacker-reclaimer is mainly used in the coal industry to handle coal in bulk or in the wood industry to handle wood chips. An attempt was made in this study to estimate the cost of handling of chopped switchgrass using this equipment. The throughput of each receiving station was assumed to be 50 tons per hour. The operating schedule of a stacker-reclaimer was planned based on the harvesting schedule. Referring to Larson et al (2010), the switchgrass was harvested 70 percent of the days per month (53 harvest days); on days having precipitation less than 0.01 inch. By assuming 53 harvest days, eight harvest hours per day, and total 371,173 tons of harvest, 875 dtons per hour were delivered to Genera Energy. The number of receiving station to handle 371,173 tons of chopped switchgrass was estimated to be 18 (with throughput of 50dtons/hour).

The throughput of the conveyance system was assumed to be 234 dtons per hour, and four conveyance systems were estimated as necessary to handle the 371,173 tons. The same operating schedule was followed as in the case of the receiving stations. The dust collection system was installed to prevent fugitive dust generated from unloading, conveying etc.

Pneumatic conveyors were used for conveying. The throughput of the stacker-reclaimer system was assumed to be same as that of the conveyance system, i.e., 234 dtons per hour, and four stacker-reclaimer systems were used. The stacker was used to build the stack of chopped switchgrass, and the reclaimer was used to reclaim the feedstock from the pile. Switchgrass was assumed to be stacked in the form of a pile on a gravel pad and covered using a membrane.

4.4.1 Revenue and cost components

The revenue estimation for the local markets was discussed previously. The total logistics cost for this scenario consisted of the opportunity costs from land conversion, switchgrass production, harvest, storage, and transportation from field to market, from field to Genera Energy, and from Genera Energy to markets (equation (33)).

$$TC_3 = C_{opp} + C_{Prod} + C_{Harv} + C_{TrnsFtoG} + C_{Stor} + C_{TrnsGtoM} \quad (33)$$

Transportation cost is comprised of machinery, labor, and energy used. The transportation costs from farm to market ($C_{TrnsFtoM}$) and from farm to Genera Energy ($C_{TrnsFtoG}$) were given by equation (34) and (35), respectively.

$$C_{TrnsFtoM} = \sum_z \theta_{1iz} \times \frac{(\sum_c XTO_{icz})}{1 - DML_{trans}} \quad (34)$$

$$C_{TrnsFtoG} = \sum_j \theta_{2ij} \times \frac{(\sum_c XTG_{icj})}{1 - DML_{trans}} \quad (35)$$

where XTO_{icz} represents the tons of switchgrass transported from farm to market and XTG_{icj} represents tons of switchgrass delivered to Genera Energy. The transportation cost per ton from farm to market and from farm to Genera Energy was represented by θ_{1iz} and θ_{2ij} , respectively.

The storage cost (C_{stor}) constituted the labor, operating costs, and ownership costs of a stacker-reclaimer used for handling and storing chopped switchgrass (equation (36)).

$$C_{stor} = \gamma_j * \sum_{ij} XSG_{icj} \quad (36)$$

where γ_j , represents the storage cost per ton and XSG_{icj} represents the tons of switchgrass stored.

The transportation cost ($C_{TrnsGoM}$) of switchgrass from Genera Energy to market during the off-harvest season was given by equation (37):

$$C_{TrnsGoM} = \sum_{icjz} \theta 3_{jz} \times XTM_{icjz} \quad (37)$$

where XTM_{icjz} represents tons of switchgrass transported and transportation cost per ton are represented by $\theta 3_{jz}$.

4.4.2 Constraints

Equation (38) showed that the switchgrass sent to Genera Energy (XG_{icj}) equaled the amount of switchgrass harvested (XH_{ic}) deducting the amount of switchgrass delivered to market (XTM_{icz}) directly during harvest season after adjusting dry matter loss during transportation (DML_{trans}).

$$XG_{icj} = XH_{ic} - \frac{XTM_{icz}}{1 - DML_{trans}} \quad (38)$$

Equation (39) ensured the transportation of switchgrass delivered to markets (XTM_{icjz}) during the off-harvest season was less than or equal to the amount stored at Genera Energy (XSG_{icj}). The demand ($DMkt_z$) and supply of switchgrass was balanced by the equation (40).

$$XSG_{icj} \geq \sum_z XTM_{icjz} \quad (39)$$

$$XTM_{icz} + \sum_j XTO_{icjz} = DMkt_z \quad (40)$$

4.5 B_P scenario

In this case, it was assumed that switchgrass was harvested as square bales. One third of the harvested switchgrass was delivered to Genera Energy during harvest season. Two-thirds of the switchgrass was stored at the farm site before delivery to market during the off-harvest season. The harvested switchgrass was preprocessed into pellets at Genera Energy before delivery to market.

Pellets were considered to be more suitable for long distance transportation as international markets were considered to be the potential market under this scenario. Switchgrass pellets were assumed to be utility grade pellets, which can be used for industrial purposes. The Netherlands and Belgium, the largest markets for industrial use of wood pellets were considered to be the potential markets. The total US export of wood pellets to these countries amounted to 500,000 tons per year (Sikkema et al 2012). It was assumed that Genera Energy would capture 20% of the total exports amounting to 100,000 tons of switchgrass pellets per year.

Transportation of the switchgrass from farm to Genera energy was by a semi-tractor trailer as the distance was less than 50 miles. The mode of transportation from Genera Energy to the domestic port was rail. The distance of domestic port from Genera Energy was more than 300 miles, making rail transport the more suitable mode of transportation. Transportation from the domestic port to international port was done via sea as it is cheapest mode of transportation for long distances.

4.5.1 Revenue and cost components

The switchgrass pellets were delivered to the international port of Rotterdam. The CIF price (cost, insurance, and freight price) of the wood pellets in Rotterdam was assumed to be the price for switchgrass pellets for the international market. The price was assumed to be \$175/ ton, calculated by taking the average of monthly price of wood pellets from March 2011 to Nov 2011 (Qian and McDow 2013). It was assumed that 100,000 tons of switchgrass pellets were transported to international markets annually. The revenue was estimated similarly for the all the scenarios dealing with international markets. The total logistics cost (TC_4) for this scenario consisted of opportunity costs from land conversion, switchgrass production, harvest, preprocessing, and transportation from field to Genera Energy and from Genera Energy to market (equation (41)).

$$TC_4 = C_{Opp} + C_{Prod} + C_{Harv} + C_{Stor} + C_{TrnsFtoG} + C_{Prepro} + C_{TrnsGtoM} \quad (41)$$

The opportunity cost (C_{Opp}), production cost (C_{Prod}), harvest cost (C_{Harv}), storage cost (C_{Stor}), and transportation cost from farm to Genera Energy ($C_{TrnsFtoG}$) were calculated similarly as in the Baseline scenario. To calculate the preprocessing costs, costs parameters were used from the study done by Grbovic (2010) (Table 19-20). The preprocessing cost (C_{Prepro}) was given by equation (42) :

$$C_{Prepro} = \beta * \sum_{icb} (XP_{icb}) \quad (42)$$

where XP_{icb} is the amount of switchgrass preprocessed and β is the pelletizing cost per ton.

Pelletized switchgrass was transported by rail to the domestic port i.e., Savannah in this case, and from the port it was shipped to an international port which was assumed to be Rotterdam. The shipping of pellets was assumed to be done four times a year (or 25,000 tons

per shipment). Storage was maintained to regulate the shipments of pellets. The freight rate for pellet transportation by rail to domestic port was based on the contract with the rail company and the consumer. In Europe, transportation within the country was mainly done through road. Depending upon the distance and truck load, the global road transport prices for wood pellets in 2009 ranged from \$17 per ton to \$25 per ton (exchange ratio from 12/31/2009 of euro: \$1.42 was used) (Sikema et al 2011). There was no data available for the pellet transportation cost by rail in US. To calculate the rail cost from Genera Energy to Savannah, the formula used by Dornburg (2008) was used ((equations (43) and (44)) :

$$TC_{pellets} = \sum d_k * stc_k \quad (43)$$

$$stc_k = ec_k + mc_k + lc_k \quad (44)$$

where, $TC_{pellets}$ is the transportation cost of pellets (\$/ton); k is the transportation mode, d_k the distance by transportation mode (km), stc_k the specific transport cost by mode, ec_k the specific energy cost of transport mode (\$/Mg/km), mc_k the management cost of the transport mode (\$/Mg/km), and lc_k the specific loading/unloading cost of the transport mode (\$/Mg). The study presented the values in Euro, and those were converted to dollars based on the exchange rate. As the Panama City port was the only port listing tariffs for wood pellets, tariff rates from Panama City port were used to calculate the ocean freight for the transportation of switchgrass pellets (Panama City Port Authorities). The transportation cost from Genera Energy to market ($C_{TrnsGtoM}$) was given by equation (45)

$$C_{TrnsGtoM} = \sum_{icbs} TC_{pellets} \times XTP_{icbs} \quad (45)$$

where XTP_{icbs} represents amount of switchgrass pellets transported to international market.

4.5.2 Constraints

Equation (46) assured that the amount kept for storage (XS_{icbs}) was equal to the amount left after delivery to Genera Energy (XH_{ic}) during the harvest season.

$$\sum_t XS_{icbs} = XH_{ic} - \frac{XTM_{icb}}{1 - DML_{trans}} \quad (46)$$

The switchgrass delivered to Genera Energy during the off-harvest season (XTO_{icbs}) should be less than or equal to switchgrass stored (XS_{icbs}) at the farm site (equation (47)). Equation (48) constrained the switchgrass preprocessed into pellets at Genera Energy (XTP_{icbs}) by the total amount delivered during harvest the season as well as during the off-harvest season. Equation (49) balanced the switchgrass demand ($DMkt_z$) and supply.

$$XS_{icbs} \geq \frac{XTO_{icbs}}{1 - DML_{trans}} \quad (47)$$

$$XTM_{icb} + \sum_t XTO_{icbs} \geq \sum_t XTP_{icbs} \quad (48)$$

$$XTP_{icbs} = DMkt_z \quad (49)$$

4.6 C_SWB_ P scenario

In this scenario, it was assumed that switchgrass was harvested as chopped material and thus there was no storage at the farm site. One-third of the harvested switchgrass (36,232 tons) was delivered to Genera Energy for preprocessing (pelletization) during the harvest season. Two-thirds (72,464) was sent to preprocessing facilities for preprocessing as stretch-wrap bale and storage before being delivery to Genera Energy for pelletization. After adjusting for dry matter loss during transportation, 35,507 tons of switchgrass were preprocessed to pellets directly from

chopped feedstock and 71,015 tons of switchgrass was first preprocessed to stretch-wrap bales before conversion into pellets which were then delivered to international markets. The market assumption was same as in B_P scenario.

4.6.1 Revenue and cost components

The revenue estimation was discussed earlier. The total logistics cost for this scenario consisted of opportunity, production, harvest, preprocessing, and transportation from field to preprocessing facility, from preprocessing facility to Genera Energy, from field to Genera Energy and from Genera Energy to international markets (equation (50)).

$$TC_5 = C_{opp} + C_{Prod} + C_{Harv} + C_{TrnsFtoG} + C_{TrnsFtoPPF} + C_{Prepro} + C_{TrnsPPFtoG} \quad (50)$$

The opportunity, production, harvest, and transportation from field to preprocessing facility, from preprocessing facility to Genera Energy, and from field to Genera Energy were calculated similarly as in C_SWB scenario. The preprocessing cost constituted the costs of preprocessing of chopped material to pellets, chopped material to stretch-wrap bales and stretch-wrap bales to pellets as discussed in previous scenarios. The transportation costs of pellets from Genera Energy to market are similar to the B_P scenario, as the quantity delivered and the markets in both scenarios were assumed to be same.

4.6.2 Constraints

Equation (51) showed that the amount of switchgrass preprocessed using stretch-wrap bale technology (XB_{icj}) equaled the amount of switchgrass harvested (XH_{ic}), deducting the amount of switchgrass delivered directly to the Genera Energy (XP_{ic}) (as chopped switchgrass) during the harvest season. Also, the chopped switchgrass converted to stretch-wrap bales was constrained by the capacity of each preprocessing facility (Cap_j) (equation (52)).

$$\sum_j XB_{icj} = XH_{ic} - XP_{ic} \quad (51)$$

$$\sum_j XB_{icj} \leq Cap_j \quad (52)$$

Equation (53) limited the tons of switchgrass pellets ($XP_{G_{icj}}$) produced at Genera Energy to be less than the total amount transported to Genera Energy. Equation (54) balanced demand and supply of switchgrass pellets.

$$XP_{G_{icj}} \leq XB_{icj} + XP_{ic} \quad (53)$$

$$XP_{G_{icj}} = DMkt \quad (54)$$

4.7 C_SR_P scenario

In this scenario, it was assumed that switchgrass was harvested as chopped material. One-third of the switchgrass was preprocessed immediately to pellets at Genera Energy during the harvest season and two-thirds of the switchgrass was stored at Genera Energy during the off-harvest season using a stacker-reclaimer. The entire amount of switchgrass was delivered to Genera Energy and was preprocessed to pellets before deliver to international markets.

4.7.1 Revenue and cost components

The assumptions for the price and quantity were same as in the previous scenario. The total logistics cost for this scenario consisted of opportunity, production, harvest, storage, preprocessing, and transportation from field to Genera Energy and from Genera Energy to international markets (equation (55)).

$$TC_6 = C_{opp} + C_{Prod} + C_{Harv} + C_{TrnsFtoG} + C_{Stor} + C_{Prepro} + C_{GtoM} \quad (55)$$

The opportunity, production, harvest, storage, and transportation costs from farm to Genera Energy were calculated similarly as in C_SR scenario. The transportation costs of pellets from Genera Energy to market were similar to the C_SWB_P scenario as the quantity delivered and the markets in both scenarios were assumed to be same.

4.7.2 Constraints

Equation (56) showed that the switchgrass stored during the off-harvest season (XS_{ic}) equaled the amount of switchgrass harvested (XH_{ic}), deducting the amount of switchgrass preprocessed (XP_{ic}) at Genera Energy during the harvest season. Equation (57) balances switchgrass pellet demand ($DMkt$) and supply ($XP_{G_{ic}}$).

$$XS_{ic} = XH_{ic} - XP_{ic} \quad (56)$$

$$XP_{G_{ic}} = DMkt \quad (57)$$

4.8 C_SWB_SLO_P scenario

In this scenario, it was assumed that one-third of switchgrass was preprocessed directly during the harvest season and the remaining two-thirds of the switchgrass was handled by silos and preprocessing facilities during the off-harvest season. 57,000 tons were delivered to the preprocessing facility for preprocessing and storage in the form of stretch-wrap bales during off-harvest season. The remaining tonnage was stored in silos during the off-harvest season. The tonnage stored in silos was estimated to be 15,464 tons. As each silo can store only 1,500 tons of chopped switchgrass, the estimated need was for 11 silos. The total of storage costs of switchgrass in silos are shown in Tables 21 and 22. The total costs consisted of total ownership costs and total operating costs. The estimated data for silos was received from Dr. Jackson, vice-president of Genera Energy (personal communication).

4.8.1 Revenue and cost components

The price and quantity assumptions were similar as with the previous scenario. The total logistic cost for this scenario consisted of opportunity, production, harvest, storage, preprocessing, and transportation from farm to Genera Energy, from farm to preprocessing facility, from preprocessing facility to Genera Energy and from Genera Energy to international markets (equation (58)). The costs were calculated similarly as in the previous scenarios.

$$TC_7 = C_{opp} + C_{Prod} + C_{Harv} + C_{TrnsFtoG} + C_{TrnsFtoPPF} + C_{TrnsPPFtoG} + C_{Stor} + C_{Prepro1} + C_{Prepro2} + C_{GtoM} \quad (58)$$

4.8.2 Constraints

The constraints in the flow of switchgrass were similar as in the previous scenarios for the production and harvest. Equation (59) showed that the switchgrass stored (XSG_{ic}) during the off-harvest season equaled the amount of switchgrass harvested (XH_{ic}), deducting the amount of switchgrass preprocessed at Genera Energy (XGP_{ic}) (via pelletization) during the harvest season and preprocessed at preprocessing facility (XPP_{icj}) (to stretch-wrap bale) during the off-harvest season. Equation (60) balanced switchgrass demand and switchgrass supply.

$$XSG_{ic} = XH_{ic} - XGP_{ic} - XPP_{icj} \quad (59)$$

$$\sum_{icj} XPP_{icj} + \sum_{ic} XSG_{ic} + \sum_{ic} XGP_{ic} \geq DMkt \quad (60)$$

4.9 Sensitivity analysis

The sensitivity analysis was to evaluate the effects of the variation of some parameters on the total profit earned in the different scenarios. In the present study an interest rate of 10% was

used. Although the real interest rate in US is about 4%, the high interest rate was assumed based on the assumption that with no existing market for the switchgrass the investment would have high risk associations. To estimate the sensitivity of the profit to this interest rate, 6% and 3% interest rates were also used.

Machinery costs are also affected by the fuel price fluctuations. Thus, changes in diesel prices would impact the logistics cost of switchgrass. To estimate the sensitivity of costs to diesel price fluctuation, diesel price was changed to $\pm 10\%$ from the benchmark value. The impact of fuel price on crop price has increased considerably since 2006 (Tyner 2010). The correlation between fuel price and crops was estimated for the 2007-2013 period (Table 23). For example, when the diesel fuel price increased by 10%, the corn price increased by 7.8% ($=10\% \times 0.78$). The impact of a change in fuel price and crop prices on total profit was also analyzed.

CHAPTER V RESULTS AND DISCUSSION

5.1 Output of Baseline scenario

Table 24 summarizes the revenue and logistics costs of supplying baled switchgrass to local markets in the baseline. Total market demand was 556,759 tons. To meet the demand, 568,121 tons of switchgrass was harvested, primarily converted from hay and pasture land. The estimated logistic cost per year of square baled switchgrass was less as compared to round bale system.

The opportunity cost from land conversion was \$1,410,875 for round bales and \$1,537,492 for square bales. Total land converted for switchgrass production was less in case of round bales as compared to square bales. The total production cost of square bales was \$8,309,709 which was higher than the round bales production cost of \$7,437,517. The production cost for square bales was higher because high dry matter loss in case of square bales required more production to meet the demand (Larson et al 2010). The estimated harvest cost (\$17,913,132) of the square bale was lower than that of the round bale (\$18,083,434) because the throughput of the square baler was more than the capacity of round baler. The results were similar with the previous study (Larson et al. 2010) which indicated that the large square bale has a larger bale capacity and size compared to the large round bale, so it allows for efficient harvest and transportation of switchgrass. Harvest cost constituted 42% of the total logistics cost.

The storage cost estimated was higher for square bales (\$2,306,573) as compared to round bales (\$1,681,639). The difference in cost was because square bales were stored using pallet and tarp while round bales were stored using tarp only. In the transportation cost section, the square bale had a lower total transportation cost (\$11,954,087) compared to the round bale

(\$13,610,227) as a result of larger bale capacity and the shorter loading and unloading times of the square bales over the round bales.

The feedstock draw area for each market was illustrated in Figure 4. The feedstock draw area was shown in different color for each local market. Resolute Fibers Inc. had the largest feedstock draw area because of the highest demand as compared to other plants. The total revenue generated was equal to \$33,405,540. For both round and square bales, the total delivered cost was higher than the received revenue, resulting in a net loss in both the cases and negative NPV.

5.2 Output of C_SWB scenario

Table 25 summarizes the logistics costs of supplying switchgrass to energy markets and revenue generated from selling the switchgrass for C_SWB scenario. The feedstock draw area for each market during harvesting season was illustrated in Figure 5. The opportunity cost was estimated to be \$1,451,249. Total 568,121 tons of switchgrass was harvested annually with an estimated harvest cost of \$8,381,269 per year.

To preprocess 371,173 tons of chopped switchgrass, seven preprocessing facilities would be needed. The optimal locations of seven preprocessing facilities and associated supply region are shown in Figure 6. Additionally, the seven preprocessing facilities were located in five different counties. Resolute Fibers was served by the preprocessing facilities located in Rhea and McMinn counties, DDCE was served by the preprocessing facility located in Monroe, and the preprocessing facilities located in Blount and Loudon served Maryville College and Oak Ridge respectively. The preprocessing and storage cost was estimated at \$4,940,577 per year. The transportation cost was estimated to be \$11,081,341 per year, which consisted of the transportation costs from the fields to the markets using tandem-axle trucks (\$2,504,569 per

year), from the fields to seven separate preprocessing facilities using tandem-axle trucks (\$2,977,551 per year), and from each preprocessing facility to the market using semi-tractor trailers (\$5,599,221 per year).

The total delivered cost of switchgrass to market in this scenario was \$33,147,144. The total logistic cost was 22% lower than the Baseline scenario. Although this scenario was capital intensive as compared to Baseline but savings in harvest and transportation costs outweighed the capital investment and the operation cost. The estimated revenue in this scenario was \$33,405,540. A profit of \$258,396 was earned and the NPV over 10 years was \$1,587,732. This scenario was profitable mainly because of the low harvest cost using chopping and preprocessing of switchgrass.

5.3 Output of C_SR scenario

Table 26 summarizes the total logistics costs for C_SR scenario. In this scenario, stacker-reclaimer was used to handle the chopped switchgrass during off-harvest season. The feedstock draw area for this scenario is shown in Figures 7 and 8. Figure 7 shows the feedstock draw area from farm to different markets during harvest season. Figure 8 shows the feedstock draw area during off-harvest season for Genera Energy where a stacker-reclaimer was located. The crop zones covered were mainly under hay production.

The opportunity cost in this scenario was estimated to be \$1,469,269 and the production cost was \$7,308,375. The storage cost of 371,173 tons of chopped switchgrass at Genera Energy using stacker-reclaimer was estimated to be \$9,498,309. The transportation cost from farms to Genera Energy and from Genera Energy to four markets was estimated to be \$6,866,620 and \$6,364,259, respectively. The transportation cost from farm to market was \$2,476,796. The total logistics costs were high in this scenario when compared to the Baseline. High storage costs

using stacker-reclaimer and high transportation cost of delivering chopped feedstock from one point to other resulted in increased logistics costs as compared to Baseline. There was net loss of \$8,959,357 in this scenario. The estimated NPV was negative in this case.

5.4 Output of B_P scenario

Table 27 summarizes the logistics costs of supplying switchgrass to international energy markets and revenue from selling the switchgrass for this scenario. The analysis was done for total market demand of 100,000 tons of switchgrass pellets. Total opportunity cost was estimated to be \$297,745. To produce 100,000 tons of pellets 108,696 tons of switchgrass was harvested. Total harvest cost for this scenario was \$3,434,188. Feedstock draw-area is shown in Figure 9 for this scenario. The storage cost amounted to \$432,480 for storing 71,015 tons of switchgrass during off-harvest season. The preprocessing cost was estimated to be \$8,145,000 and it included the storage cost of pellets (in silo). Total transportation cost was estimated to be \$6,546,757 and it included the transportation cost from farm to Genera Energy by truck (\$1,613,757), from Genera Energy to domestic port (Savannah in this case) by rail (\$2,310,000), and from Savannah to Rotterdam by ocean (\$2,623,000).

The revenue for this scenario was estimated to be \$17,500,000. The total logistics costs were high as compared to the revenue generated. Harvest form was similar with the baseline scenario but there was additional cost of pelletization and transportation cost to international markets. There was overall loss of \$2,952,356 in this scenario. Increased number of operations in the supply chain led to high logistics costs in this scenario. International transport also added up to the total costs. The net present value was less than zero in this scenario.

5.5 Output of C_SWB_P scenario

Table 28 summarizes the logistics costs for C_SWB_P scenario. Figure 10 shows the switchgrass supply to Genera Energy during harvest season. The opportunity cost was estimated to be \$282,369 and production cost was \$1,424,084. The switchgrass was harvested as chopped material. 108,696 tons of switchgrass was harvested with the cost of \$1,636,274 to meet the demand of international markets. The preprocessing cost of chop to stretch-wrap bale was estimated to be \$983,266 and it included the facility cost of two preprocessing facilities. It was estimated that two preprocessing facilities were required to preprocess two-third (71,015 tons) of the total chopped feedstock. The location of preprocessing facilities and the feedstock draw area is shown in Figure 11. The preprocessing facilities were located in Monroe County. The preprocessing cost of pelletizing was estimated to be \$8,112,000. The preprocessing cost was less in this scenario as compared to previous scenario because no additional grinding was needed in case of chopped material.

Transportation costs from the fields to the Genera Energy using tandem-axle trucks was \$259,786 and from the fields to two preprocessing facilities using tandem-axle trucks was \$479,390. As shown in Figure 10 and Figure 11, the feedstock draw area for both Genera Energy and preprocessing facilities was not too far from their respective locations and the quantity delivered was less so the transportation cost was not too high. The transportation cost from each preprocessing facility to the Genera Energy using semi-tractor trailers was \$633,334; from Genera Energy to Savannah; and from Savannah to Rotterdam it was estimated to be \$2,310,000 and \$2,623,000 respectively. There was a loss of \$1,243,503 in this scenario. The loss in this scenario was less compared to the B_P scenario in spite of additional preprocessing in this scenario because of less harvest cost in case of chopped feedstock as compared to baled one and

low transportation cost in case of stretch-wrap bales delivered to Genera Energy. NPV was less than zero in this scenario.

5.6 Output of C_SR_P scenario

There was storage of switchgrass during off harvest-season at Genera Energy using stacker-reclaimer in this scenario. The total logistic cost for this scenario is presented in Table 29. The feedstock draw area for this scenario is shown in Figure 12. The opportunity cost was \$298,160 and the production cost amounted to \$1,429,665. The harvest cost was estimated to be \$1,636,274 and the storage cost was \$2,142,514. The total pelletizing cost was estimated to be \$8,112,000. The total transportation cost constituted of transportation from farm to Genera Energy (\$1,122,108) and from Genera Energy to Savannah (\$2,310,000), and from Savannah to Rotterdam (\$2,623,000). Revenue in this scenario was \$17,500,000. There was a loss of \$2,173,721 in this scenario and the net present value was negative.

5.7 Output of C_SWB_SLO_P scenario

The total logistic cost for this scenario is shown in Table 30. Figure 13 shows the feedstock draw area which was to be delivered to Genera Energy and Figure 14 shows feedstock draw area for preprocessing facility. The opportunity cost amounted to \$302,879 and the production cost was estimated to be \$1,425,406. The storage cost of silo was estimated to be \$4,026,609 for storing 15,464 tons of switchgrass.

The preprocessing cost of converting chopped feedstock into stretch-wrap bale was estimated to be \$740,460. The total transportation cost was estimated to be \$6,158,132 which comprised of transportation cost from farm to preprocessing facility (\$378,682), preprocessing facility to Genera Energy (\$579,890), farm to Genera Energy (\$266,560) and from Genera

Energy to Savannah (\$2,310,000), and from Savannah to Rotterdam (\$2,623,000). There was a loss of \$4,901,761 in this scenario. The NPV was less than zero.

5.8 Comparison of different scenarios and breakeven market price

Figure 15 shows the NPV and profit earned in each scenario. The figure shows that for the local market, C_SWB was the only scenario which showed the potential of penetrating energy market with positive NPV. The baseline and C_SR scenario required considerable improvements in the logistics systems to make profits for Genera Energy. For the EU market, all the scenarios showed negative NPV. The C_SWB_P scenario showed higher potential of penetrating the market profitably, while C_SWB_SLO_P scenario had the least likelihood to reach the EU market. Figure 16 shows the breakeven market price for each scenario. In the scenarios dealing with local markets: only C_SWB scenario showed lower breakeven market price than the price assumed for switchgrass in the local market (\$60 per ton) but for Baseline scenario and C_SR scenario breakeven market prices were \$75 and \$76 respectively. In case of international markets, breakeven market price ranged from \$187 per ton to \$224 per ton. The price range was higher than assumed for the international markets i.e. \$175 per ton. Thus all the four logistics configurations for international markets showed negative NPV.

5.9 Sensitivity analysis

The sensitivity analysis showed that there was significant reduction in overall total logistic costs when the interest rate was reduced from 10% to 6% and 3%. Table 31 and Figure 17 summarize the total logistic cost, profit and NPV for each scenario at 6% interest rate. For Baseline scenario there was 8% reduction in total costs with harvest and production costs showing the maximum reduction in costs. The scenario still showed net loss with NPV less than

zero at 6% interest rate. C_SWB scenario also showed significant cost reduction and the profit increased from \$258,396 to \$2,820,069 and NPV increased from \$1,587,732 to \$20,755,953. For C_SR scenario storage cost observed maximum reduction followed by harvest cost and production cost. The storage cost reduced from \$9,498,309 to \$8,295,709. Net loss was observed for this scenario at 6% interest rate. In case of international markets; C_SWB_P scenario nearly breakeven at 6% interest rate and other scenarios showed net loss.

Table 32 and figure 18 summarize the total logistic cost, profit, and NPV for each scenario at 3% interest rate. Profit for C_SWB scenario increased further and C_SWB_P and C_SR_P scenarios also showed profit of \$671,958 and \$423,651 with positive NPV of \$5,731,938 and \$3,613,829 respectively. For C_SWB_P scenario there was 10% reduction in total cost when interest rate was reduced from 10% to 3%. In case of C_SR_P scenario there was 13% reduction in total costs when interest rate was reduced to 3% from benchmark value. Storage costs reduced significantly in case of C_SR_P scenario with reduction in interest rate. Figure 18 shows the increase in NPV in each scenario with decrease in interest rate to 6% and 3% from benchmark value. Figure 19 presents comparison of NPVs at different interest rates. With decrease in interest rates NPV increased for each scenario. For the scenarios serving local markets, NPV improved with decrease in interest rate as costs of machinery used in every operation decreased significantly. For the scenarios dealing with international markets, the changes in NPV with interest rate were relatively moderate as compared to the scenarios serving local markets. The less impact of interest rate on NPV of profit observed in the scenarios for international markets was due to the minimal changes in international transportation cost that is, one of the major cost components in international logistics.

There was around three percent change in total costs among all scenarios with $\pm 10\%$ change in fuel price from benchmark value. Table 33 and Figure 20 summarize the total logistics costs, profit, and NPV with 10% decrease in fuel price from benchmark value. When the fuel price was decreased 10%, the logistics costs were reduced for each scenario. Although the logistics costs for each scenario decreased but still only C_SWB scenario showed positive NPV. The C_SWB_P scenario showed little potential of penetrating the market with decrease in fuel price. Table 34 and Figure 21 summarize the output of sensitivity analysis at 10% fuel price increase from benchmark value. Logistics costs increased around 3% in each scenario with increase in fuel price. With increase in fuel price none of the scenario was profitable. All the scenarios showed negative NPV. As shown in Figure 22, NPV increased with decrease in fuel price and vice-versa. When compared with the NPV at benchmark value, the change in NPV with change in fuel price was not so significant among all the scenarios.

CHAPTER VI SUMMARY AND CONCLUSION

Energy derived from biomass is a renewable energy source with growing potential because it emits less GHG compared to fossil fuels. Switchgrass, a perennial grass, is considered a promising feedstock for the bioenergy market; however, the logistics challenges of its low bulk density pose a major constraint in developing the switchgrass-based energy market. The objective of this study was to optimize the feedstock logistics pathway managed by a collection/distribution hub for Tennessee produced switchgrass to penetrate energy markets.

A mathematical programming model in integration with the GIS was used to maximize the profit of Genera Energy Inc., a collection hub/depot of switchgrass located in east Tennessee. Seven logistics scenarios were evaluated: the Baseline scenario utilized the conventional baler harvest and storage system to serve the local market 70 miles from Genera Energy. One scenario applied a stretch-wrap bale technology to increase the density of chopped feedstock for local market and another scenario incorporated an outdoor storage system for chopped feedstock to serve the local market. The remaining four scenarios utilized pelletization to increase feedstock density along with various harvest and storage methods to reach the EU market.

The results showed that only one out of the seven evaluated logistics configurations was found to be profitable for the collection hub/depot under the given assumptions, which confirms the challenging issues of feedstock logistics for the biomass energy industry. The finding is consistent with Larson et al (2010) that concluded that utilizing the stretch-wrap bale technology in the satellite sites is more cost effective when compared to conventional baler methods in the southeastern US. Increasing feedstock density provides the benefits of feedstock handling and storage efficiency but could be capital intensive. The high capital and operating costs of pelletization dominated the efficiency gains from storage and transportation of the densified

feedstock in the present study. An outdoor bulk storage system, such as stacker-reclaimer, handled the loose feedstock efficiently but the high initial investment increased the total costs. In the case of local market, the estimated breakeven market price for the baseline and the bulk outdoor storage system was around 26% higher than the assumed price. For the EU market, the gap between breakeven price and assumed market price ranged from 7% to 28%. The sensitivity analysis based on different interest rates showed that lowering the investment risk in the emerging biomass energy sector can help the collection/distribution hub penetrate switchgrass-based energy market. Government incentives or policies could boost the confidence of investors in this industry and expedite the development of the bioenergy industry.

Although most of scenarios were not profitable in the analysis, several factors may change the conclusions and can be studied further. First, the potential market prices for switchgrass in local and international market could be higher than what were assumed in the study. The local switchgrass price of \$60 per ton was based on certain assumptions of productivity for biomass feedstock in the Billion Ton study (US DOE 2011). US DOE is not an active participant in markets so the price assumption could differ from the real market. In addition, switchgrass pellets price was based on the price of wood pellets and the price of wood pellets in international markets fluctuates depending upon the season and demand. Also, the present study assumed Netherland and Belgium to be the major potential international markets. Other potential international markets that prompt grass-based feedstock for energy, such as UK, can also be explored if the price data is available.

Second, feedstock quality was not considered in the present study. The quality of baled and chopped switchgrass was assumed to be indifferent. The potential variations in the market prices for different feedstock forms (e.g. bale vs. chop) were also assumed to be negligible. In

addition, the quality of switchgrass pellets was assumed to be comparable to the quality of industrial wood pellets. The impact of quality of switchgrass delivered to markets on the total profit earned requires further study.

Finally, the impact of change in throughput of different machineries on the total profits by logistics configurations in the study was not analyzed. Variations in throughput of the machineries can affect the total costs and potentially the results of the total profit. Exploring different options of harvest, storage, preprocessing, and transportation to penetrate energy markets profitably is also necessary.

REFERENCES

AEBIOM. Annual report AEBIOM: European Biomass Association; 2010

Alfonso, D., C. Perpiñá, A. Pérez-Navarro, E. Peñalvo, C. Vargas, and R. Cárdenas. 2009.

"Methodology for optimization of distributed biomass resources evaluation, management and final energy use." *Biomass and Bioenergy* 33(8):1070-1079.

Allen, J., M. Browne, A. Hunter, J. Boyd, and H. Palmer. 1998. "Logistics management and costs of biomass fuel supply." *International Journal of Physical Distribution & Logistics Management* 28(6):463-477.

Amos, W. 2002. "Summary of Chariton Valley Switchgrass Co-Fire Testing at the Ottumwa Generating Station in Chillicothe, Iowa: Milestone Completion Report." National Renewable Energy Lab., Golden, CO.(US).

An, H., W.E. Wilhelm, and S.W. Searcy. 2011. "A mathematical model to design a lignocellulosic biofuel supply chain system with a case study based on a region in Central Texas." *Bioresource Technology* 102:7860-7870.

Aravindhakshan, S.C., F.M. Epplin, and C.M. Taliaferro. 2010. "Economics of switchgrass and miscanthus relative to coal as feedstock for generating electricity." *Biomass and Bioenergy* 34(9):1375-1383.

Bals, B.D., and B.E. Dale. 2012. "Developing a model for assessing biomass processing technologies within a local biomass processing depot." *Bioresource Technology* 106(0):161-169.

Baxter, L. 2005. "Biomass-coal co-combustion: opportunity for affordable renewable energy." *Fuel* 84:1295-1302.

Boylan, D., V. Bush, and D.I. Bransby. 2000. "Switchgrass cofiring: pilot scale and field evaluation." *Biomass and Bioenergy* 19(6):411-417.

- Brechbill, S.C., and W.E. Tyner. 2008. "The Economics of Biomass Collection, Transportation, and Supply to Indiana Cellulosic and Electric Utility Facilities." Dept. of Agricultural Economics, Purdue University
- Carolan, J.E., S.V. Joshi, and B.E. Dale. 2007. "Technical and Financial Feasibility Analysis of Distributed Bioprocessing Using Regional Biomass Pre-Processing Centers." *Journal of Agricultural & Food Industrial Organization* 5(2).
- Conti, J., P. Holtberg, J. Beamon, and A. Schaal. 2011. "Annual energy outlook 2011 with projections to 2035." *US Energy Information Administration*.
- Cundiff, J.S., N. Dias, and H.D. Sherali. 1997. "A linear programming approach for designing a herbaceous biomass delivery system." *Bioresource Technology* 59(1):47-55.
- Cundiff, J.S., and R.D. Grisso. 2008. "Containerized handling to minimize hauling cost of herbaceous biomass." *Biomass and Bioenergy* 32(4):308-313.
- Cundiff, J.S., and L.S. Marsh. 1996. "Harvest and storage costs for bales of switchgrass in the southeastern United States." *Bioresource Technology* 56(1):95-101.
- Dal-Mas, M., S. Giarola, A. Zamboni, and F. Bezzo. 2011. "Strategic design and investment capacity planning of the ethanol supply chain under price uncertainty." *Biomass and Bioenergy* 35:2059-2071.
- De La Torre Ugarte, D.G., and D.E. Ray. 2000. "Biomass and bioenergy applications of the POLYSYS modeling framework." *Biomass and Bioenergy* 18:291-308.
- de Lourdes Bravo, M., M.M. Naim, and A. Potter. 2012. "Key issues of the upstream segment of biofuels supply chain: a qualitative analysis." *Logistics Research* 5:21-31.
- Domac, J., K. Richards, and S. Risovic. 2005. "Socio-economic drivers in implementing bioenergy projects." *Biomass and Bioenergy* 28:97-106.

- Dornburg, V. 2008. "Developments in Bioenergy Production Across the World – Electricity, Heat and Second Generation Biofuels". Organisation for Economic Co-operation and Development. Trade and Agriculture Directorate.
- Duffy, M. 2007. "Estimated costs for production, storage, and transportation of switchgrass." Iowa State University, Department of Economics
- Duffy, M., and V.Y. Nanhon. 2001. *Costs of producing switchgrass for biomass in southern Iowa*: Iowa State University, University Extension.
- Dunnett, A., C. Adjiman, and N. Shah. 2007. "Biomass to heat supply chains: applications of process optimization." *Process Safety and Environmental Protection* 85:419-429.
- Ekşioğlu, S.D., A. Acharya, L.E. Leightley, and S. Arora. 2009. "Analyzing the design and management of biomass-to-biorefinery supply chain." *Computers & Industrial Engineering* 57(4):1342-1352.
- English, B. C., Jensen, K., Menard, J., Walsh, M. E., Brandt, C., Van Dyke, J., & Hadley, S. 2007. "Economic impacts of carbon taxes and biomass feedstock usage in Southeastern United States coal utilities." *Journal of Agricultural and Applied Economics*, 39(1): 103.
- English, B., J. Larson, and D. Mooney. 2008. "Switchgrass harvest and storage costs and bale quality." *25th Milan No-Till Crop Production Field Day Tour Report*:11-12.
- Eranki, P.L., B.D. Bals, and B.E. Dale. 2011. "Advanced Regional Biomass Processing Depots: a key to the logistical challenges of the cellulosic biofuel industry." *Biofuels, Bioproducts and Biorefining* 5(6):621-630.
- Faaij, A.P., and J. Domac. 2006. "Emerging international bio-energy markets and opportunities for socio-economic development." *Energy for Sustainable Development* 10:7-19.

- Fraas, A., & Johansson, R. C. 2009. "Conflicting Goals: Energy Security vs. GHG Reductions under the EISA Cellulosic Ethanol Mandate." *Resources for the Future Discussion Paper*, (09-24).
- Frombo, F., R. Minciardi, M. Robba, and R. Sacile. 2009. "A decision support system for planning biomass-based energy production." *Energy* 34:362-369.
- Fike, J.H., D.J. Parrish, D.D. Wolf, J.A. Balasko, J.T. Green Jr, M. Rasnake, and J.H. Reynolds. 2006. "Long-term yield potential of switchgrass-for-biofuel systems." *Biomass and Bioenergy* 30(3):198-206.
- Freppaz, D., R. Minciardi, M. Robba, M. Rovatti, R. Sacile, and A. Taramasso. 2004. "Optimizing forest biomass exploitation for energy supply at a regional level." *Biomass and Bioenergy* 26:15-25.
- Fuller, W.S. 1985. "Chip pile storage—a review of practices to avoid deterioration and economic losses." *Tappi J* 68:48-52.
- Gao, Y. 2011. "Evaluation of Pre-processing and Storage Options in Biomass Supply Logistics: A Case Study in East Tennessee." Master Thesis. The University of Tennessee.
- Gold, S., and S. Seuring. 2011. "Supply chain and logistics issues of bio-energy production." *Journal of Cleaner Production* 19(1):32-42.
- Gonzalez, R.W., R. Phillips, H. Jameel, R. Abt, A. Pirraglia, D. Saloni, and J. Wright. 2011. "Biomass to energy in the southern United States: supply chain and delivered cost." *BioResources* 6:2954-2976.
- Grbovic, M. 2010. "Export Potential of U.S. - Produced Switchgrass and Wood Pellets for the EU Market.", University of Tennessee - Knoxville.

- Guretzky, J., J. Biermacher, B. Cook, M. Kering, and J. Mosali. 2011. "Switchgrass for forage and bioenergy: harvest and nitrogen rate effects on biomass yields and nutrient composition." *Plant and Soil* 339(1-2):69-81.
- Hamelinck, C.N., G.v. Hooijdonk, and A.P.C. Faaij. 2005. "Ethanol from lignocellulosic biomass: techno-economic performance in short-, middle- and long-term." *Biomass and Bioenergy* 28(4):384-410.
- Haque, M., and F.M. Epplin. 2012. "Cost to produce switchgrass and cost to produce ethanol from switchgrass for several levels of biorefinery investment cost and biomass to ethanol conversion rates." *Biomass and Bioenergy* 46(0):517-530.
- Heinimö, J., and M. Junginger. 2009. "Production and trading of biomass for energy—an overview of the global status." *Biomass and Bioenergy* 33(9):1310-1320.
- Hughes, E.E. 1998. "Utility coal-biomass cofiring tests." Proceedings of the Advanced Coal-Based Power and Environmental Systems Conference
- Hughes, E. 2000. Biomass Cofiring: Economics, Policy and Opportunities. *Biomass and Bioenergy*. 19(6): 457–465.
- International Energy Administration Bioenergy Task 32. 2010. International cofiring database. 27 February 2013. <http://www.ieabcc.nl/database/cofiring.php>.
- Jannasch, R., R. Samson, A.d. Maio, and T. Helwig. 2001. "Switchgrass Fuel Pellet Production In Eastern Ontario: A Market Study." Resource Efficient Agricultural Production (REAP)
- Jensen, K., C.D. Clark, P. Ellis, B. English, J. Menard, M. Walsh, and D. de la Torre Ugarte. 2007. "Farmer willingness to grow switchgrass for energy production." *Biomass and Bioenergy* 31(11–12):773-781.
- Jackson, S. Personal Communication. Vice President for Feedstock Operations at Genera

- Energy, January 2014.
- Kang, S., H. Önal, Y. Ouyang, J. Scheffran, and Ü. Tursun (2010) Optimizing the Biofuels Infrastructure: Transportation Networks and Biorefinery Locations in Illinois, ed. M. Khanna, J. Scheffran, and D. Zilberman, vol. 33, Springer New York, pp. 151-173.
- Keshwani, D.R., and J.J. Cheng. 2009. "Switchgrass for bioethanol and other value-added applications: A review." *Bioresource Technology* 100(4):1515-1523.
- Kumar, A., and S. Sokhansanj. 2007. "Switchgrass (*Panicum virgatum*, L.) delivery to a biorefinery using integrated biomass supply analysis and logistics (IBSAL) model." *Bioresource Technology* 98(5):1033-1044.
- Kumar, A., S. Sokhansanj, and P. Flynn. 2006. "Development of a multicriteria assessment model for ranking biomass feedstock collection and transportation systems." *Applied Biochemistry and Biotechnology* 129(1-3):71-87.
- Larson, J.A., T.-H. Yu, B.C. English, D.F. Mooney, and C. Wang. 2010. "Cost evaluation of alternative switchgrass producing, harvesting, storing, and transporting systems and their logistics in the Southeastern USA." *Agricultural Finance Review* 70(2):184 - 200.
- Larson, J.A. 2013. "Switchgrass Enterprise Budgeting". *University of Tennessee*.
- Lewandowski, I., J.M.O. Scurlock, E. Lindvall, and M. Christou. 2003. "The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe." *Biomass and Bioenergy* 25(4):335-361.
- Ma, Z., C.W. Wood, and D.I. Bransby. 2000. "Impacts of soil management on root characteristics of switchgrass." *Biomass and Bioenergy* 18(2):105-112.
- Mahmudi, H., and P. Flynn. 2006. "Rail vs truck transport of biomass." *Applied Biochemistry and Biotechnology* 129(1-3):88-103.

- Mani, S., S. Sokhansanj, X. Bi, and A. Turhollow. 2006. "Economics of producing fuel pellets from biomass." *Applied Engineering in Agriculture*:421-426.
- McCormick, K., and T. Kåberger. 2007. "Key barriers for bioenergy in Europe: Economic conditions, know-how and institutional capacity, and supply chain co-ordination." *Biomass and Bioenergy* 31(7):443-452.
- McLaughlin, S.B., D.G. de la Torre Ugarte, C.T. Garten, L.R. Lynd, M.A. Sanderson, V.R. Tolbert, and D.D. Wolf. 2002. "High-Value Renewable Energy from Prairie Grasses." *Environmental Science & Technology* 36:2122-2129.
- McKendry, P. 2002. "Energy production from biomass (part 2): conversion technologies." *Bioresource Technology* 83(1):47-54.
- Miao, Z., Y. Shastri, T.E. Grift, A.C. Hansen, and K.C. Ting. 2012. "Lignocellulosic biomass feedstock transportation alternatives, logistics, equipment configurations, and modeling." *Biofuels, Bioproducts and Biorefining* 6:351-362.
- Mitchell, R., K.P. Vogel, and G. Sarath. 2008. "Managing and enhancing switchgrass as a bioenergy feedstock." *Biofuels, Bioproducts and Biorefining* 2(6):530-539.
- Mooney, D.F., J.A. Larson, B.C. English, and D.D. Tyler. 2012. "Effect of dry matter loss on profitability of outdoor storage of switchgrass." *Biomass and Bioenergy* 44(0):33-41.
- Mukunda, A., K.E. Ileleji, and H. Wan. 2006. "Simulation of corn stover logistics from on-farm storage to an ethanol plant." Paper presented at 2006 ASABE Annual Meeting. Portland, OR.
- Nicholls, D. and John Z. 2012. "Cofiring biomass and coal for fossil fuel reduction and other benefits–Status of North American facilities in 2010." PNW-GTR-867. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

- O'Mahoney, A., F. Thorne, and E. Denny. 2013. "A cost-benefit analysis of generating electricity from biomass." *Energy Policy* 57:347-354.
- Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. "Biomass as Feedstock for A Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply." Oak Ridge National Laboratory.
- Qian, Y., and W. McDow. 2013. "An economic analysis of the wood pellet supply chain from the Southeast United States to European Consumers."
- Qin, X., T. Mohan, M. El-Halwagi, G. Cornforth, and B.A. McCarl. 2006. "Switchgrass as an alternate feedstock for power generation: an integrated environmental, energy and economic life-cycle assessment." *Clean Technologies and Environmental Policy* 8:233-249.
- Ravula, P.P., R.D. Grisso, and J.S. Cundiff. 2008. "Comparison between two policy strategies for scheduling trucks in a biomass logistic system." *Bioresource Technology* 99(13):5710-5721.
- Rentizelas, A.A., A.J. Tolis, and I.P. Tatsiopoulos. 2009. "Logistics issues of biomass: The storage problem and the multi-biomass supply chain." *Renewable and Sustainable Energy Reviews* 13:887-894.
- Rentizelas, A.A., I.P. Tatsiopoulos, and A. Tolis. 2009. "An optimization model for multi-biomass tri-generation energy supply." *Biomass and Bioenergy* 33:223-233.
- Samson, R., M. Drisdelle, L. Mulkins, C. Lapointe, and P. Duxbury. 2000. The use of switchgrass biofuel pellets as a greenhouse gas offset strategy, pp. 1-11.

- Samson, R., S. Mani, R. Boddey, S. Sokhansanj, D. Quesada, S. Urquiaga, V. Reis, and C. Ho Lem. 2005. "The Potential of C4 Perennial Grasses for Developing a Global BIOHEAT Industry." *Critical Reviews in Plant Sciences* 24:461-495.
- Samson, R., C. Lem, S. Stamler, and J. Dooper. 2008. *Developing Energy Crops for Thermal Applications: Optimizing Fuel Quality, Energy Security and GHG Mitigation*, ed. D. Pimentel, Springer Netherlands, pp. 395-423.
- Sanderson, M.A., R.L. Reed, S.B. McLaughlin, S.D. Wulschleger, B.V. Conger, D.J. Parrish, D.D. Wolf, C. Taliaferro, A.A. Hopkins, W.R. Ocumpaugh, M.A. Hussey, J.C. Read, and C.R. Tischler. 1996. "Switchgrass as a sustainable bioenergy crop." *Bioresource Technology* 56(1):83-93.
- Schmer, M.R., K.P. Vogel, R.B. Mitchell, and R.K. Perrin. 2008. "Net energy of cellulosic ethanol from switchgrass." *Proceedings of the National Academy of Sciences* 105(2):464-469.
- Searcy, E., P. Flynn, E. Ghafoori, and A. Kumar. 2007. "The relative cost of biomass energy transport." *Applied Biochemistry and Biotechnology* 137-140(1-12):639-652.
- Searcy, E., and J. Hess. 2010. "Uniform-format feedstock supply system design for lignocellulosic biomass: A commodity-scale design to produce an infrastructure-compatible biocrude from lignocellulosic biomass." INL/EXT-10-20372. INL. Available at: www.inl.gov/bioenergy/uniform-feedstock.
- Selkimäki, M., B. Mola-Yudego, D. Röser, R. Prinz, and L. Sikanen. 2010. "Present and future trends in pellet markets, raw materials, and supply logistics in Sweden and Finland." *Renewable and Sustainable Energy Reviews* 14(9):3068-3075.

- Sikkema, R., M. Steiner, M. Junginger, W. Hiegl, M.T. Hansen, and A. Faaij. 2011. "The European wood pellet markets: current status and prospects for 2020." *Biofuels, Bioproducts and Biorefining* 5:250-278.
- Sokhansanj, S., and J.R. Hess (2009) Biomass Supply Logistics and Infrastructure, ed. J.R. Mielenz, vol. 581, Humana Press, pp. 1-25.
- Sokhansanj, S., A. Kumar, and A.F. Turhollow. 2006. "Development and implementation of integrated biomass supply analysis and logistics model (IBSAL)." *Biomass and Bioenergy* 30(10):838-847.
- Sokhansanj, S., S. Mani, S. Tagore, and A.F. Turhollow. 2010. "Techno-economic analysis of using corn stover to supply heat and power to a corn ethanol plant – Part 1: Cost of feedstock supply logistics." *Biomass and Bioenergy* 34(1):75-81.
- Sokhansanj, S., S. Mani, A. Turhollow, A. Kumar, D. Bransby, L. Lynd, and M. Laser. 2009. "Large-scale production, harvest and logistics of switchgrass (*Panicum virgatum* L.) – current technology and envisioning a mature technology." *Biofuels, Bioproducts and Biorefining* 3(2):124-141.
- Sultana, A., A. Kumar, and D. Harfield. 2010. "Development of agri-pellet production cost and optimum size." *Bioresource Technology* 101(14):5609-5621.
- Sultana, A., and A. Kumar. 2012. "Ranking of biomass pellets by integration of economic, environmental and technical factors." *Biomass and Bioenergy* 39(0):344-355.
- Tatsiopoulou, I.P., and A.J. Tolis. 2003. "Economic aspects of the cotton-stalk biomass logistics and comparison of supply chain methods." *Biomass and Bioenergy* 24(3):199-214.

- Tembo, Gelson, Francis M. Epplin, and Raymond L. Huhnke. 2003. "Integrative investment appraisal of a lignocellulosic biomass-to-ethanol industry." *Journal of Agricultural and Resource Economics* : 611-633.
- Thek, G., and I. Obernberger. 2004. "Wood pellet production costs under Austrian and in comparison to Swedish framework conditions." *Biomass and Bioenergy* 27(6):671-693.
- Tiller, K. 2011. "Tennessee case study in full-scale development and integration of switchgrass feedstocks with biorefinery operations: Genera Energy and UT Biofuels Initiative." *Industrial Biotechnology* 7(5):357-364.
- Tillman, D.A. 2000. "Biomass cofiring: the technology, the experience, the combustion consequences." *Biomass and Bioenergy* 19(6):365-384.
- Tyner, W. 2010. "The Integration of Energy and Agricultural Markets" *Agricultural Economics* 41: 193-201
- U.S. Congress. 2007. "Energy independence and security act of 2007." *Public Law* (110-140).
- USDA. 2012. Soil Survey Geographical Database (SSURGO). 2012. Available at:
<http://soils.usda.gov/survey/geography/ssurgo/>.
- USDA. National Agricultural Statistics Service. 2011. Crop Values Annual Summary. Available at: <http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1050>
- USDA. Farm Service Agency. 2013. "2012 acreage data as of January 2013." Available at:
<http://www.fsa.usda.gov/FSA/webapp?area=newsroom&subject=landing&topic=foi-er-fri-cad>.
- U.S. Department of Energy. 2011. U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN.

- Vadas, P.A., K.H. Barnett, and D.J. Undersander. 2008. "Economics and Energy of Ethanol Production from Alfalfa, Corn, and Switchgrass in the Upper Midwest, USA." *BioEnergy Research* 1(1):44-55.
- Van Dam, J., A. Faaij, J. Hilbert, H. Petruzzi, and W. Turkenburg. 2009. "Large-scale bioenergy production from soybeans and switchgrass in Argentina: Part A: Potential and economic feasibility for national and international markets." *Renewable and Sustainable Energy Reviews* 13:1710-1733.
- Walsh, M., D. de la Torre Ugarte, H. Shapouri, and S. Slinsky. 2003. "Bioenergy Crop Production in the United States: Potential Quantities, Land Use Changes, and Economic Impacts on the Agricultural Sector." *Environmental and Resource Economics* 24:313-333.
- Wang, C. 2009. Economic analysis of delivering switchgrass to a biorefinery from both the farmers' and processor's perspectives. University of Tennessee, Knoxville.
- Wee, H.-M., W.-H. Yang, C.-W. Chou, and M.V. Padilan. 2012. "Renewable energy supply chains, performance, application barriers, and strategies for further development." *Renewable and Sustainable Energy Reviews* 16:5451-5465.
- Wright, C.T., P.A. Pryfogle, N.A. Stevens, J.R. Hess, and C.W. Radtke. 2006. "Value of Distributed Preprocessing of Biomass Feedstocks to a Bioenergy Industry." Paper presented at ASABE Annual International Meeting. Portland, Oregon.
- Yu, T., J.A. Larson, B.C. English, and Y. Gao. 2011. "Evaluating the Optimal Logistics System of Biomass Feedstocks for a Biorefinery with Alternative Harvest, Storage and Preprocessing Options: A Case Study of East Tennessee." *American Society of Agricultural and Biological Engineers Proceedings*, Vol. 5: 3733-3740, Louisville, KY"

- Zegada-Lizarazu, W., D. Parrish, M. Berti, and A. Monti. 2013. "Dedicated crops for advanced biofuels: Consistent and diverging agronomic points of view between the USA and the EU-27." *Biofuels, Bioproducts and Biorefining* 7:715-731.
- Zhang, J., A. Osmani, I. Awudu, and V. Gonela. 2012. "An integrated optimization model for switchgrass-based bioethanol supply chain." *Applied Energy* 102(0):1205-1217.
- Zhu, X., and Q. Yao. 2011. "Logistics system design for biomass-to-bioenergy industry with multiple types of feedstocks." *Bioresource Technology* 102(23):10936-10945.
- Zhu, X., X. Li, Q. Yao, and Y. Chen. 2011. "Challenges and models in supporting logistics system design for dedicated-biomass-based bioenergy industry." *Bioresource Technology* 102(2):1344-1351.

APPENDIX

Table 1: Research on Biomass for Energy Production

Reference	Objective	Feedstock	Region	Findings
Amos et al (2002)	To evaluate boiler efficiency and emissions from co-firing biomass with coal	switchgrass	Iowa	no impact on boiler efficiency; 4% reduction in emissions
Boylan et al (2000)	To evaluate feasibility, costs, and benefits of co-firing biomass feedstocks with coal	switchgrass	Alabama	switchgrass co-firing in existing coal fired units as one of the low cost renewable energy options
English et al (2007)	To examine the economic impacts of co-firing biomass feedstocks with coal	forest residues, mill waste, agricultural residues, switchgrass, and urban wood wastes	Southeastern US	co-firing biomass at 2% (by weight) with coal is economical
Samson et al (2000)	To compare various biofuel production pathways: co-firing, ethanol, heat energy from pellets	switchgrass	North America	pelletized switchgrass had higher energy conversion rate
Schmer et al (2008)	To evaluate switchgrass as bioenergy crop in terms of net energy and GHG emissions	switchgrass	Mid-continental US	switchgrass produced more energy than consumed and has significant environmental benefits
Sultana and Kumar (2012)	To evaluate biomass feedstock based pellets based on environmental, economical, and technical factors	wood, straw, switchgrass, alfalfa, and poultry litter	-	switchgrass pellets were found similar to wood pellets in terms of suitability for use in large heat and power generation plants
Vadas et al (2008)	To assess energy conversion efficiency by comparing different cropping systems	corn, alfalfa, and switchgrass	Wisconsin	net energy produced by switchgrass was greatest

Table 2: Research on Biomass Supply Chain

Reference	Logistics component							Analytical Method
	*FS	*CH	*PR	*ST	*FT	*CF	*BD	
Alfonso et al (2009)	X	X	X	X	X	X	X	GIS*+Cost min*+GHG min*
Cundiff et al (1997)		X		X				LP*+Cost min
Dal-Mas et al (2011)	X	X	X		X	X	X	GIS+MILP+Inv. Risk Min*
Dunnett et al (2007)		X		X	X	X		MILP+Cost min
Ekşioğlu et al (2009)	X	X	X	X	X	X	X	MILP+Cost min
Freppaz et al (2004)		X				X		DSS*+GIS+MILP+Cost min
Frombo et al (2009)		X	X			X		EDSS*+GIS+MILP+Cost min
Gonzalez et al 2011	X	X			X			Financial model+NPV+IRR*
Mukunda et al (2006)		X			X			LP+Distance Min
Rentizelas et al (2009)	X	X			X	X		DSS+Cost min
Sokhansanj et al (2010)		X	X		X			Enterprise Budgeting
Tatsiopoulou and Tolis (2003)		X		X	X			LP+Cost min
Tembo et al (2003)	X		X	X	X			MILP+NPWM
Wang et al (2012)	X	X	X		X	X	X	MILP+Cost min
Zhang et al (2012)	X	X	X	X	X	X	X	MILP+Cost min

*FS-Feedstock source, *CH-Collection/Harvest, *PR-Pre-processing, *ST-Storage, *FT-Feedstock transportation, *CF-Conversion facility, *BD-Biofuel distribution, GIS*-Geographic information system, Cost min*-cost minimization, GHG min*-Greenhouse gas minimization, MILP*- Mixed-integer linear programming, LP*- Linear programming, Inv. Risk Min*-Investment risk minimization, DSS*- Decision support system, EDSS*-Environmental decision support system, IRR- Internal rate of return

Table 3: List of Potential Local Markets (within 70 miles of Genera Energy)

Facility Name	Facility Type	Capacity (short tons)
Resolute Fibers/Bowater Southern Paper Corporation	Pulp and paper - With cogen/Wood energy user	520,000
Oak Ridge National Lab Gasification Plant (ORNL)	Biomass power producer - 100% biomass	28,470
Maryville College	Institutional wood energy user - University/College	5,000
DuPont Danisco Cellulosic Ethanol (DDCE)	Cellulosic ethanol producer - Pilot / Demonstration facility	3,289

Source: Wood2Energy (<http://www.wood2energy.org/Studies.htm>)

Table 4: Operations Sequences for each Scenario

Operation	Baseline	C_SWB	C_SR	B_P	C_SWB_P	C_SR_P	C_SWB_ SLO_P
Mow	1	-	-	1	-	-	-
Bale	2	-	-	2	-	-	-
Chop	-	1	1	-	1	1	1
Haul by tandem-axle truck to preprocessing facility	-	2	-	-	2	-	2
Haul by tandem-axle truck to Genera Energy	-	-	2	3	3	2	3
Storage at farm	3	-	-	4	-	-	-
Dump in holding area	-	3	3	-	4	3	4
Front-end load into conveyer	-	4	4	-	5	4	5
Compact/bale/wrap	-	5	-	-	6	-	6
Storage at preprocessing facility	-	6	-	-	7	-	7
Storage at Genera Energy (Stacker-Reclaimer)	-	-	5	-	-	5	-
Storage at Genera Energy (Silo)	-	-	-	-	-	-	8
Pelletization	-	-	-	5	8	6	9
Haul by semi-tractor trailer to domestic market	4	7	6	-	-	-	-
Transportation to international market	-	-	-	6	9	7	10

Table 5: Total Machinery Cost of Mower

Mower	Unit	Item
Fuel Use	gallon/hour	0.00
Purchase Price	dollars	6,500.00
List Price	dollars	7,647.00
Useful life	years	6
Hours of use	per year	325
Salvage Factor		0.35
Salvage Value	dollars	2,661.00
Interest rate	%	0.10
Lubrication factor		0.15
Fuel Price	dollar per gallon	3.50
CRF	dollars	0.23
Housing % of PP	%	0.75
Tax Rate % of PP	%	1.00
Insurance % of PP	%	0.25
Diesel Fuel	(\$/hour)	0.00
Lubrication Costs	(\$/hour)	0.00
Repair & Maintenance	(\$/hour)	5.71
Operating Costs	(\$/hour)	5.71
Capital Recovery	(\$/hour)	3.48
TIH	(\$/hour)	0.40
Ownership Costs	(\$/hour)	3.88
Total Machinery Cost	(\$/hour)	9.60

Source: Larson (2013) (personal communication)

Table 6: Total Machinery Cost of Front End Loader

Front End Loader	Unit	Item
Fuel Use	gallon/hour	0.00
Purchase Price	dollars	7,500.00
List Price	dollars	8,824.00
Useful life	years	3
Hours of use	per year	325
Salvage Factor		0.38
Salvage Value	dollars	3,348.00
Interest rate	%	0.10
Lubrication factor		0.00
Fuel Price	dollar per gallon	3.50
CRF	dollars	0.40
Housing % of PP	%	0.75
Tax Rate % of PP	%	1.00
Insurance % of PP	%	0.25
Diesel Fuel	(\$/hour)	0.00
Lubrication Costs	(\$/hour)	0.00
Repair & Maintenance	(\$/hour)	4.06
Operating Costs	(\$/hour)	4.06
Capital Recovery	(\$/hour)	6.06
TIH	(\$/hour)	0.46
Ownership Costs	(\$/hour)	6.52
Total Machinery Cost	(\$/hour)	10.58

Source: Larson (2013) (personal communication)

Table 7: Total Machinery Cost of Tractor, 150 H.P.,W/Cab, Air

Tractor, 150 H.P.,W/Cab, Air	Unit	Item
Fuel Use	gallon/hour	6.57
Purchase Price	dollars	150,000.00
List Price	dollars	176,471.00
Useful life	years	18
Hours of use	per year	666
Salvage Factor		0.18
Salvage Value	dollars	31,412.00
Interest rate	%	0.10
Lubrication factor		0.15
Fuel Price	dollar per gallon	3.50
CRF	dollars	0.12
Housing % of PP	%	0.75
Tax Rate % of PP	%	1.00
Insurance % of PP	%	0.25
Diesel Fuel	(\$/hour)	23.00
Lubrication Costs	(\$/hour)	3.45
Repair & Maintenance	(\$/hour)	6.35
Operating Costs	(\$/hour)	32.80
Capital Recovery	(\$/hour)	26.42
TIH	(\$/hour)	4.50
Ownership Costs	(\$/hour)	30.92
Total Machinery Cost	(\$/hour)	63.72

Source: Larson (2013) (personal communication)

Table 8: Total Machinery Cost of 5' x 6' Large Round Baler

5' x 6' Large Round Baler	Unit	Item
Fuel Use	gallon/hour	0.00
Purchase Price	dollars	23,000.00
List Price	dollars	27,059.00
Useful life	years	5
Hours of use	per year	325
Salvage Factor		0.40
Salvage Value	dollars	10,911.00
Interest rate	%	0.10
Lubrication factor		0.00
Fuel Price	dollar per gallon	3.50
CRF	dollars	0.26
Housing % of PP	%	0.75
Tax Rate % of PP	%	1.00
Insurance % of PP	%	0.25
Diesel Fuel	(\$/hour)	0.00
Lubrication Costs	(\$/hour)	0.00
Repair & Maintenance	(\$/hour)	16.09
Operating Costs	(\$/hour)	16.09
Capital Recovery	(\$/hour)	13.81
TIH	(\$/hour)	1.42
Ownership Costs	(\$/hour)	15.22
Total Machinery Cost	(\$/hour)	31.32

Source: Larson (2013) (personal communication)

Table 9: Total Machinery Cost of 4' x 4 'x 8' Large Rectangular Baler

4' x 4 'x 8' Large Rectangular Baler	Unit	Item
Fuel Use	gallon/hour	0.00
Purchase Price	dollars	87,700.00
List Price	dollars	103,176.00
Useful life	years	9
Hours of use	per year	325
Salvage Factor		0.30
Salvage Value	dollars	30,536.00
Interest rate	%	0.10
Lubrication factor		0.15
Fuel Price	dollar per gallon	3.50
CRF	dollars	0.17
Housing % of PP	%	0.75
Tax Rate % of PP	%	1.00
Insurance % of PP	%	0.25
Diesel Fuel	(\$/hour)	0.00
Lubrication Costs	(\$/hour)	0.00
Repair & Maintenance	(\$/hour)	24.85
Operating Costs	(\$/hour)	24.85
Capital Recovery	(\$/hour)	39.46
TIH	(\$/hour)	5.40
Ownership Costs	(\$/hour)	44.85
Total Machinery Cost	(\$/hour)	69.70

Source: Larson (2013) (personal communication)

Table 10: Total Machinery Cost of Chopper w/Rotary Header

Chopper w/Rotary Header	Unit	Item
Fuel Use	gallon/hour	19.71
Purchase Price	dollars	354,732.00
List Price	dollars	201,471.00
Useful life	years	12
Hours of use	per year	325
Salvage Factor		0.25
Salvage Value	dollars	49,638.00
Interest rate	%	0.10
Lubrication factor		0.15
Fuel Price	dollar per gallon	3.50
CRF	dollars	0.15
Housing % of PP	%	0.75
Tax Rate % of PP	%	1.00
Insurance % of PP	%	0.25
Diesel Fuel	(\$/hour)	68.99
Lubrication Costs	(\$/hour)	10.35
Repair & Maintenance	(\$/hour)	50.08
Operating Costs	(\$/hour)	129.41
Capital Recovery	(\$/hour)	143.88
TIH	(\$/hour)	21.83
Ownership Costs	(\$/hour)	165.71
Total Machinery Cost	(\$/hour)	295.12

Source: Larson (2013) (personal communication)

Table 11: Total Machinery Cost of Tandem Axle Truck

Tandem Axle Truck	Unit	Item
Fuel Use	gallon/hour	2.40
Purchase Price	dollars	29,750.00
List Price	dollars	35,000.00
Useful life	years	37
Hours of use	per year	325
Salvage Factor		0.10
Salvage Value	dollars	3,500.00
Interest rate	%	0.10
Lubrication factor		0.00
Fuel Price	dollar per gallon	3.50
CRF	dollars	0.10
Housing % of PP	%	0.75
Tax Rate % of PP	%	1.00
Insurance % of PP	%	0.25
Diesel Fuel	(\$/hour)	8.40
Lubrication Costs	(\$/hour)	1.26
Repair & Maintenance	(\$/hour)	2.92
Operating Costs	(\$/hour)	12.58
Capital Recovery	(\$/hour)	9.40
TIH	(\$/hour)	1.83
Ownership Costs	(\$/hour)	11.23
Total Machinery Cost	(\$/hour)	23.81

Source: Larson (2013) (personal communication)

Table 12: Total Machinery Cost of Semi-Tractor Trailer

Semi-Tractor Trailer	Unit	Item
Fuel Use	gallon/hour	22.12
Purchase Price	dollars	120,000.00
List Price	dollars	141,176.00
Useful life	years	22
Hours of use	per year	1000
Salvage Factor		0.13
Salvage Value	dollars	18,171.00
Interest rate	%	0.10
Lubrication factor		0.15
Fuel Price	dollar per gallon	3.50
CRF	dollars	0.11
Housing % of PP	%	0.01
Tax Rate % of PP	%	0.01
Insurance % of PP	%	0.00
Diesel Fuel	(\$/hour)	77.42
Lubrication Costs	(\$/hour)	11.61
Repair & Maintenance	(\$/hour)	21.74
Operating Costs	(\$/hour)	110.77
Capital Recovery	(\$/hour)	13.43
TIH	(\$/hour)	2.40
Ownership Costs	(\$/hour)	15.83
Total Machinery Cost	(\$/hour)	126.60

Source: Larson (2013) (personal communication)

Table 13: Total Machinery Cost of Compactor Baler

Compactor Baler	Unit	Item
Purchase Price	dollars	1,190,000.00
List Price	dollars	1,400,000.00
Useful life	years	12
Hours of use	per year	1,218
Salvage Factor		0.10
Salvage Value	dollars	140,000.00
Interest rate	%	0.10
Electricity price	dollar per kWh	0.09
CRF	dollars	0.15
Electricity costs	(\$/hour)	13.80
Repair & Maintenance	(\$/hour)	155.56
Operating Costs	(\$/hour)	169.00
Capital Recovery	(\$/hour)	24.63
TIH	(\$/hour)	9.24
Ownership Costs	(\$/hour)	33.88
Total Machinery Cost	(\$/hour)	203.23

Source: Larson (2013) (personal communication)

Table 14: Total Cost of Building to House Compactor Baler

Compactor Baler	Unit	Item
Purchase Price	dollars	507,401.00
List Price	dollars	596,942.00
Useful life	years	37
Hours of use	per year	1218
Salvage Factor		0.00
Salvage Value	dollars	0.00
Interest rate	%	0.10
Electricity price	dollar per kWh	0.09
CRF	dollars	0.05
Electricity costs	(\$/hour)	0.12
Repair & Maintenance	(\$/hour)	9.80
Operating Costs	(\$/hour)	9.92
Capital Recovery	(\$/hour)	1.50
TIH	(\$/hour)	3.94
Ownership Costs	(\$/hour)	5.44
Total Machinery Cost	(\$/hour)	15.36

Source: Larson (2013) (personal communication)

Table 15: Total Cost of Bulk Receiving Station in Stacker-Reclaimer System

Bulk Receiving Station (4 units)	Unit	Value
List Price	dollars	1,333,333.00
Interest Rate	%	0.10
Useful life	years	20
CRF	dollars	0.12
Salvage Value	dollars	0.00
County rate		2.01
Assessment ratio		0.40
Repair and maintenance		0.01
Electricity (\$ per year)	(\$/year)	12,449.45
Repair & Maintenance (\$ per year)	(\$/year)	13,333.00
Total Operating Costs (Yearly)	(\$/year)	32,449.45
CRC	(\$/year)	156,613.00
TIH	(\$/year)	10,720.00
Total Ownership Costs (Yearly)	(\$/year)	167,333.00
Total Machinery Costs (Yearly)	(\$/year)	190,151.00

Source: Jackson (2014) (personal communication)

Table 16: Total Cost of Conveyance in Stacker-Reclaimer System

Conveyance	Unit	Value
List Price	dollars	2,500,000.00
Interest Rate	%	0.10
Useful life	years	20
CRF	dollars	0.12
Salvage Value	dollars	0.00
County rate		2.01
Assessment ratio		0.40
Repair and maintenance		0.02
Electricity (Receiving)	(\$/year)	41,498.19
Electricity (Discharge)	(\$/year)	44,741.99
Repair & Maintenance	(\$/year)	50,000.00
Total Operating Costs	(\$/year)	136,240.00
CRC	(\$/year)	293,649.00
TIH	(\$/year)	20,100.00
Total Ownership Costs	(\$/year)	313,749.00
Total Machinery Costs	(\$/year)	449,989.00

Source: Jackson (2014) (personal communication)

Table 17: Total Cost of Dust Collection in Stacker-Reclaimer System

Dust Collection System	Unit	Value
List Price	dollars	750,000.00
Interest Rate	%	0.10
Useful life	years	20
CRF	dollars	0.12
Salvage Value	dollars	0.00
County rate		2.01
Assessment ratio		0.40
Repair and maintenance		0.02
Electricity	(\$/year)	44,741.00
Repair & Maintenance	(\$/year)	15,000.00
Total Operating Costs	(\$/year)	32,449.45
CRC	(\$/year)	88,094.72
TIH	(\$/year)	6,030.00
Total Ownership Costs	(\$/year)	94,124.00
Total Machinery Costs	(\$/year)	153,866.00

Source: Jackson (2014) (personal communication)

Table 18: Total Cost of Stacking & Reclaiming in Stacker-Reclaimer System

Stacking & Reclaiming	Unit	Value
List Price	dollars	5,000,000.00
Interest Rate	%	0.10
Useful life	years	20
CRF	dollars	0.12
Salvage Value	dollars	0.00
County rate		2.01
Assessment ratio		0.40
Repair and maintenance		0.02
Electricity (Receiving)	(\$/year)	2,766.54
Electricity (Discharge)	(\$/year)	29827.99
Repair & Maintenance	(\$/year)	100,000.00
Total Operating Costs	(\$/year)	132,594.00
CRC	(\$/year)	587,298.00
TIH	(\$/year)	40,200.00
Total Ownership Costs	(\$/year)	627,498.00
Total Machinery Costs	(\$/year)	449,989.00

Source: Jackson (2014) (personal communication)

Table 19: Annualized Capital Costs of Pelletization

	Number of units	Total capital costs	Useful life	Annualized cost
Processing equipment				
Receiving and scale	1	\$130,000.00	50	\$13,111.69
Wood Hog	1	\$709,256.00	10	\$115,428.15
Grinding receiving belt with magnet and screen	1	\$174,230.00	10	\$28,355.13
Air-vey system to dryer feed	1	\$69,384.00	10	\$11,291.93
Dryer (Furnace, rotary drum dryer and fan)	1	\$1,387,674.00	15	\$182,442.74
Pre pellet storage bin 2700 CU FT	2	\$215,860.00	20	\$25,354.83
Dry material screener	1	\$58,591.00	10	\$9,535.42
Milled material conveying system	1	\$69,384.00	10	\$11,291.93
Explosion Detection	1	\$69,384.00	10	\$11,291.93
Hammermill	1	\$154,186.00	10	\$25,093.06
Pellet-mill steam system	1	\$53,965.00	10	\$8,782.56
Pellet-mill	4	\$1,850,233.00	10	\$301,116.90
Air-vey system to pellet cooler	4	\$185,023.00	10	\$30,111.64
Pellet cooler (with air system)	1	\$92,512.00	15	\$12,162.90
Pellet shaker/screener	1	\$29,295.00	10	\$4,767.63
Dust collection system and piping	1	\$77,093.00	10	\$12,546.53
Wheel loaders	2	\$339,209.00	10	\$55,204.70
Control center, automation, lab equipment		\$770,930.00	10	\$125,465.31
Consumable and spare parts		\$77,093.00	1	\$84,802.30
Storage (silo storage)		\$5,550,698.00	20	\$651,982.90

Table 19 continued...

	Total capital costs	Useful life	Annualized cost
Processing equipment			
Site development	\$509,875.00	50	\$51,425.57
Field expenses + Proreatable expenses	\$2,586,775.00	50	\$260,899.99
Home office and construction fee	\$3,233,469.00	50	\$326,125.01
Project contingency	\$377,216.00	50	\$38,045.72
Other costs	\$1,877,134.00	50	\$189,326.14
Total project investment	\$20,648,469.00		\$2,585,962.60

Source: Grbovic (2010)

Table 20: Maintenance Cost of Pelletizing Equipment

Processing equipment	Maintenance factor	Maintenance costs
Receiving and scale	0.01	\$1,300.00
Wood Hog	0.18	\$127,666.08
Grinding receiving belt with magnet and screen	0.02	\$3,484.60
Air-vey system to dryer feed	0.02	\$1,387.68
Dryer (Furnace, rotary drum dryer and fan)	0.03	\$34,691.85
Pre pellet storage bin 2700 CU FT	0.02	\$3,237.90
Dry material screener	0.02	\$1,171.82
Milled material conveying system	0.02	\$1,387.68
Explosion Detection	0.02	\$1,387.68
Hammermill	0.18	\$27,753.48
Pellet-mill steam system	0.02	\$1,079.30
Pellet-mill	0.10	\$18,5023.30
Air-vey system to pellet cooler	0.02	\$3,700.46
Pellet cooler (with air system)	0.02	\$1,850.24
Pellet shaker/screener	0.02	\$585.90
Dust collection system and piping	0.02	\$1,541.86
Wheel loaders	0.02	\$6,784.18
Control center, automation, interduction, lab equipment	0.02	\$15,418.60
Storage (silo storage)	0.02	\$83,260.47
Site development	0.01	\$5,098.75
Home office and construction fee	0.01	\$32,334.69
Total maintenance cost		540146.52

Source: Grbovic (2010)

Table 21: Total Annualized Cost of Silos (11 Silos)

Equipment	Total Capital Cost	Useful Life	Annualized cost
Receiving and Silos			
Silos	\$7,370,000	20	\$865,677
Satellite receiving reclaimer	\$1,100,000	10	\$179,020
Silo foundations, receiving pit (Concrete)	\$5,775,000	50	\$582,462
Compactor Equipment			
Marathon compactor and installation	\$209,300	10	\$34,063
Trailer equipment: K&L Trailer & Leasing, Inc.	\$30,995	10	\$5,044
Trailer equipment: Steco Trailer	\$67,762	10	\$11,028
Generator: Stowers Caterpillar	\$39,743	10	\$6,468
Conveyances			
Tubes, supports, blowers	\$6,600,000	10	\$1,074,120
Electrical controls/automation	\$3,850,000	10	\$626,570
Structures			
Buildings, covers, etc	\$150,000	50	\$15,129
Total Capital	\$25,192,800	20	\$3,399,580

Source: Jackson (2014) (personal communication)

Table 22: Total Maintenance Cost of Silos (11 Silos)

Equipment	Total Capital Cost	Maintenance factor	Maintenance Cost
Receiving and Silos			
Silos	\$7,370,000	0.01	\$73,700
Satellite receiving reclaimer	\$1,100,000	0.01	\$11,000
Silo foundations, receiving pit (Concrete)	\$5,775,000	0.01	\$57,750
Compactor Equipment			
Marathon compactor and installation	\$209,300	0.01	\$2,093
Trailer equipment: K&L Trailer & Leasing,	\$30,995	0.01	\$310
Trailer equipment: Steco Trailer	\$67,762	0.01	\$678
Generator: Stowers Caterpillar	\$39,743	0.01	\$397
Conveyances			
Tubes, supports, blowers	\$6,600,000	0.02	\$132,000
Electrical controls/automation	\$3,850,000	0.02	\$77,000
Structures			
Buildings, covers, etc	\$150,000	0.01	\$1,500
Total Capital	\$25,192,800		\$356,428

Source: Jackson (2014) (personal communication)

Table 23: Crop Prices and Diesel Fuel Price Correlations (Year: 2007-2013)

Correlation type (crop with diesel price)	Correlation
corn-diesel	0.78
cotton-diesel	0.69
hay-diesel	0.74
sorghum-diesel	0.80
soybeans-diesel	0.77
wheat-diesel	0.74

Table 24: Summary of Output of Baseline Scenario:

Method	RT*	ST*
Total Revenue (\$/year)	33,405,540	33,405,540
Total Cost (\$/year)	42,223,692	42,020,993
Opportunity	1,410,875	1,537,492
Production	7,437,517	8,309,709
Harvest	18,083,434	17,913,132
Storage (at farm)	1,681,639	2,306,573
Transportation (Field to market)	13,610,227	11,954,087
Total Profit (\$/year)	(8,818,152)	(8,615,453)
Net Present Value (\$ over 10 years)	(54,183,727)	(52,938,229)
Total Land Converted (Acres)	77,321	86,389
Total Demand (Tons)	556,759	556,759

Note: RT* -round bales with tarp protection; ST – square bales on pallet with tarp protection

Table 25: Summary of Output of C_SWB Scenario:

Method	C_SWB*
Total Revenue (\$/year)	33,405,540
Total Cost (\$/year)	33,147,144
Opportunity	1,451,249
Production	7,292,708
Harvest	8,381,269
Transportation (Field to market)	2,504,569
Transportation (Field to Preprocessing facility)	2,977,551
Preprocessing and Storage	4,940,577
Transportation (Preprocessing facility to market)	5,599,221
Total Profit (\$/year)	258,396
Net Present Value (\$ over 10 years)	1,587,732
Transportation (w/o preprocessing) tons	185,586
Transportation (w/ preprocessing) tons	371,173
Total Land Converted (Acres)	75,816
Total Demand (Tons)	556,759
Note: C_SWB*- Chopped switchgrass with stretch-wrap bale technology as preprocessing option	

Table 26: Summary of Output of C_SR Scenario

Method	C_SR*
Total Revenue (\$/year)	33,405,540
Total Cost (\$/year)	42,364,897
Opportunity	1,469,269
Production	7,308,375
Harvest	8,381,269
Transportation (Field to Genera Energy)	6,866,620
Transportation (Field to Market)	2,476,796
Storage	9,498,309
Transportation (Genera Energy to Market)	6,364,259
Total Profit (\$/year)	(8,959,357)
Net Present Value (\$ over 10 years)	(55,051,370)
Transportation (w/o storage) tons	185,586
Transportation (after storage) tons	371,173
Total Land Converted (Acres)	75,978
Total Demand (Tons)	556,759

Note: C_SR*-Chopped switchgrass and stacker-reclaimer as storage method

Table 27: Summary of Output of B_P Scenario

Method	B_P*
Total Revenue (\$/year)	17,500,000
Total Cost (\$/year)	20,452,356
Opportunity	297,745
Production	1,596,186
Harvest	3,434,188
Storage (at farm)	432,480
Transportation (Field to Genera)	1,613,757
Pelletizing and storage	8,145,000
Transportation (Genera-Savannah)	2,310,000
Transportation (Savannah-Rotterdam)	2,623,000
Total Profit (\$/year)	(2,952,356)
Net Present Value (\$ over 10 years)	(18,140,950)
Storage at farm (Tons)	71,015
Total Land Converted (Acres)	16,594
Total Demand (Tons)	100,000

Note: B_P*-baled switchgrass and pelletization as preprocessing option

Table 28: Summary of Output of C_SWB_P Scenario

Method	C_SWB_P*
Total Revenue (\$/year)	17,500,000
Total Cost (\$/year)	18,743,503
Opportunity	282,369
Production	1,424,084
Harvest	1,636,274
Transportation (Field to Genera)	259,786
Transportation (Field to Preprocessing)	479,390
BaleWrap and Storage (two-third)	983,266
Transportation (Preprocessing to Genera)	633,334
Pelletizing	8,112,000
Transportation (Genera-Savannah)	2,310,000
Transportation (Savannah-Rotterdam)	2,623,000
Total Profit (\$/year)	(1,243,503)
Net Present Value (\$ over 10 years)	(7,460,788)
Total Land Converted (Acres)	14,805
Total Demand (Tons)	100,000

Note: C_SWB_P-chopped switchgrass, stretch-wrap bale technology and pelletization as preprocessing options

Table 29: Summary of Output of C_SR_P Scenario

Method	C_SR_P*
Total Revenue (\$/year)	17,500,000
Total Cost (\$/year)	19,673,721
Opportunity	298,160
Production	1,429,665
Harvest	1,636,274
Transportation (Field to Genera)	1,122,108
Storage	2,142,514
Pelletizing from chop	8,112,000
Transportation (Genera-Savannah)	2,310,000
Transportation (Savannah-Rotterdam)	2,623,000
Total Profit (\$/year)	(2,173,721)
Net Present Value (\$ over 10 years)	(13,356,574)
Total Land Converted (Acres)	14,863
Total Demand (Tons)	100,000

Note: C_SR_P-chopped switchgrass, stacker-reclaimer as storage method and pelletization as preprocessing option

Table 30: Summary of Output of C_SWB_SLO_P Scenario

Method	C_SWB_SLO_P*
Total Revenue (\$/year)	17,500,000
Total Cost (\$/year)	22,401,761
Opportunity	302,879
Production	1,425,406
Harvest	1,636,274
Transportation (Field to Genera)	266,560
Storage (at Genera in Silo)	4,026,609
Transportation (Field to Preprocessing)	378,682
BaleWrap and Storage	740,460
Transportation (Preprocessing to Genera)	579,890
Pelletizing	8,112,000
Transportation (Genera-Savannah)	2,310,000
Transportation (Savannah-Rotterdam)	2,623,000
Total Profit (\$/year)	(4,901,761)
Net Present Value (\$ over 10 years)	(30,119,199)
Total Harvested (Tons)	14,817
Total Demand (Tons)	100,000

Note: C_SWB_SLO_P- chopped switchgrass, silo as storage option, stretch-wrap bale and pelletization as preprocessing options

Table 31: Summary of Sensitivity Analysis at 6% Interest Rate

	Baseline	C_SWB	C_SR	B_P	C_SWB_P	C_SR_P	C_SWB_SLO_P
Profit (\$/year)	(5,304,748)	2,820,069	(4,960,200)	(1,667,814)	(99,708)	(473,869)	(2,694,171)
Net Present Value (\$ over 10 years)	(\$39,043,407)	\$20,755,953	(\$36,507,504)	(\$12,275,256)	(\$733,860)	(\$3,487,717)	(\$19,829,333)
Total Cost (\$/year)	38,710,288	30,404,041	38,365,740	19,167,814	17,599,708	17,973,869	20,194,171
Opportunity	1,537,248	1,451,445	1,469,269	297,745	282,369	297,717	304,091
Production	7,450,172	6,535,760	6,552,389	1,431,075	1,276,775	1,281,917	1,278,663
Harvest	16,096,674	7,367,372	7,367,372	3,085,888	1,438,331	1,438,331	1,438,331
Storage (at farm)	2,177,798	-	-	408,335	-	-	-
Storage (at Genera)	-	-	8,295,709	-	-	1,555,435	2,837,489
Preprocessing (Compact bale)	-	4,801,633	-	-	\$949,678	-	\$690,362
Preprocessing (Pellets)	-	-	-	7,476,000	7,447,000	7,447,000	7,447,000
Transportation (Field to market)	11,448,396	2,291,673	2,234,781	-	-	-	-
Transportation (Field to PPF)	-	2,903,224	-	-	435,843	-	324,436
Transportation (PPF to Genera)	-	-	-	-	600,525	-	526,125
Transportation (Field to Genera)	-	-	6,259,883	1,535,771	236,187	1,020,469	414,674
Transportation (Genera to local market)	-	-	6,186,337	-	-	-	-
Transportation (PPF to Market)	-	5,234,364	-	-	-	-	-
Transportation (Genera to international market)	-	-	-	4,933,000	4,933,000	4,933,000	4,933,000

Table 32: Summary of Sensitivity Analysis at 3% Interest Rate

	Baseline	C_SWB	C_SR	B_P	C_SWB_ P	C_SR_P	C_SWB_ SLO_P
Profit (\$/year)	(2,957,201)	4,655,418	(2,260,751)	(784,678)	671,958	423,651	(1,924,523)
Net Present Value (\$ over 10 years)	(\$25,225,524)	\$39,711,660	(\$19,284,665)	(\$6,693,462)	\$5,731,938	\$3,613,829	(\$16,416,571)
Total Cost (\$/year)	36,362,741	28,629,642	35,666,291	18,284,678	16,828,042	17,076,349	19,424,523
Opportunity	1,536,630	1,452,220	1,469,269	297,810	281,789	297,716	303,518
Production	6,877,414	6,035,739	6,048,651	1,321,345	1,178,936	1,183,365	1,180,313
Harvest	14,758,571	6,646,757	6,646,757	2,829,626	1,297,646	1,297,646	1,297,646
Storage (at farm)	2,086,899	-	-	391,291	-	-	-
Storage (at Genera)	-	-	7,501,400	-	-	1,406,503	2,829,603
Preprocessing (Compact bale)	-	4,706,490	-	-	\$926,946	-	\$676,740
Preprocessing (Pellets)	-	-	-	7,030,000	7,004,000	7,004,000	7,004,000
Transportation (Field to market)	11,103,227	2,159,911	2,080,221	-	-	-	-
Transportation (Field to PPF)	-	2,678,939	-	-	411,553	-	307,676
Transportation (PPF to Genera)	-	-	-	-	573,573	-	507,763
Transportation (Field to Genera)	-	-	5,853,799	1,481,606	220,599	953,119	383,264
Transportation (Genera to local market)	-	-	6,066,194	-	-	-	-
Transportation (PPF to Market)	-	5,070,066	-	-	-	-	-
Transportation (Genera to international market)	-	-	-	4,933,000	4,933,000	4,933,000	4,933,000

Table 33: Summary of Sensitivity Analysis at 10% Fuel Price Decrease

	Baseline	C_SWB	C_SR	B_P	C_SWB_P	C_SR_P	C_SWB_SLO_P
Profit (\$/year)	(7,423,651)	978,996	(8,044,558)	(2,493,331)	(864,934)	(1,819,732)	(4,528,206)
Net Present Value (\$ over 10 years)	(\$45,615,122)	\$6,015,507	(\$49,430,326)	(\$15,320,440)	(\$5,314,645)	(\$11,181,465)	(\$27,823,866)
Total Cost (\$/year)	40,829,191	32,223,870	41,450,098	19,993,331	18,364,934	19,319,732	22,028,206
Opportunity	1,536,129	1,451,458	1,467,633	297,738	284,490	300,378	302,879
Production	8,284,688	7,270,811	7,286,352	1,591,338	1,419,824	1,425,355	1,421,109
Harvest	17,450,819	8,160,514	8,150,910	3,345,439	1,591,301	1,591,301	1,591,301
Storage (at farm)	2,306,573	-	-	432,480	-	-	-
Storage (at Genera)	-	-	9,498,309	-	-	2,142,514	4,026,609
Preprocessing (Compact bale)	-	4,940,577	-	-	\$983,266	-	\$740,460
Preprocessing (Pellets)	-	-	-	8,139,000	8,106,000	8,106,000	8,106,000
Transportation (Field to market)	11,250,982	2,437,081	2,392,973	-	-	-	-
Transportation (Field to PPF)	-	2,896,877	-	-	463,379	-	368,478
Transportation (PPF to Genera)	-	-	-	-	597,515	-	546,993
Transportation (Field to Genera)	-	-	6,698,241	1,522,336	251,692	1,089,184	259,377
Transportation (Genera to local market)	-	-	5,955,680	-	-	-	-
Transportation (PPF to market)	-	5,269,311	-	-	-	-	-
Transportation (Genera to international market)	-	-	-	4,665,000	4,665,000	4,665,000	4,665,000

Table 34: Summary of Sensitivity Analysis at 10% Fuel Price Increase

	Baseline	C_SWB	C_SR	B_P	C_SWB_P	C_SR_P	C_SWB_SLO_P
Profit (\$/year)	(9,890,768)	(537,683)	(9,948,049)	(3,452,640)	(1,664,276)	(2,573,050)	(5,379,919)
Net Present Value (\$ over 10 years)	(\$60,774,488)	(\$3,303,829)	(\$61,126,455)	(\$21,214,978)	(\$10,226,256)	(\$15,810,278)	(\$33,057,273)
Total Cost (\$/year)	43,296,308	33,715,155	43,353,589	20,952,640	19,164,276	20,073,050	22,879,919
Opportunity	1,617,638	1,509,948	1,543,441	315,044	282,466	334,525	319,310
Production	8,334,792	7,314,719	7,330,409	1,602,490	1,432,807	1,434,795	1,436,828
Harvest	18,377,106	8,611,614	8,611,614	3,524,899	1,681,244	1,681,244	1,681,244
Storage (at farm)	2,306,573	-	-	432,480	-	-	-
Storage (at Genera)	-	-	9,498,309	-	-	2,142,514	4,026,609
Preprocessing (Compact bale)	-	4,940,577	-	-	983,266	-	740,460
Preprocessing (Pellets)	-	-	-	8,151,000	8,118,000	8,118,000	8,118,000
Transportation (Field to market)	12,660,199	2,575,344	2,533,483	-	-	-	-
Transportation (Field to PPF)	-	3,061,964	-	-	491,456	-	481,683
Transportation (PPF to Genera)	-	-	-	-	702,206	-	542,555
Transportation (Field to Genera)	-	-	7,063,955	1,724,727	270,645	1,159,972	331,230
Transportation (Genera to local market)	-	-	6,772,378	-	-	-	-
Transportation (PPF to market)	-	5,929,128	-	-	-	-	-
Transportation (Genera to international market)	-	-	-	5,202,000	5,202,000	5,202,000	5,202,000



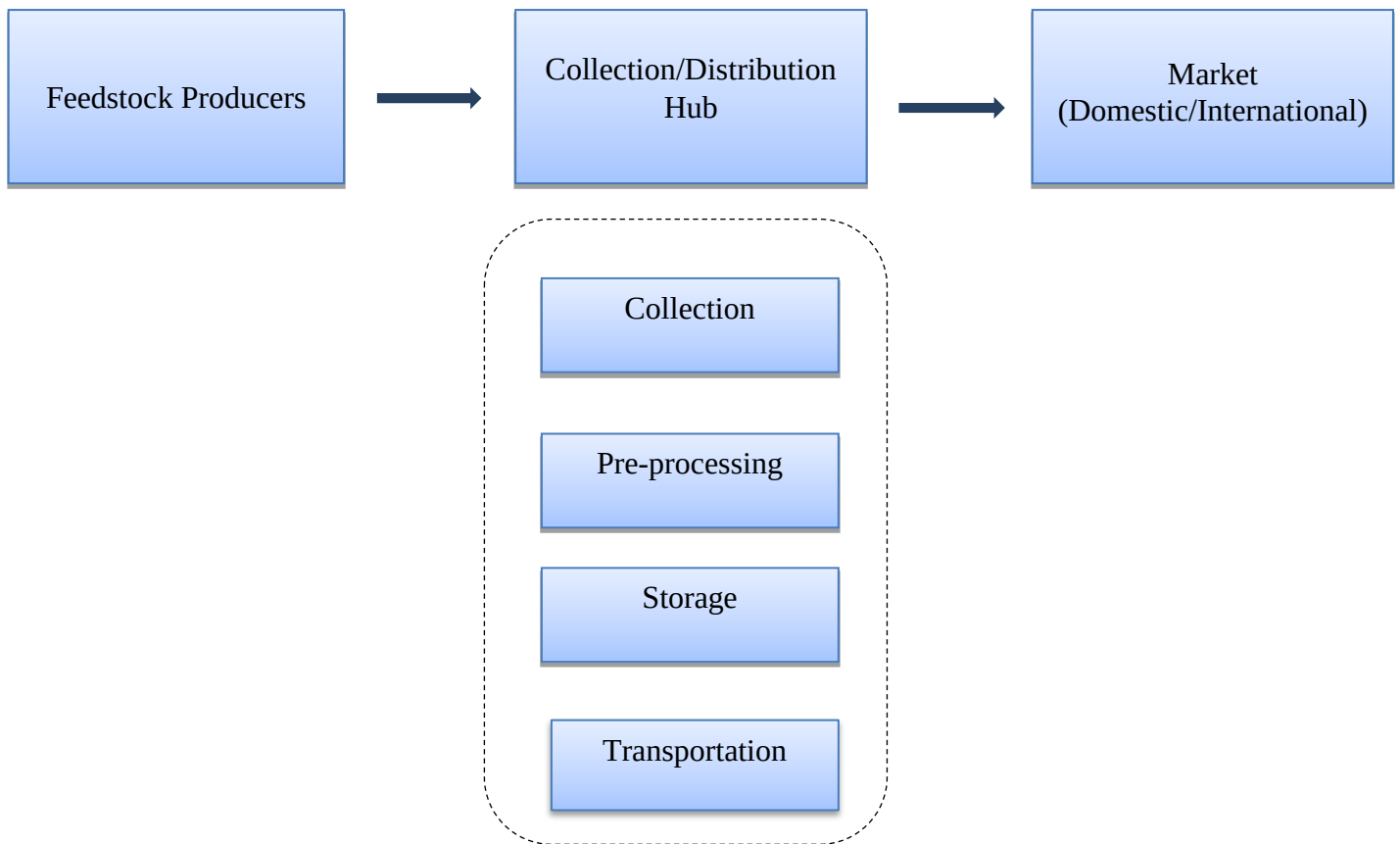


Figure 2: Feedstock Supply System

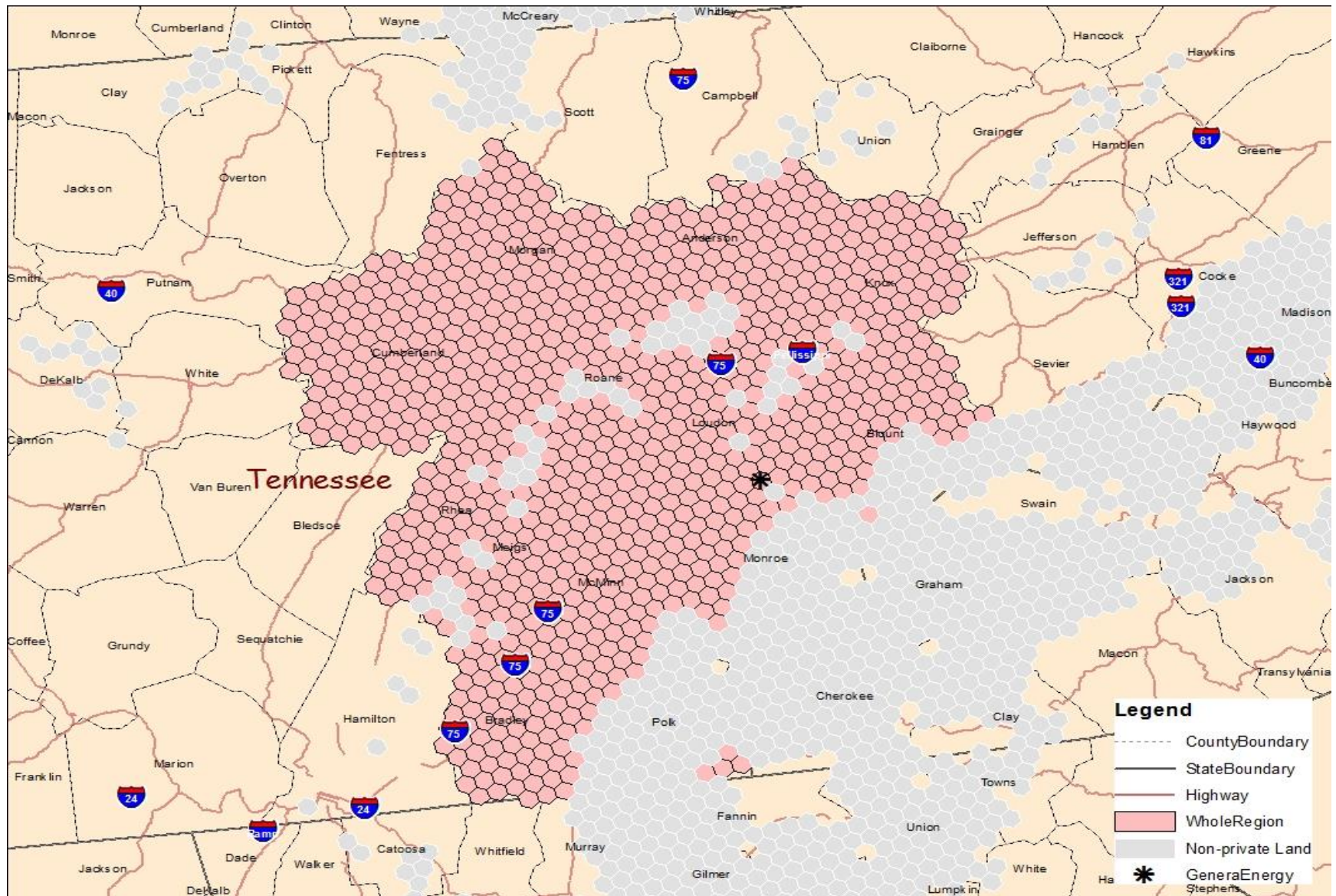


Figure 3: Location of Genera Energy and associated supply region

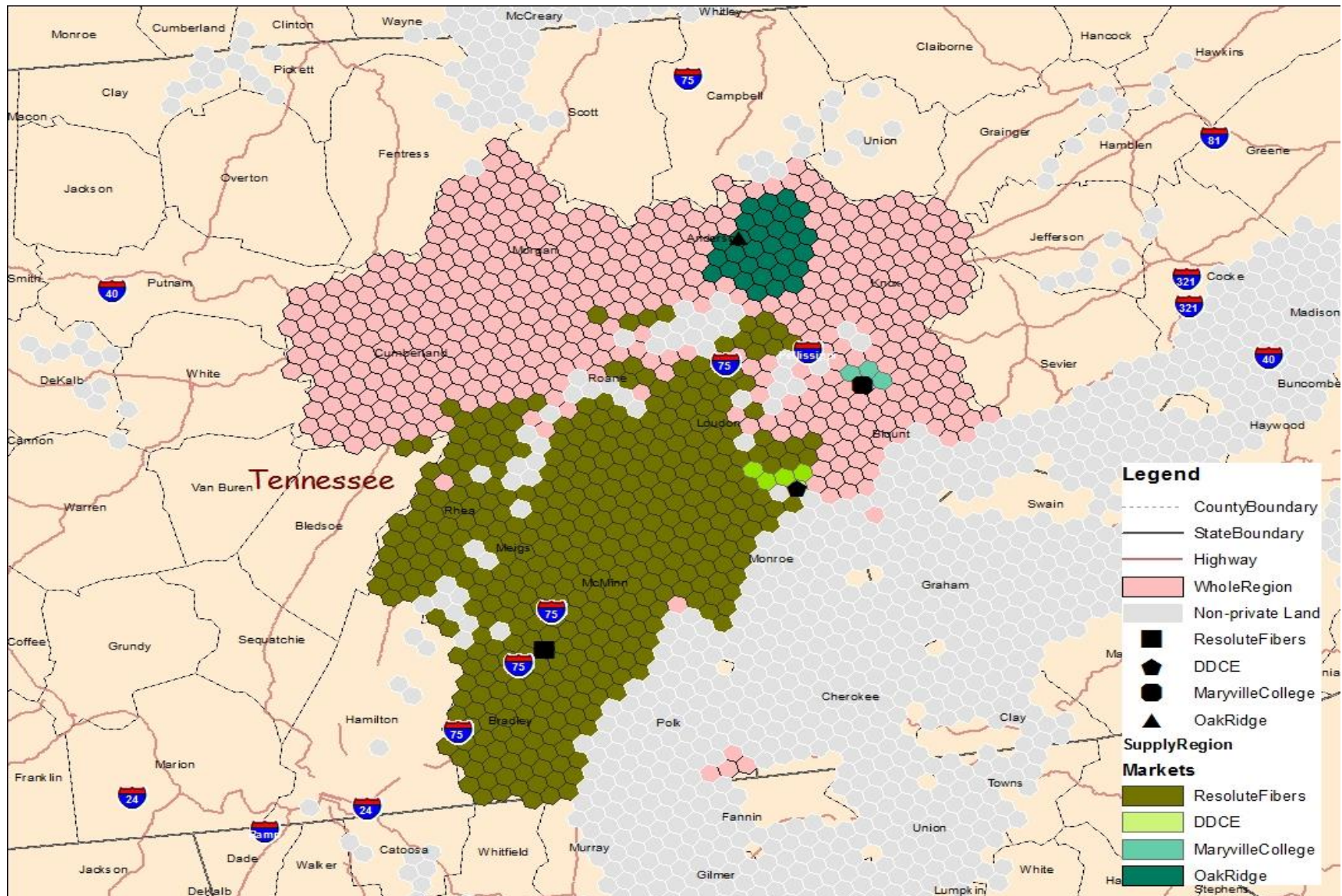


Figure 4: Location of markets and associated supply region for the Baseline scenario

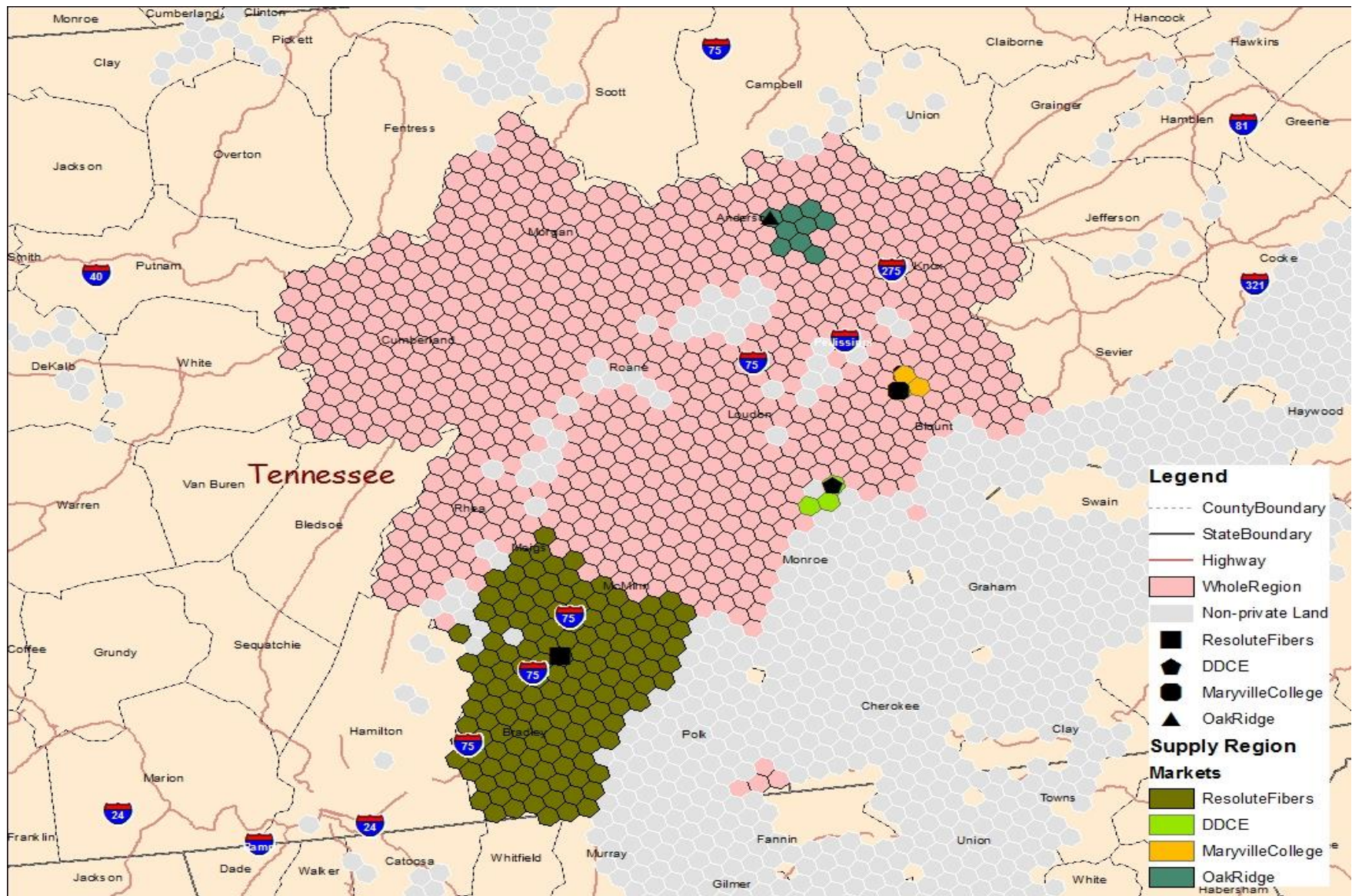


Figure 5: Location of markets and associated supply region for C_SWB scenario (during harvest season)

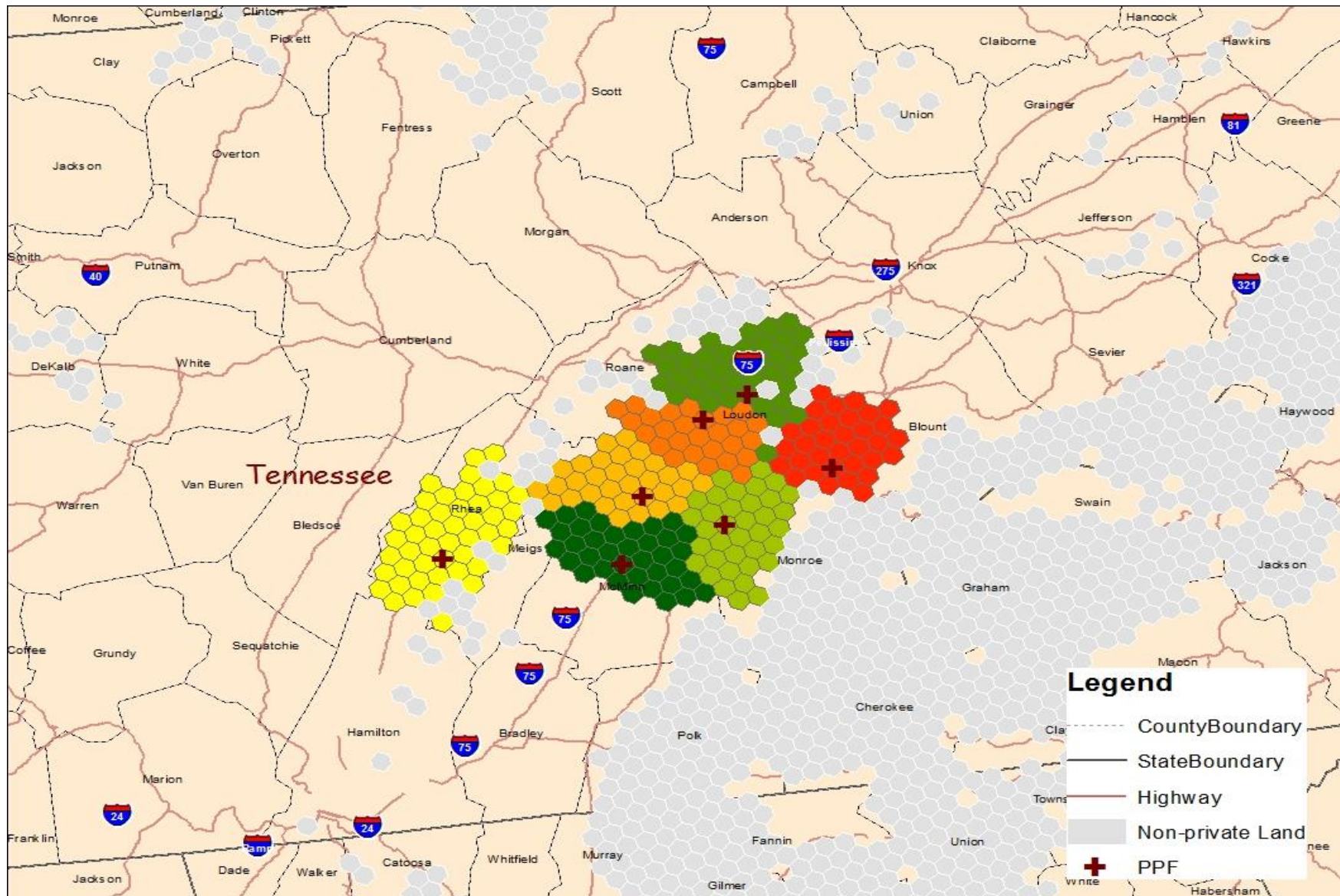


Figure 6: Location of preprocessing facilities (PPF) and associated supply region for C_SWB scenario (during off-harvest season)

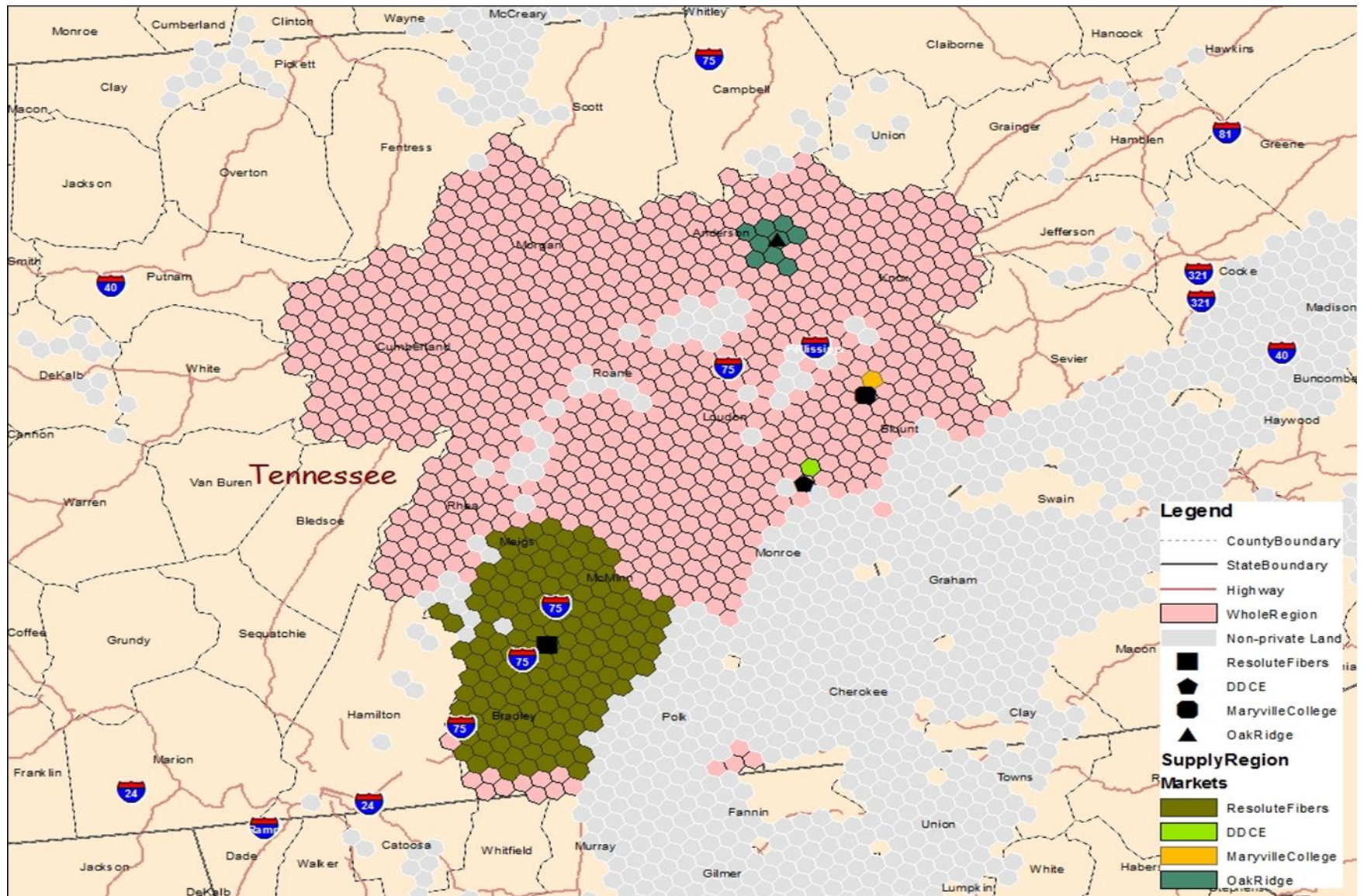


Figure 7: Markets and associated supply region for C_SR scenario (during harvest season)

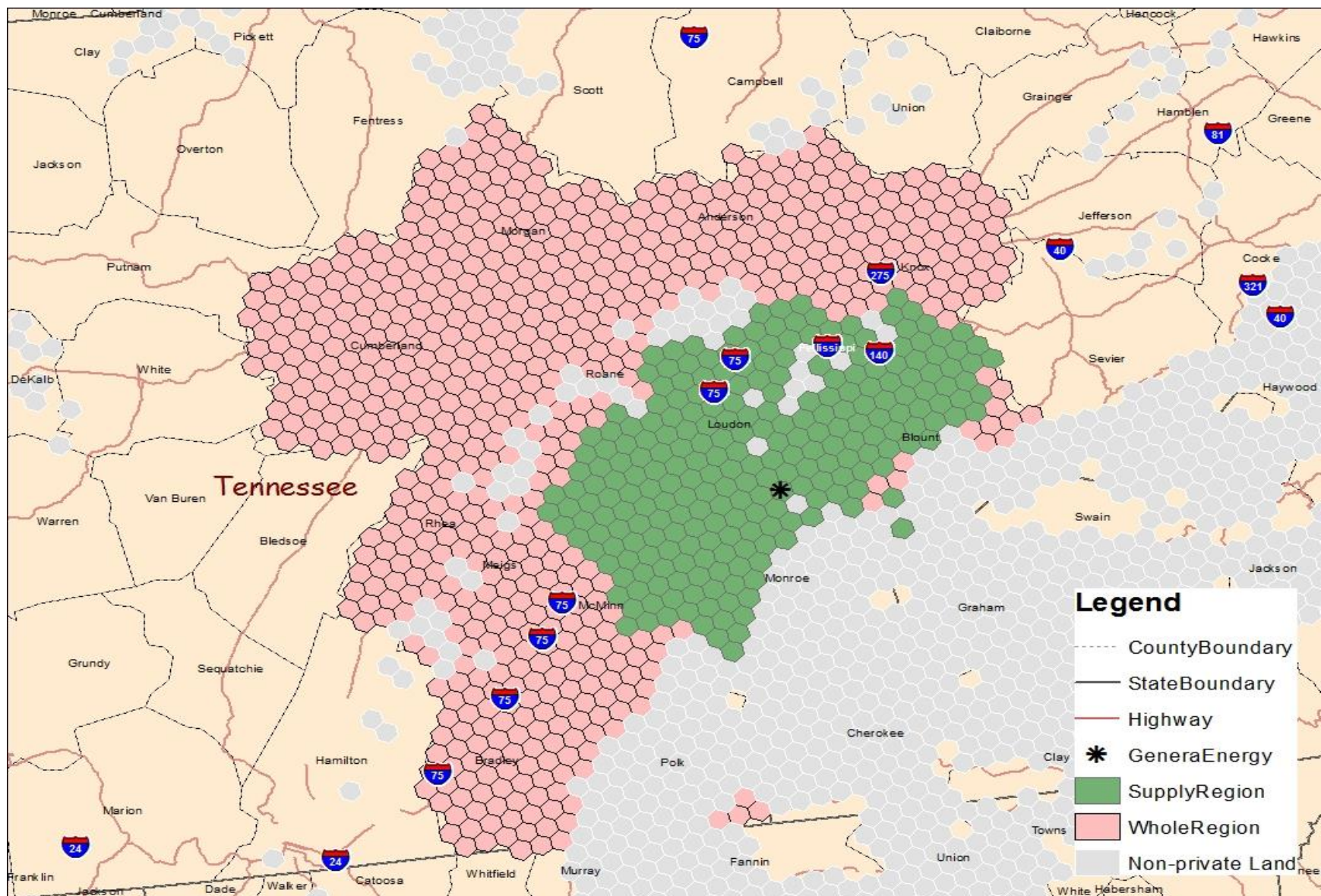


Figure 8: Supply region from farm to Genera Energy for C_SR scenario (during off-harvest season)

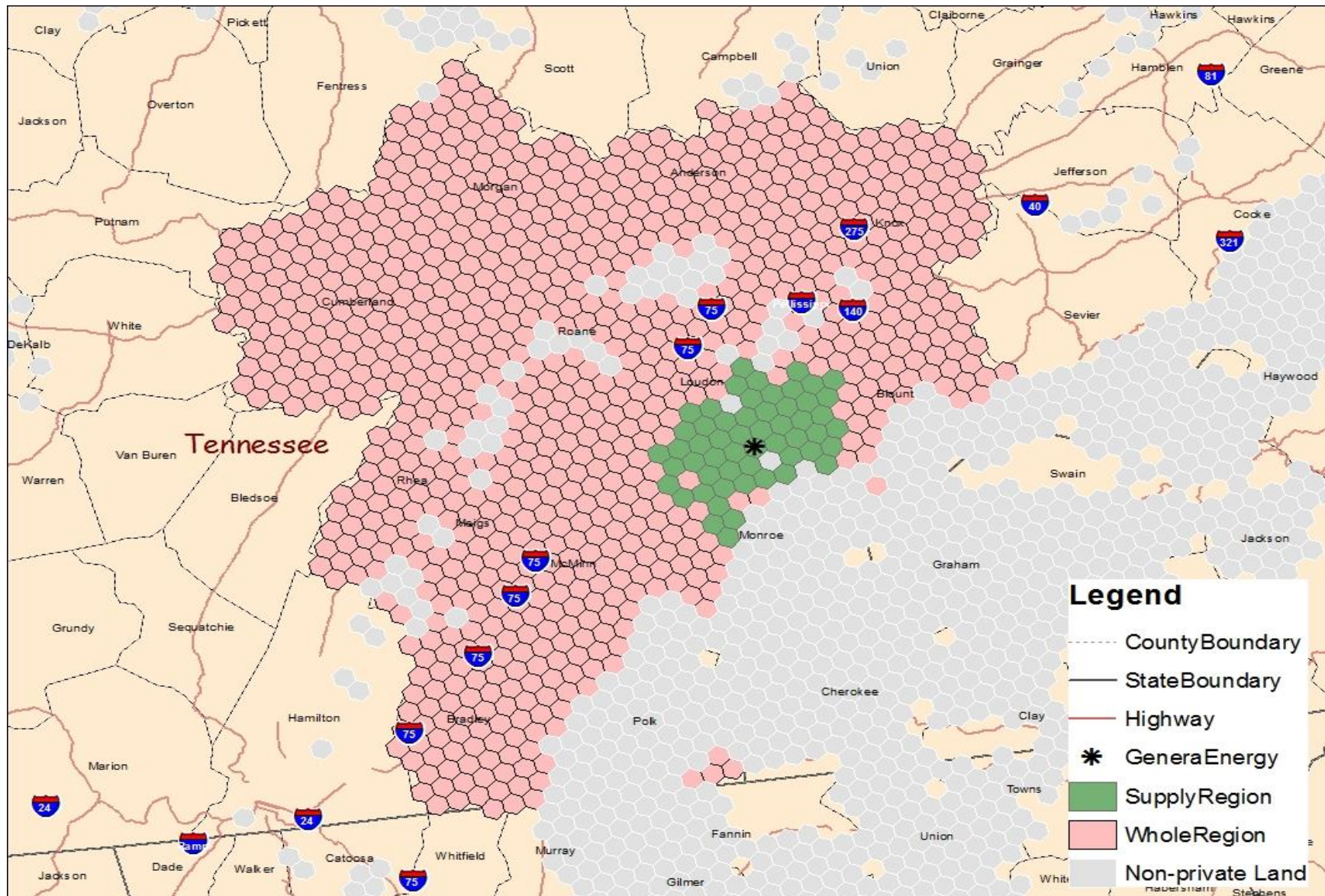


Figure 9: Feedstock supply region for B_P scenario from farm to Genera Energy

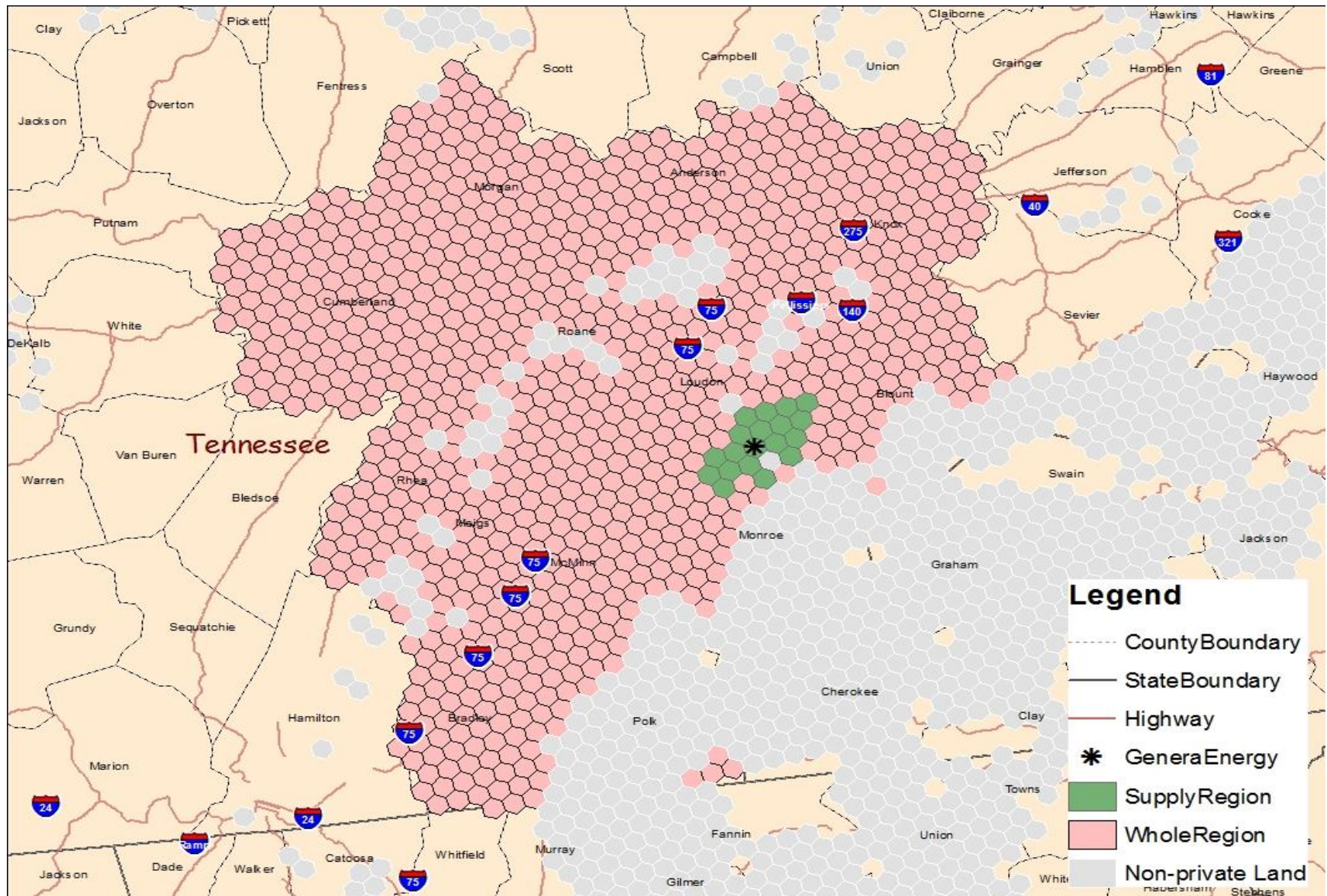


Figure 10: Feedstock supply region for C_SWB_P scenario from farm to Genera Energy (during harvest season)

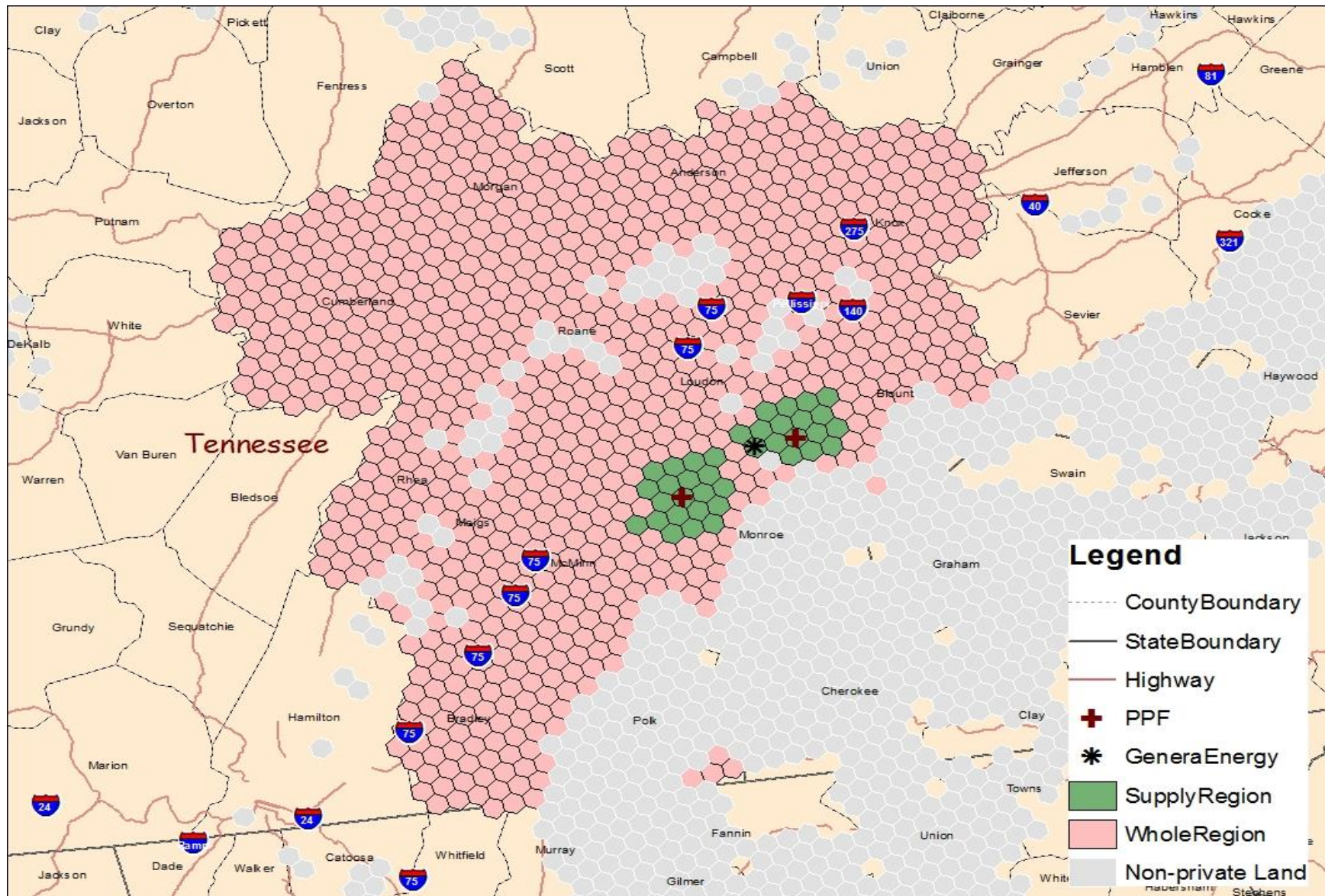


Figure 11: Location of preprocessing facilities (PPF) and supply region for C_SWB_P scenario (during off-harvest season)

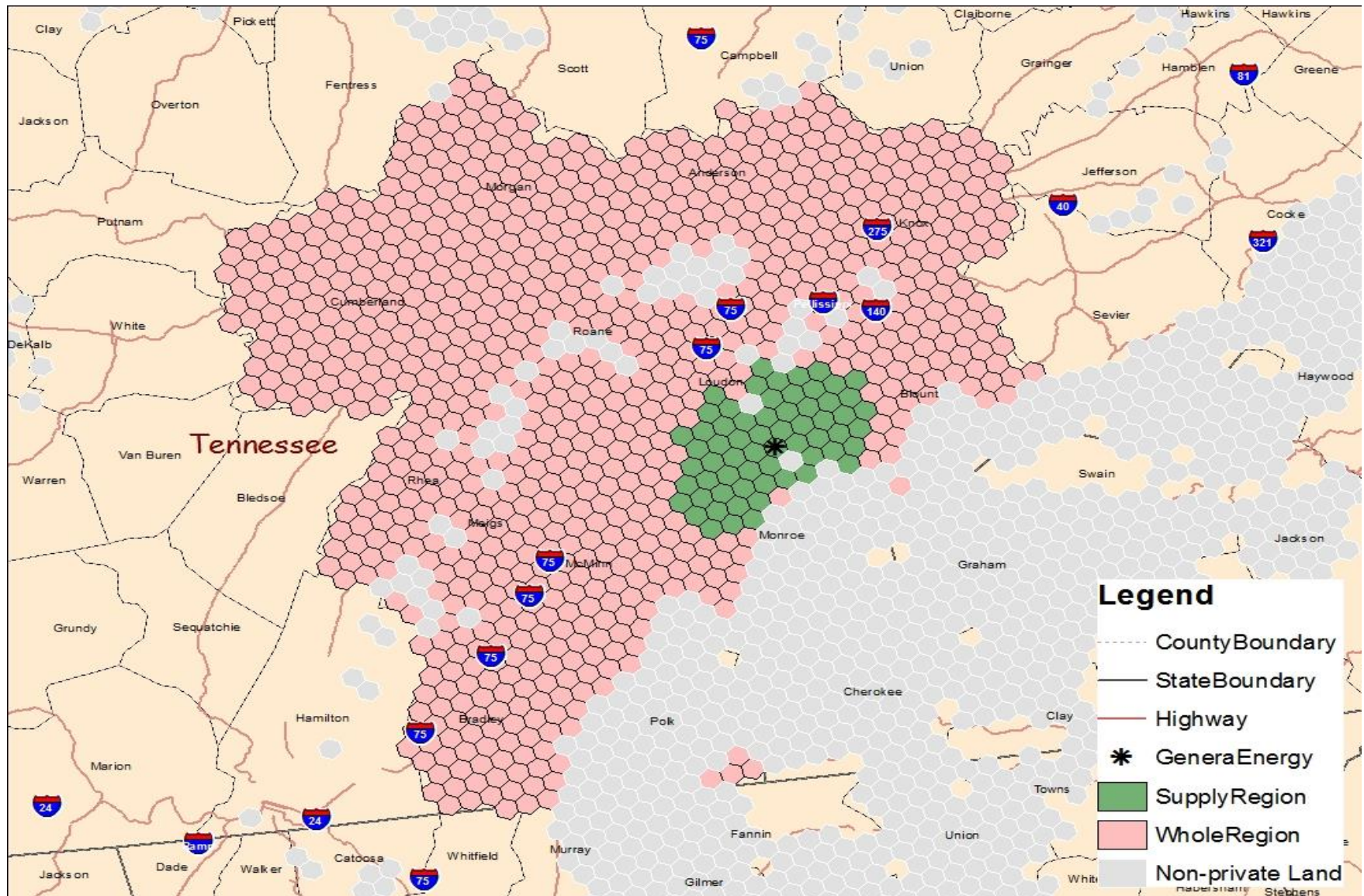
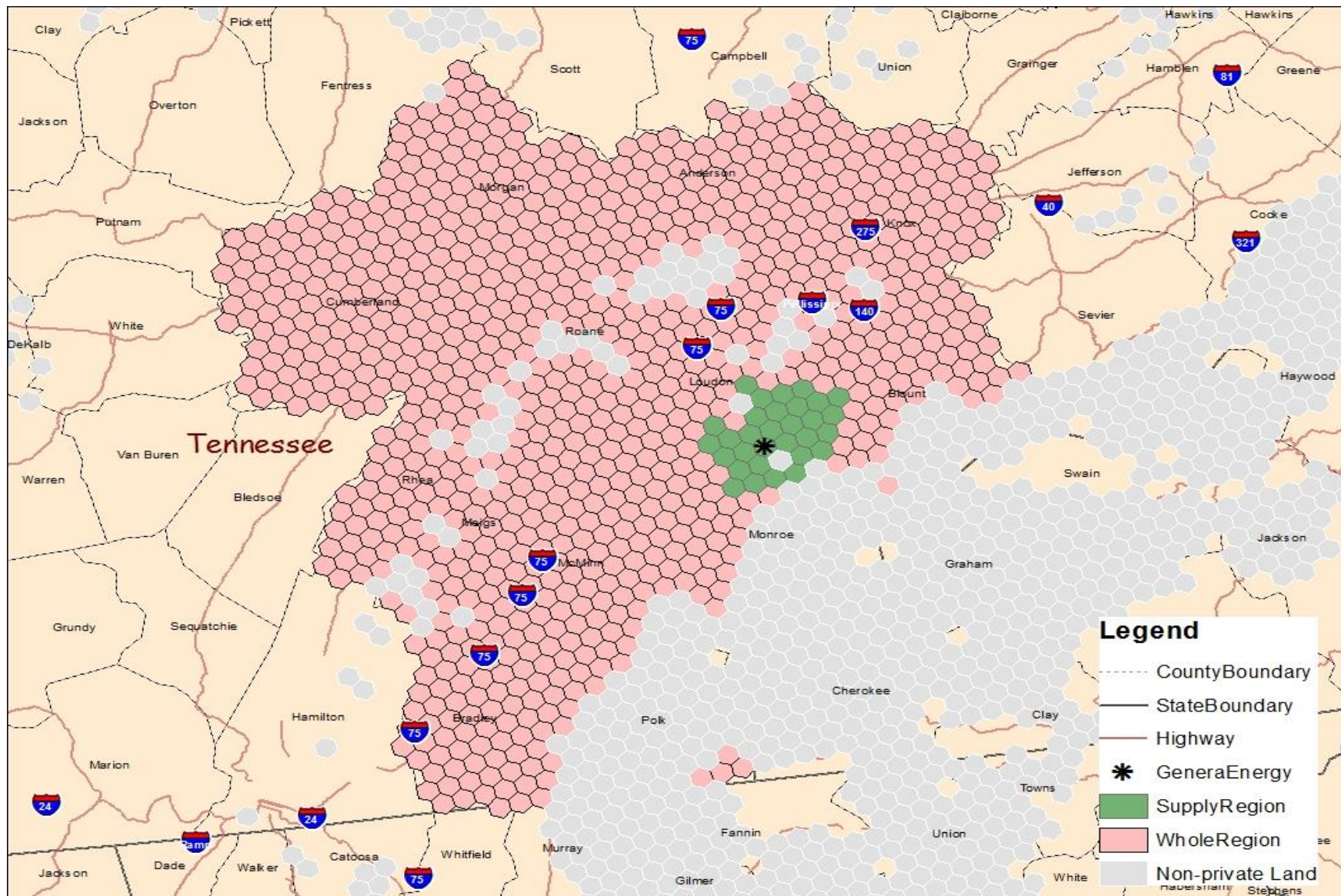


Figure 12: Feedstock supply area from farm to Genera Energy for C_SR_P scenario



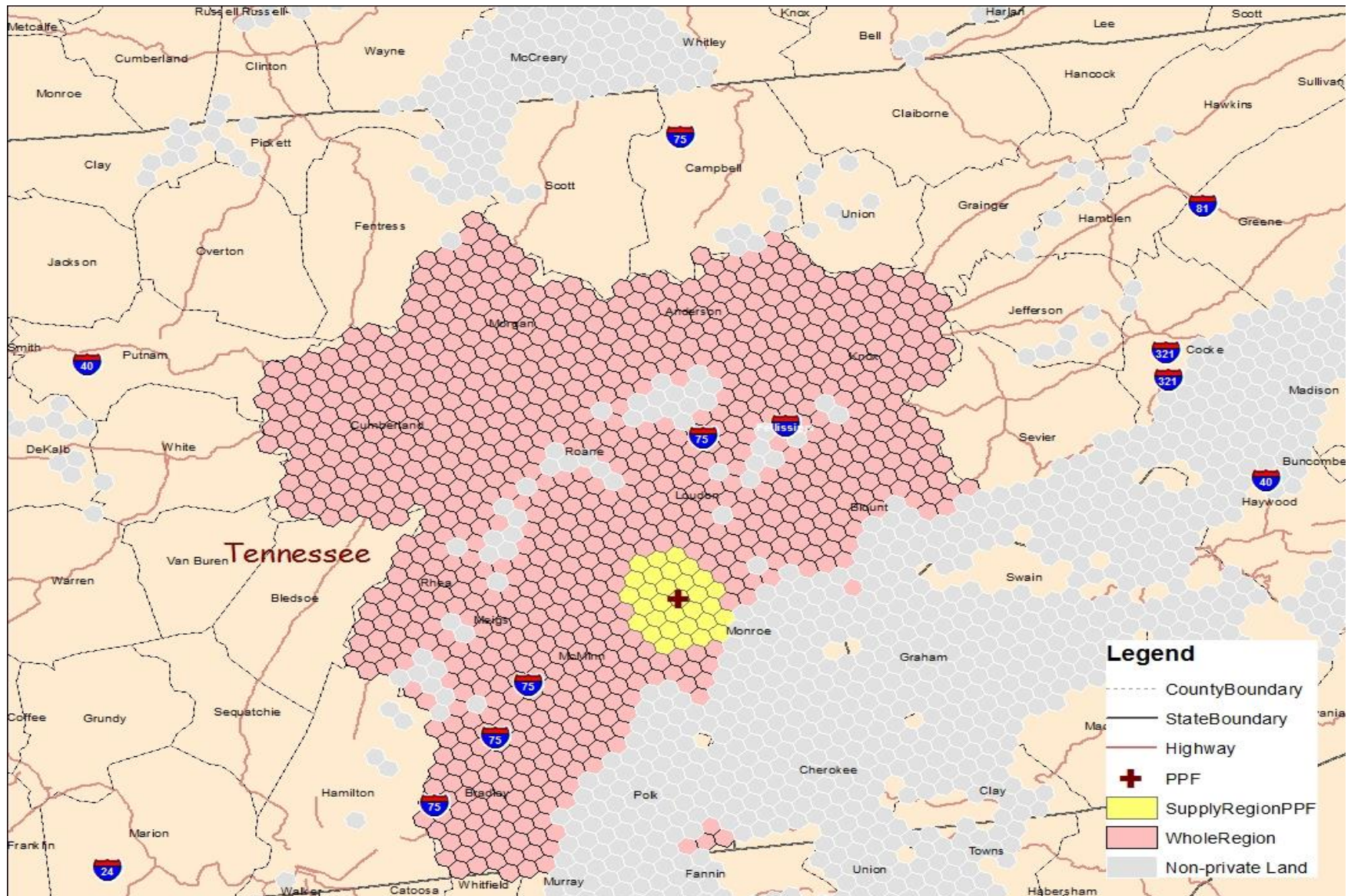


Figure 14: Feedstock draw area from farm to PPF for C_SWB_SLO_P scenario (during off-harvest season)

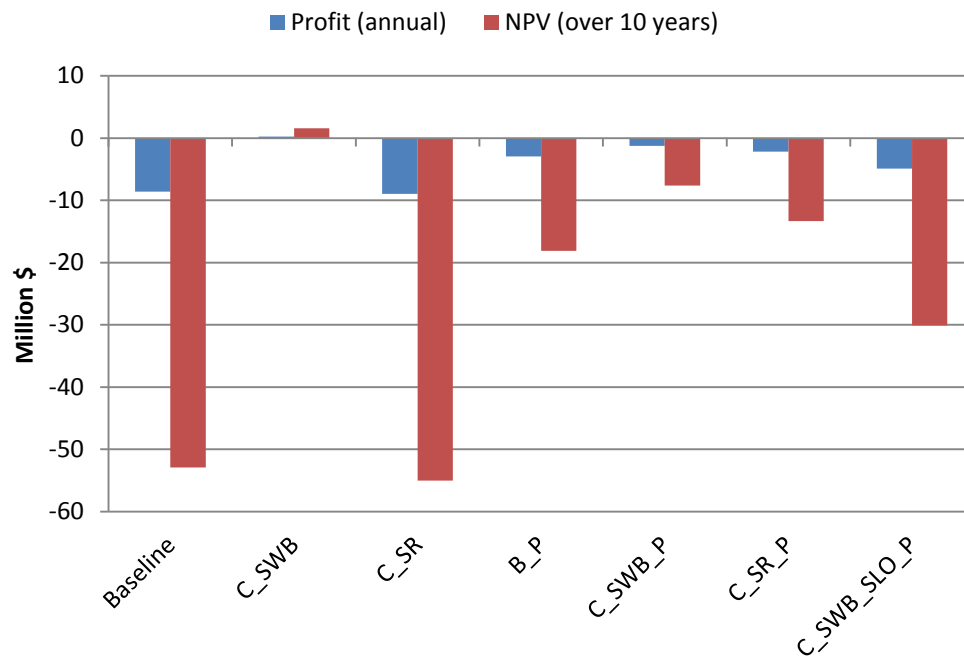


Figure 15: Profit and NPV in each scenario

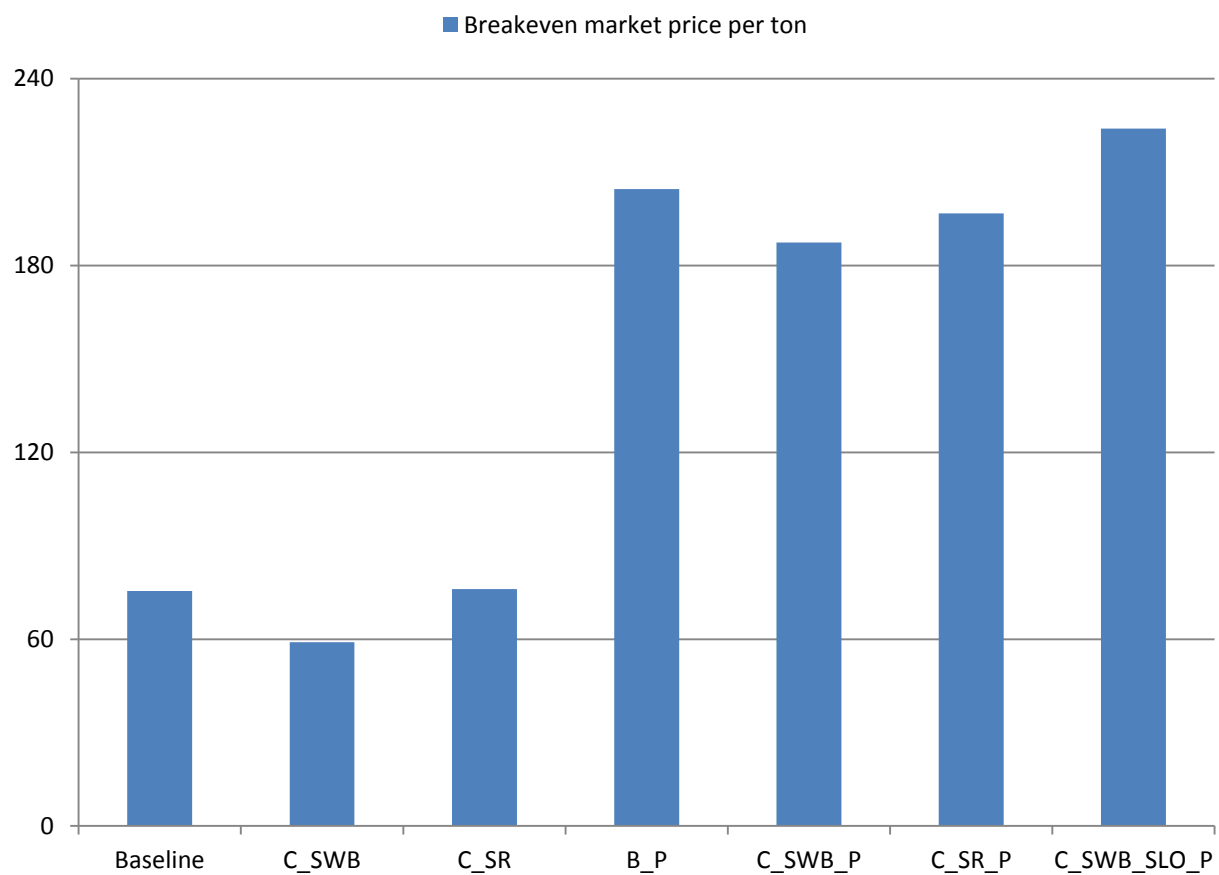


Figure 16: Breakeven market price in each scenario

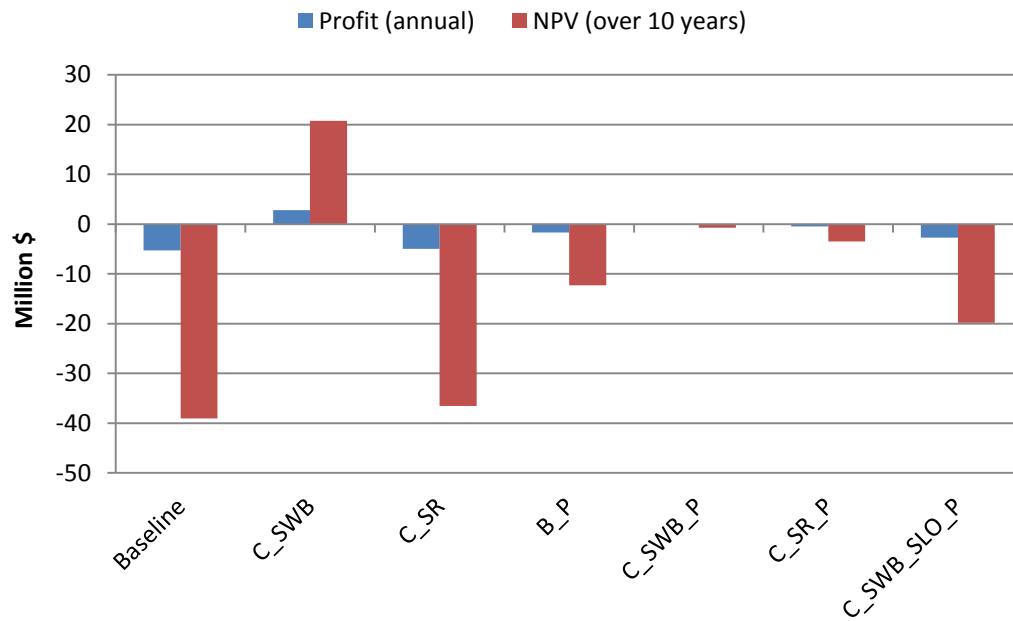


Figure 17: Profit and NPV in each scenario at 6% interest rate

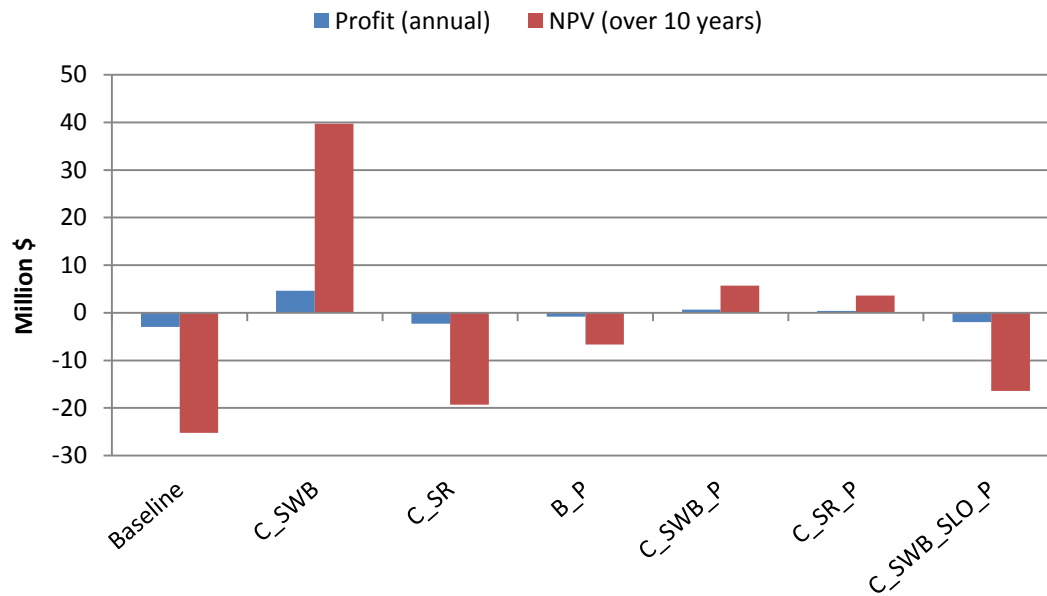


Figure 18: Profit and NPV in each scenario at 3% interest rate

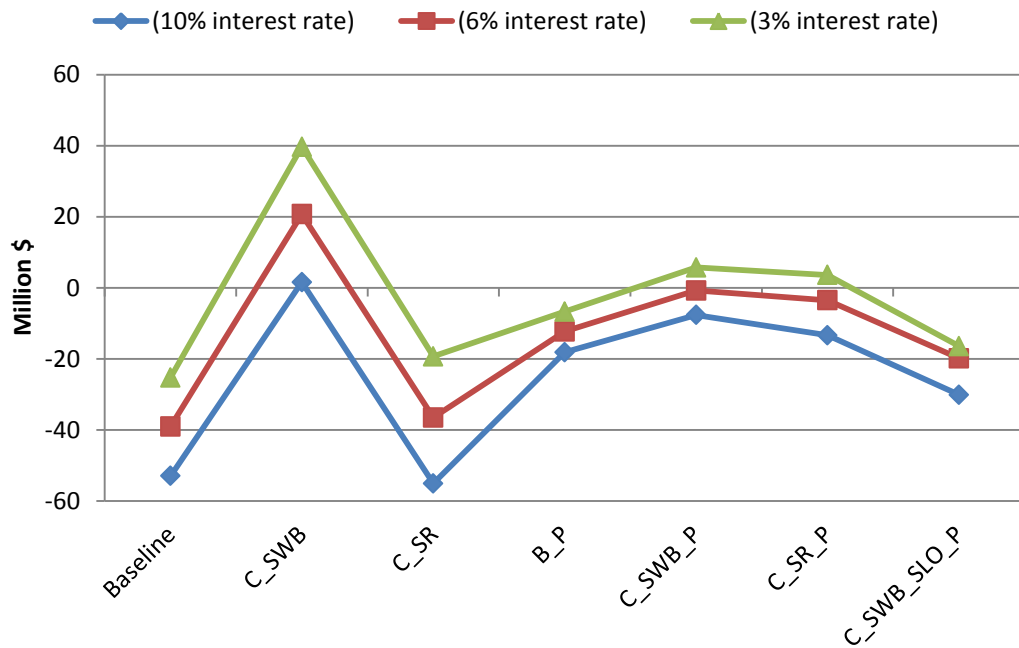


Figure 19: Comparison of NPV at different interest rates in each scenario

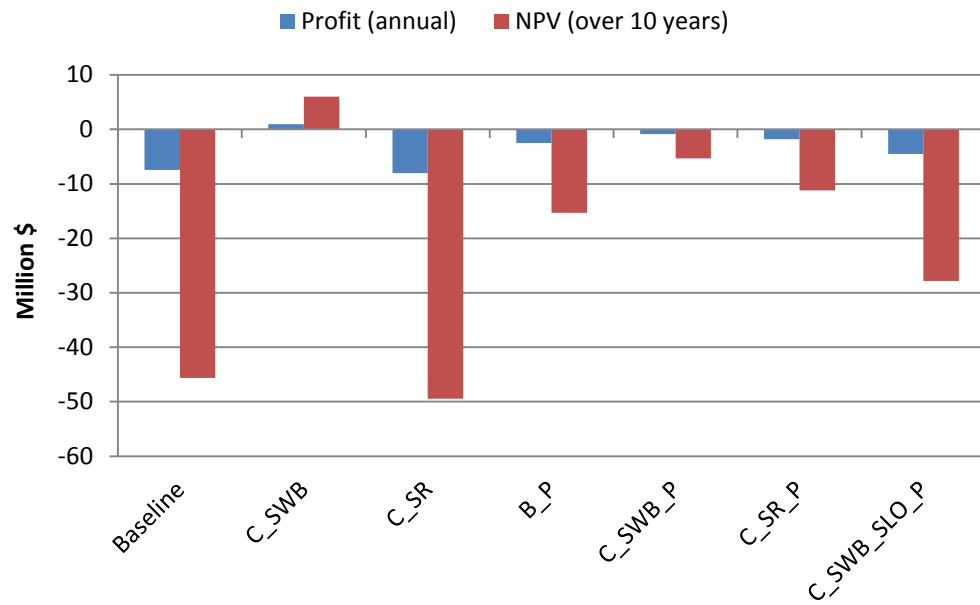


Figure 20: Profit and NPV in each scenario with 10% decrease in fuel price

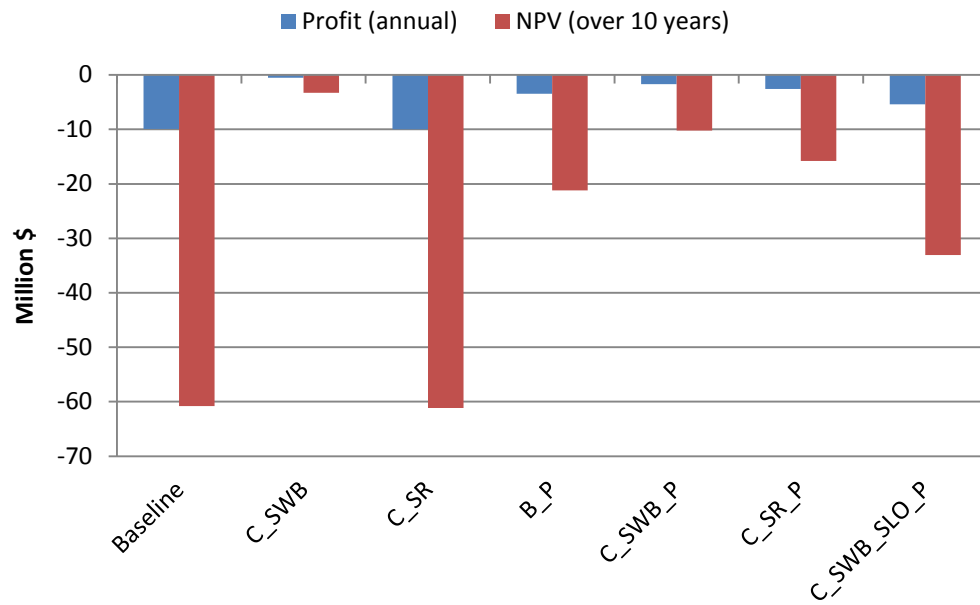


Figure 21: Profit and NPV in each scenario with 10% increase in fuel price

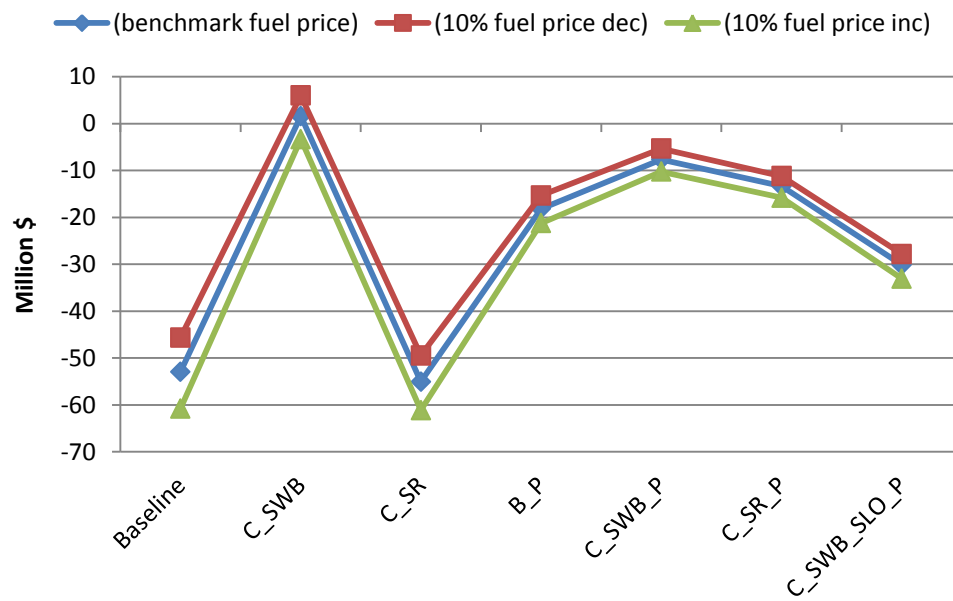


Figure 22: Comparison of NPV at different fuel prices

VITA

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