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BIOMASS ENERGY CROP PRODUCTION AND RESIDENTIAL PELLET
CONSUMPTION IN THE MIDWESTERN U.S.

BY

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THESIS

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Abstract

Concerns about national energy security and climate change have recently increased interest in renewable bioenergy. Specifically, the market for perennial grasses and agricultural residue for combustion for heat and electricity in the form of biomass pellets is explored. We present a cost-benefit analysis of consuming pellets for residential home heating, using previously published data, that is applied to the Midwestern U.S., in order to find out if biomass pellet fuel is competitive with non-renewable fuel. We then compare the costs to the actual production and consumption cost data from the Dudley Smith Farm production in Illinois and show the effects of current and potential policies. Using the data from Dudley Smith we investigate the current production cost in Illinois and compare it to estimated production costs in the literature. Finally, we present the results of a survey of current members and non-members of a biomass feedstock production cooperative in Missouri.

We show that the policies in place do substantially lower the cost of biomass pellets, making them competitive with natural gas, under our assumptions. Without the policies, natural gas is substantially less expensive than biomass pellets. Biomass fuel would be competitive without the policies only to consumers without access to natural gas, i.e. rural consumers. Carbon pricing has the effect of increasing the cost of non-renewable fuel at a much higher rate than non-renewable fuels, making biomass fuel increasingly competitive. Sensitivity analysis shows that substantial increases in production costs or decreases in yield will have noteworthy effects on the annual home heating cost. Our survey results show that almost half of the consumers switched from propane to biomass pellets, which allows us to propose that they did not have access to cheaper fuels such as natural gas and wood. Thus, biomass pellets may be more competitive in rural markets where choice is limited.

To my family.

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Chapter 1

Introduction

Concerns about national energy security and climate change have recently increased interest in renewable bioenergy. Specifically, the market for perennial grasses and agricultural residue for combustion for heat and electricity has gained momentum in recent years as non-renewable fuel prices have increased and legislation regulating greenhouse gas emissions has become likely. Using renewable feedstocks for heat and electricity provides a domestic source of energy that can lower greenhouse gas emissions and sequester carbon dioxide in the soil. However, renewable energy must be able to compete economically with nonrenewable fuels in order to be viable. Several governmental policies are in place that assist in the establishment of the renewable fuel market.

Current policies encourage the use of renewable energy by electric utilities, require the use of renewable transportation fuel blending and subsidize residential consumption of renewable energy. The Renewable Portfolio Standard sets various statewide requirements for renewable electricity production, and the Renewable Fuel Standard requires a national minimum of renewable transportation fuel production. The Biomass Crop Assistance Program subsidizes production of agricultural renewable biomass crops, and the EPA's Energy Star Program offers tax credit for purchasing appliances that consume renewable fuels. All policies provide incentives for increasing the production and consumption of bioenergy.

Agriculture forms a basic constituent of new bioenergy policies, as many forms of renewable fuels are derived from agricultural products. Developing the agricultural bioenergy market will have private costs and benefits for agricultural producers and consumers, and will also have social costs and benefits. This study accounts for the private costs and benefits of a single agricultural bioenergy market: biomass pellets. While this study focuses on only one of the social benefits— the reduction in greenhouse gas emissions from bioenergy consumption – other social benefits are worth mentioning, such as reducing dependence on imported fossil fuels, leading to greater energy security, and reducing nitrogen run-off and improving soil quality. Social costs may include the externalities from the production of bioenergy crops, such as diminished biodiversity from monocropping a single species of prairie grass, and the impact that replacing native prairie grasses with dedicated energy crops has on wildlife habitats.

“Biomass” in the widest sense refers to material derived from recently living organisms that are a part of the carbon cycle (including plants, animals, and their byproducts and waste), which can be converted into bioenergy. Biomass, in the form of plant feedstocks, can be used to produce various types of bioenergy: ethanol by fermentation, electricity from gasification, biodiesel from plant oils, and biomass feedstock pellets for combustion for heat and electricity. This study will focus specifically on bioenergy in the form of combustible pellets derived from three biomass feedstocks: *miscanthus x giganteous* (hereafter miscanthus), *panicum virgatum* (hereafter switchgrass), and corn stover, or the remains of corn crops post-harvest.

We focus on miscanthus, switchgrass and corn stover for several reasons. Simulated and actual data from Europe and the U.S. have shown that the Midwestern U.S. could have a comparative advantage in producing these particular plant species due to its geographic, soil and weather conditions (Khanna et al. [2008], Heaton et al. [2004]). These feedstocks are also uniquely well-suited to be processed into biomass pellets for combustion to generate heat and electricity, because their physical characteristics allow for smooth processing and because they have a high level of mBTUs per ton (Mani et al. [2006]). And while these crops are good candidates for combustible biomass pellets, they’re also good candidates for producing cellulosic ethanol. A developed market for miscanthus, switchgrass, and corn stover is a precondition for generating a commercially viable cellulosic production market. Early technology, like pellet production, may offer a possible end-use until the cellulosic ethanol production technology exists.

Biomass pellets used for home heating are small, densified, spheres of plant material that function much like wood pellets, producing efficient heat and energy with little ash residue. Some new furnaces and boilers specialize in the combustion of this material, while still accepting wood pellets, which are more widely available. We will first investigate to what extent there are private incentives to use biomass pellets for residential heating, followed by an analysis of government programs used to create incentives to produce and consume pellets for home heating.

In order to analyze the private incentives to consume biomass pellets, the costs involved in each step of the production process must be accounted for. This includes the break-even farm-gate production cost, transportation costs, and processing costs. The total cost combines all steps and represents a simplified break-even, conservative estimate of the cost of the biomass pellets. The case study is an economic cost-benefit analysis under representative conditions and assumes that profitability is the only factor in the production decision and a desire to minimize costs of residential heating is the only factor in the decision to consume biomass pellets. There are many other factors that effect production and consumption decisions: information barriers, beliefs about the future price and demand for biomass, as well as unaccounted for transactions costs. As the case study is a generalized calculation, we will use the survey to supplement

straightforward cost-benefit analysis in order to identify the differences in perceptions, information, and metrics for evaluation that exist for producers and consumers.

To succeed, renewable bioenergy must be economically competitive with non-renewable fuels. Previous literature has provided separate economic analysis of each step of the production and consumption of biomass pellets. Production literature uses field trials and simulations to find the per ton farm-gate cost of producing biomass feedstocks (Heaton et al. [2008], Khanna et al. [2008]). Transportation cost literature estimates transport costs specific for biomass feedstock (Searcy et al. [2007]). Biomass pellet processing costs have been studied as well (Samson and Duxbury [2000], Mani et al. [2006], Smeets et al. [2009]). However very few studies have combined this data to present a full estimate of the costs of using bioenergy in the form of pellets for home heating in the U.S. (Smeets et al. [2009] does so, but focuses on the EU).

Currently no established market for biomass pellet fuel exists, so production costs must be constructed from representative studies that provide costs for each step of the production process. We will itemize the private costs to produce feedstocks for biomass pellet production and the costs to consume bioenergy for home heating. We then present the comparative annual costs, annualized at a 4% discount rate and the lifetime of each feedstock. After investigating the private incentives for production and consumption, we will discuss the implication of governmental policies, and the way that current and future policies change the price of biomass relative to traditional fuel.

We have also collected actual cost data on the production and processing of miscanthus in Illinois. The Dudley Smith Initiative at the University of Illinois funded planting of miscanthus at the Dudley Smith farm in 2004 and expanded acreage in 2005 and again in 2008. Currently, there are 6 acres of miscanthus: 2 acres total from the first two plantings and about 4 acres from the most recent planting. The miscanthus has been harvested annually and processed into pellets for combustion at the Christian County Extension office, where two biomass furnaces are installed.

As Villamil et al. [2008] point out in their study of potential biomass producers, the decision to produce biomass feedstock is not based solely on cost-benefit analysis; many other characteristics of each unique production situation effect the decision, such as education, age and location. Likewise, the decision to consume biomass feedstock is expected to be just as complex as the decision to produce, as several studies of European consumers have shown (Jablonski et al. [2008], Nyrud et al. [2008], Verma et al. [2009], Fielder [2004]). In order to further describe the complex decision-making process, we present the results of a survey of producers and consumers in Missouri. We chose Missouri because a biomass pellet processing plant is located in Centerview, which provides producers with a market and consumers with a product.

Thus, this study will examine biomass feedstock pellet production and consumption from several angles.

We present a cost-benefit analysis of consuming pellets for residential home heating, using previously published data, that is applied to the Midwestern U.S., in order to find out if biomass pellet fuel is competitive with non-renewable fuel. We seek to answer the following questions: Do the policies in place subsidize the production costs significantly enough to make biomass fuel competitive? Would biomass fuel be competitive without the policies that are in place? What are the possible effects of the pending policy of carbon pricing? How much does biomass production cost effect overall annual heating cost?

We then compare the costs to the actual production and consumption cost data from the Dudley Smith Farm production in Illinois and show the effects of current and potential policies. Using the data from Dudley Smith we investigate the current production cost in Illinois and compare it to estimated production costs in the literature. Finally, we present the results of a survey of current members and non-members of a biomass feedstock production cooperative in Missouri. Questions we attempted to answer using the survey include: What type of farm production characterizes current biomass producers? What production changes were made on farms to allow for biomass production? What type of producer is likely to consume biomass, and what types of appliances are used? What are the motivations behind producing, consuming, not consuming and not producing biomass?

To begin, we present background information about the production of each biomass feedstock and the consumption of biomass pellets at the private and industrial level. We will also describe the traditional fuels consumed for home heating that are used in our comparison.

Chapter 2

Background

Miscanthus is a non-invasive tall perennial grass that features C4 photosynthesis, allowing it to store high amounts of energy. Historically, the grass has shown high yields in Illinois, and it promises even higher yields through genetic and technical development (Heaton et al. [2008], Khanna et al. [2008]). Miscanthus has been bred to be sterile, so rhizomes of the grass must be planted for cultivation. It will not yield biomass the first year it is planted and may yield only half of its potential the second year it is produced. It has an estimated lifespan is 15 years.

Switchgrass is another perennial prairie grass, native to Iowa. It has lower yields than miscanthus in Illinois (Khanna et al. [2008]). It also has a one year initial development, not yielding its first full crop until the second year. The average estimated lifespan of switchgrass is 10 years. Neither switchgrass nor miscanthus require substantial inputs of chemical pesticides and fertilizers (Khanna et al. [2008]).

Corn stover, a third option considered for biomass feedstock production in Illinois, is the residual post-harvest biomass after corn harvest. Corn itself can still be harvested and sold, and therefore, the opportunity costs of producing corn stover are lower compared to complete conversion to prairie grass. Some studies have shown that removing certain proportions of biomass post-harvest is not detrimental to the soil nor future cultivation (Gallagher et al. [2003]).

Mechanical densification, or pelletization, of biomass for combustion has been in existence since at least the early 1900's (Mahapatra and Madlener [2007]). Wood waste residue has been the traditional source of biomass pellets and fueled the early development of pellet producing technology. The market for dedicated crops, rather than wood waste, for densification and combustion is relatively young in the U.S. Miscanthus, switchgrass, and corn stover, have attractive and promising characteristics for pellet production. They are high in density, low in ash content, and have low moisture levels at harvest.

Residential biomass consumption involves using biomass pellets as a source of home heating fuel. Although residential consumption of biomass has begun in the United States, is far from widespread. Several companies sell furnaces and other appliances specifically designed for burning biomass pellets, and pellets are commercially available (albeit predominantly wood-based). Currently only one pellet production facility

in the Biomass Crop Assistance Program database of facilities is eligible for government subsidies in Illinois (ADM in Decatur). However, several wood pellet processing plants are considering expanding into the biomass feedstock processing market (Gary Letterly, personal communication).

Residential heating using pellets can be done with several different appliances: fireplace inserts, free-standing stoves, and boiler and forced-air furnaces. The prices of these appliances vary widely, depending on the amount of heat they are expected to provide, the amount of maintenance and installation necessary, and their expected lifetime. Using these new products requires new household infrastructure and increased education and labor, compared to traditional heating fuels.

Industrial biomass consumption, while relatively young as well, has been studied as an answer to growing concerns about climate change and a national carbon pricing policy. Industrial biomass consumption generally involves co-firing biomass with non-renewable fuels, such as coal, generating heat and power. “Co-firing” refers to combining biomass feedstock with non-renewable fuel (primarily coal), for combustion in order to create energy. Co-firing allows industries to produce less greenhouse gas emissions and consume less non-renewable fuel, while still producing the same amount of heat or energy. Industries seeking to preemptively lower their greenhouse gas emissions before legislation is passed can do so by retrofitting current systems to accept biomass as well as coal. Baxter and Koppejan [2004] describes the process as one of the lowest risk and least expensive options for lowering emissions for power producers.

Traditional heating fuels used in the Midwestern U.S. for heating, according to the Energy Information Administration, are natural gas, electricity, propane, fuel oil, wood, and kerosene. Natural gas is generally the cheapest and most popular choice for residential heat, but natural gas lines do not always extend to rural areas. For rural consumers, electricity is more widely available. The cost and environmental effects of electricity vary across the U.S. as the source for electricity varies. Electricity in the state of Illinois comes from approximately 50% nuclear energy and 50% coal fired energy. Electricity is the most expensive source in our comparison, but can also be consumed at a higher efficiency (new electric furnaces are rated 95%-100% efficient, while new natural gas furnaces may still hover around 80%-90%). Rural homes that have access to inexpensive wood may choose a wood-based heating system as the primary or secondary heating source. Propane, fuel oil, and kerosene are generally more expensive and therefore used primarily in rural areas, where choice of heating fuel is quite limited. Kerosene was the least popular fuel for heating (and falling sharply in popularity from over 4,000 users in 2003 to just over 1,000 users in 2008 in Illinois) and is not included in our comparison. Average 2009 prices per GJ¹ in the Midwestern U.S. were \$30.93 for electricity, \$22.18 for propane, \$17.79 for fuel oil, \$11.52 for natural gas. Wood pellets in 2009 were selling for \$13.00

¹Three-year or two-year Illinois averages from the Energy Information Administration, if available; Indiana average if not.

GJ⁻¹ in Fisher, Illinois.

The average home in the U.S. is 164.35 meters² (1769 ft.²) according to the U.S. census. The amount of energy required to heat a home is determined by many things, including the location, design, and material of the home, which can range from very efficient to very inefficient. The national average amount of BTUs consumed by a house that is 139.35-185.71 meters² (1500-1999 ft.²), the national average size of a home, is 72.69 GJ (68.9 million BTUs) per year, according to the Energy Information Administration. Efficiency levels of heating systems vary according to fuel source, age, and the home's infrastructure. For this study, we will assume that the average required GJ includes, endogenously, an average efficiency as well. That is to say that the average energy requirement takes into account the average efficiency levels of all reporting homes, thereby giving us an average energy requirement that automatically includes the average efficiency. Using 72.69 GJ as the average annual consumption, the average annual cost of heating a home, using EIA averaged prices is \$2,248.54 for electricity, \$1,664.07 for propane, \$1,292.94 for fuel oil, and \$837.68 for natural gas.

Biomass pellet consumption requires installation of an appliance specifically designed to consume pellets. There are typically three options for combustion of biomass in a home: stand-alone stoves (like traditional wood-burning stoves), fireplace inserts, and full-size furnaces. Stoves and inserts provide supplementary heat for a home, and still require a furnace. Pellet furnaces are generally capable of heating average-sized homes, but for this study we will assume that there will be a back-up furnace capable of producing heat using traditional fuel sources. Under that assumption, the cost of the furnace will be additional and will effect the overall home heating costs. Nine manufacturers offer similar models at similar prices; the average BTU maximum is 100,000 and the average price is \$4,098, without installation costs.

There are several categories of government policy that effect the cost of renewable energy. The first category of policy includes the Renewable Portfolio Standard, or RPS. Statewide initiatives increase demand for renewable energy by creating mandates concerning the source of electricity generation. For example, in Missouri, voters enacted a statewide initiative that mandated a renewable electricity requirement of 15% by 2021. In Illinois, the legislature mandated that 25% of the electricity generated by investor-owned utilities be renewable. This policy also creates demand for producers of renewable electricity.

This category also includes voluntary agreements between producers and consumers of renewable electricity generation, like the Green Power Partnership within the EPA. According to the EPA, most states have Green Power providers that provide renewable electricity at a premium ranging from around \$.009 to \$.03/KWh. The renewable energy is from landfill gas, wind, hydroelectric, or other bioenergy products. The EPA also provides a "partnership" relationship with organizations that purchase from Green Power

providers, which can be used in the same way that Energy Star labels on appliances increase their value and appeal to environmentally conscious consumers.

The next category are the incentives for liquid fuel production, as seen in the Renewable Fuel Standard, or RFS. As mentioned earlier, the RFS requires a certain amount of the national fuel production of fuel to be renewable (the current goal is 136 billion liters by 2022), and offers production subsidies to make it less expensive.

The third category of incentives are direct subsidies for the production and consumption costs of biomass feedstocks. We will investigate the effects of these policies as they will effect the costs of production and consumption of biomass pellets for home heating. The production subsidy is called the Biomass Crop Assistance Program, or BCAP; it pays producers 75% of the cost of establishment of biomass crops for two years and up to \$45 a ton in matching payments to the producer. The lower production costs decrease the final cost of biomass pellets. The consumption subsidy is in the form of a tax credit for the purchase of a new appliance that uses renewable bioenergy up to \$1500 of the purchase and installation price. The purchase of a pellet-based appliance is included in this opportunity.

The last category of incentives for renewable energy production and consumption are possible future policy. One future policy that may directly effect the economic incentives for biomass feedstock production and consumption is greenhouse gas pricing, or a tax on greenhouse gas emissions. While no national program to limit or tax greenhouse gas emissions presently exists, congress has introduced several bills that attempt to price greenhouse gas emissions. Recently, the Waxman-Markey Bill was introduced in the Senate, outlining a method of limiting greenhouse gas emissions using a cap-and-trade system. While not as direct as a “carbon tax”, cap-and-trade issues permits that allow a certain amount of emissions that can then be bought and sold, which could essentially “price” greenhouse gas emissions. Such permits can then be bought or sold, creating a market for greenhouse gas emissions.

The European Union began a cap-and-trade system in 2005. Businesses must hold permits in order to emit greenhouse gases, and these permits are bought and sold on a market that functions much like traditional commodity markets. CO₂-equivalency is the method used to convert all greenhouse gases into a comparable measurement that reflects their global warming potential (GWP). Carbon dioxide, as the baseline, has a GWP of 1, while methane has a GWP of 12, meaning that each ton of methane emitted is 12 times more harmful than one ton of carbon dioxide (or is the equivalent of 12 tons of carbon dioxide). So one ton of methane equals 12 tons of CO₂-equivalent greenhouse gas emissions. The market price of one ton of CO₂-equivalent emissions was traded at around \$20 at the the beginning of 2010 in the European Union.

Using the IPCC coefficients for fuel generation and previous research in greenhouse gas emissions from

biomass pellet production, we can approximate the effect of a carbon price on the present value cost of heating a home, while combining it with the policies previously described. Chen [2010] calculated the emissions at the farm-level for production of biomass and Mani [2005] calculated the per ton emissions of processing biomass feedstock. Combining these emissions will allow us to calculate the effects that a carbon pricing policy could have on the cost of home heating using biomass pellets. Production of agricultural crops releases greenhouse gas emissions from chemical production and application, and farm machinery fuel use, for example. Table 1 shows the emissions from production of each biomass feedstock, according to Huang and Khanna.

The total emissions from biomass feedstock pellet production are 44 Kg CO₂-eq. ton⁻¹, based on the emissions reported in Mani [2005], and modified for grass processing rather than wood chip processing. Greenhouse gas emissions vary, of course, depending on several variables, including the fuel used to dry the feedstock, the amount of heat and power used, and the scale of the operation. The total used here is based on a streamlined or simplified life cycle analysis performed by Mani [2005], which is thorough enough to include emissions from such processes as diesel and electricity production, but is simplified to meet economic, logistical and scientific constraints. The calculation was modified to account for the lower moisture content of miscanthus, switchgrass, and corn stover, compared to wood residue (15% versus 40%), the basis for Mani [2005]. Less fuel is used to dry the biomass, consequently, less greenhouse gas emissions are produced.

The emissions reported in Mani [2005] are based on coefficients specific to British Columbia, where 90% of electricity is produced via hydropower. The emission factors of hydro-powered electricity generation range from 2-48 g CO₂-Eq./kWh according to Savocool [2008]. According to the Energy Information Administration, half of Illinois' electricity generation comes from coal and most of the other half comes from nuclear energy. Nuclear energy has an emission coefficient of 0, according to the IPCC, but coal-generated electricity has an emission coefficient of 790-1182 g CO₂-Eq./kWh. Taking the average of the range, we can estimate the coefficient for coal-generated electricity at 986 g CO₂-Eq./kWh and the average for hydropower-generated electricity is 25g CO₂-Eq./kWh. Therefore, the difference between hydropower emissions and coal-generated emissions is 961g CO₂-Eq./kWh. In applying this difference to half of the electricity used in the pelletizing process to make the study applicable to Illinois, the total emissions increase by .03 Kg CO₂-Eq. ton⁻¹. This brings total emissions from processing to 44.03 Kg CO₂-eq. ton⁻¹.

The emissions from pellet production are added to the emissions from production of each biomass feedstock, and Table 2 shows the total emissions from production, processing and use of each fuel. Traditional fuel emissions come from the Energy Information Administration, EIA.

Chapter 3

Literature Review

Our review of relevant literature begins with an overview of studies concerning the production of switchgrass, miscanthus, and corn stover. We then survey the literature relevant to the decision of the potential biomass producer. Finally, we present current research about the consumption of biomass in residential and industrial settings.

3.1 Biomass Feedstock Production

The U.S. Department of Energy established the Herbaceous Energy Crops Research Program in 1984 to study the potential of various perennial energy crops in the U.S. Of the 35 grasses studied, switchgrass was chosen as the most promising for U.S. production, and has therefore been studied more than miscanthus in the U.S. However, as further research has shown, miscanthus is competitive with switchgrass, and could surpass it in yield in some locations (Heaton et al. [2008], Lewandowski et al. [2003], Khanna et al. [2008]).

There are many studies concerning switchgrass and miscanthus production in the EU and other countries (Smeets et al. [2009], Huisman et al. [1997], Clifton-Brown et al. [2004]), but few that focus specifically on U.S. biomass production costs and even fewer that focus specifically on miscanthus and switchgrass production costs in the Midwest. The studies that cover biomass production costs vary widely due to differing assumptions about production costs.

Studies differ in their estimate of costs due to differences in the assumed yields, the categories of costs included, the year in which prices are reported, and the discount rate used in calculating the net present value. Yield estimate vary in the timing of the measurement as well as the percentage of yield loss that is assumed throughout the production process. Certain variables are included in some studies and not included in other calculations, such as transportation, storage, and land rent, or the opportunity cost of producing alternative crops. All of these differences in calculation affect the final production cost per ton.

3.1.1 Switchgrass

Switchgrass occurs in two forms that have very different morphology: upland and lowland. The upland type is shorter and more cold-tolerant, while the lowland variety is taller, coarser, more productive, and less cold-tolerant. The variety of switchgrass called Cave-in-Rock, an upland type, is well-suited for the midwestern U.S., while lowland varieties such as Alamo and Kanlow are better suited for southern regions of the U.S. (Lemus and Parrish [2009], Mooney et al. [2009]). Estimates of yield and production costs will vary depending on the variety that is being studied.

Table 3 summarizes data from the literature on switchgrass production. In one of the earliest field trials of switchgrass production costs, Sladden et al. [1991] reported yields of eight varieties of switchgrass in Shorter, Alabama, ranging from 6.76 Mg ha^{-1} all the way to 34.60 Mg ha^{-1} , depending on the variety of switchgrass grown. The two higher yielding (and thus, lower costing) varieties are Alamo and Kanlow.

The production cost is estimated between \$9.94 to \$50.89 Mg^{-1} , with Alamo and Kanlow estimated at \$19.70 and \$24.91 Mg^{-1} , in 1989, respectively and \$9.94 and \$14.82 Mg^{-1} , in 1990, respectively. This cost calculation does not explicitly include land rent costs, or the opportunity cost of land with respect to alternative crops. It also does not include storage and transportation costs, which could be why it is among the lowest of the calculations.

Another early survey of potential biomass crops in the U.S. by Turhollow [1994] included simulations of the costs of switchgrass production in the Midwest. Using assumptions about improved technology and increased education, Turhollow [1994] calculated costs in 1989 and simulated costs in 2010, both in 1989 dollars. These break-even costs include land rent, storage, and production costs, but not transportation costs. Land rent is based on corn production in the midwest and is $\$154 \text{ ha}^{-1}$. Yield losses are assumed to be about 30%, with final yields being 9 Mg ha^{-1} in 1989 and 14.4 Mg ha^{-1} in 2010. Total annualized costs are $\$68 \text{ Mg}^{-1}$ in 1989 and $\$48 \text{ Mg}^{-1}$ in 2010. This assumes that technology and knowledge will lead to improvements in production thereby decreasing costs. Such assumptions of improved technology and knowledge are supported by McLaughlin and Kszos [2005] in their report on the effects of ten years of research on switchgrass yields and costs. They found that yield increased by about 50%, and the need for inputs decreased as well due to breeding. This led to decreases in production costs estimated at 25%, in line with Turhollow [1994]’s assumptions. Still, even with the increased education and lower costs, the cost per Mg is much higher than Sladden et al. [1991], presumably because the cost of land, storage and transportation are included.

Hallam et al. [2001] use results of actual field trials to estimate costs of biomass energy crop production in Iowa. The trials lasted from 1988 to 1992 and switchgrass yields ranged from 6.5 t ha^{-1} to 15.8 t ha^{-1} ,

with an average between 11.13 and 11.60 t ha⁻¹, depending on the location. Total cost per ton includes storage, transport, capital, labor and cost of land; it averages \$38.90-\$47.65 t⁻¹, depending on location. The total cost per ton estimate is lower than a similar study specific to Iowa by Duffy [2001]. This is likely because the yield is lower in the study by Duffy [2001] (they used a yield of 4 t DM acre⁻¹ or about 8.8 t ha⁻¹). The cost of land is slightly lower (about \$165 ha versus \$197.68-\$284.17) in Duffy [2001], but the end cost total is still higher at \$66.15. Yields from field trials in Iowa published by Vogel et al. [2002] support Hallam et al. [2001]’s yield results rather than those by Duffy [2001]: they ranged from 10.5-12.6 Mg ha⁻¹.

More recently, Perrin et al. [2008] report the results of field trials in the Upper Plain states: North Dakota, South Dakota and Nebraska. The trials cover five years, and data was averaged and extrapolated to simulate a 10 year rotational period reflecting the lifetime of switchgrass stands. The extrapolated estimate of yield and production cost is 7 t ha⁻¹ and \$59.10 Mg⁻¹, including storage and land rent (\$64-\$222 ha⁻¹), and not including transport costs.

Khanna et al. [2008] and Jain et al. [2010] report much higher figures than the previous studies. Both studies simulate costs specific to Illinois, using delivered yield, including land rent and storage. Khanna et al. [2008] reports a total cost of production at \$98.19 t⁻¹, and Jain et al. [2010] reports \$117-\$151 t⁻¹. The higher total costs in these studies are attributable to several variables. Khanna et al. [2008] use a lower yield (7.01 t ha⁻¹) than other studies, as well as higher land rent (\$192.76 ha⁻¹) and transportation costs. Jain et al. [2010] use a high yield (14.57 t ha⁻¹) and does not include transportation costs, but have much higher land costs (\$1,064-\$1,195 ha⁻¹) compared to other studies, and high production costs as well. James et al. [2010] reports a total cost that is almost as high as the estimate in Jain et al. [2010], for the same variety of switchgrass.

3.1.2 Miscanthus

Table 4 summarizes data from the literature on miscanthus production costs. Huisman et al. [1997] simulated production in the Netherlands under widely varying assumptions concerning production system, harvest, storage, planting and transport. They extend the economic study to include processing of the grass; we present the sub-total pre-processing to compare to other farm-gate prices. They use an average yield of 12 t ha⁻¹ and find total production costs between \$95-\$129 t⁻¹(converted from 119-161 ECU).¹

A study by Bullard [2001] describes the economics of miscanthus in Europe and shows simulations with higher yields and lower costs than Huisman et al. [1997]. Using average fixed costs for each country (based on country-specific average farm sizes) of 11 countries, and a yield range of 12-24 t ha⁻¹, the mean cost

¹Converted from European Currency Unit to U.S. dollar at the 1997 exchange rate of 1 ECU = \$1.25 dollars

per hectare for all countries ranged from \$68.38- \$131.39 t^{-1} (54.70-105.11 ECU) depending on the yield assumed. The fixed costs were assumed to be the same for miscanthus as they are for current production systems; Bullard [2001] assumes that there is no need to purchase new equipment.

Using data from field trial plots across Europe, Lewandowski et al. [2000] provide us with actual production data for Europe. The yield per hectare varies widely from 4 t DM $\text{ha}^{-1} \text{yr}^{-1}$ to 44 t DM $\text{ha}^{-1} \text{yr}^{-1}$, depending on the location, harvest schedule, and age of the stand. Relying on the same production model, Heaton et al. [2004] used Midwestern weather and soil information to simulate miscanthus production in the U.S. Heaton et al. [2004] found a mean yield of 33 t DM ha^{-1} across the state of Illinois, with yields ranging from 27-44 t DM ha^{-1} . Heaton et al. [2004] go on to model costs of miscanthus production and compare them to the costs of production of a corn/soy rotation, the most profitable land-use alternative. Given a price of \$38 t^{-1} for miscanthus, annualized net profit is large and positive (\$2900 ha^{-1}), leading to the conclusion that the break-even farm-gate price is actually lower than \$38 t^{-1} .

In a study concerning production in Ireland, Styles et al. [2008] provide a comparatively low estimate of yield (8.2-15.2 t ha^{-1}) and production costs (\$45.75-59.35 t^{-1}). This may be because they did not include transportation costs, nor the cost of land.

Khanna et al. [2008] provide models of miscanthus production in Illinois that are similar to Heaton et al. [2004]’s model. Khanna et al. [2008] used different modeling software (MISCANMOD), but similar EU production data, with similar yield results (35.8 t ha^{-1} average yield). Khanna et al. [2008] calculate the break-even cost of production, which ranges \$41-\$58 across the state, in 2003 dollars, not including land rent. The average break-even farm-gate price of miscanthus including land rent is \$59.24 in 2003 dollars. Khanna et al. [2008] conclude that miscanthus shows much more promise of economic viability (due to higher yields) than switchgrass.

In a comparative study based in Michigan, James et al. [2010] calculate costs of eight possible sources of cellulosic bioenergy. The break-even cost includes opportunity costs based on a corn price of \$138 t^{-1} . The break-even cost for miscanthus is \$46-\$198 t^{-1} , which depends mainly on the assumptions regarding the cost of rhizomes. They then take a different approach and show the yield demands that each crop must reach in order to reach a break-even point. This approach takes into account the opportunity cost of land (using a corn price of \$138 t^{-1} and a corn-corn rotation) and a price of biomass of \$60 t^{-1} . They conclude that miscanthus is the most likely crop to meet the yield demands under those assumptions.

Finally, Jain et al. [2010] provide a study of miscanthus production in the entire Midwestern U.S. using field data and a biophysical model similar to Khanna et al. [2008], MISCANMOD, they estimate the potential yield in each state, as well as potential costs, given the varying local costs, such as inputs, land, and row crop

prices. The average yield in Illinois is slightly higher than previous studies of Illinois production at 39.97 - 40.26 t ha⁻¹ and the break-even cost is higher as well, at \$69-\$106 t⁻¹. This is because their study is based on 2007 prices for corn, soy, and fuel, which are comparatively high. Due to the higher corn and soy prices, the opportunity cost of converting from a corn-soy rotation in Jain et al. [2010]’s study is therefore higher than previous studies (\$31-\$43 t⁻¹, or \$1,239-\$1,731 ha⁻¹), which accounts for the higher break-even price.

3.1.3 Corn Stover

Table 5 summarizes data from literature concerning corn stover production. A number of studies have investigated the economics of corn stover production in the U.S. After the harvest of corn, corn stover is what remains of the plant on the field. Some of the biomass may be harvested for use as a bioenergy feedstock or animal feed, and some must be left on the field to protect it from wind and erosion, and to return nutrients to the soil from the breakdown of organic matter. When computing costs of corn stover it must be kept in mind that removing the organic matter may require additional inputs to replace the nutrients that were removed. Previous research describes a wide range of costs, calculated in several different ways. Because there are two crops being produced, corn grain and corn stover, production costs can be attributed in different ways, which accounts for the widely varying costs of production in the literature.

In one study, Gallagher et al. [2003] estimate the supply curve as well as social costs for U.S. crops with potential for residue removal, including corn stover. They estimate that residues are the cheapest form of biomass in the corn-belt region, at \$16-\$18 t⁻¹ for production costs. Included in the production cost are harvest costs, on-farm transportation costs, fertilizer replacement costs, and fixed operational costs including labor costs. The low cost per ton is related to the method of calculating the fixed and variable production costs. The calculations are based on research by the Society for Agricultural Engineers and are constant for all regions. The variable costs are divided by the residue harvested in each location and fixed costs are added to that total. Opportunity costs are assumed to be very low for unused residues or are assumed to be already covered in the crop value for residues that are desirable raw materials. All costs are very low in comparison to other studies, which helps explain the relatively low break-even estimate.

In a study by Hallam et al. [2001], the cost of corn stover is deduced by first investigating the cost of corn production. The production cost of corn is calculated at two sites of field trials in Iowa which shows corn production operating at a loss, given the current price of corn (\$39.37 t⁻¹ in 1993). They calculate that the production cost of corn stover is then the difference between the break-even production cost of corn and the current revenue from corn, which amounts to \$6.80-\$34.77 t⁻¹, depending on location. Additional costs from corn stover harvesting, including additional machinery and fertilizer costs, are not included in

this value.

Larson et al. [2010] and Chen [2010] do include machinery and fertilizer costs, among other production costs, and their costs are higher than Hallam et al. [2001]’s. While describing the potential of co-producing decarbonized synfuels and electricity from co-firing, Larson et al. [2010] estimate potential costs of corn stover at $\$3.8 \text{ GJ}^{-1}$ ($\$66 \text{ t}^{-1}$), using a yield of 3.82 t ha^{-1} , respectively. The corn stover yield in Chen [2010]’s study is just slightly higher at 4.09 t ha^{-1} , and the production costs are much higher, at $\$117.32 \text{ t}^{-1}$, than Larson et al. [2010]’s estimation. Both studies include storage in the calculation of final costs, but Larson et al. [2010] does not include land rent, fertilizer costs or establishment costs. Larson et al. [2010] assumes those costs will be attributed to the cost of corn grain. Chen [2010] includes fertilizer costs, establishment costs and land rent in the cost of producing corn stover, which accounts for the higher production cost. Assuming that producing corn stover demands a corn-corn rotation and prevents a corn-soy rotation, which yields higher net profit than a corn-corn rotation, the cost of land calculated by Chen [2010] is significant at $\$189.09 \text{ ha}^{-1}$ and helps explain the higher production costs per ton compared to previous research.

3.2 Biomass Pellet Processing

Total costs of biomass pellet processing depend on the local costs of fuel, feedstock, and labor, and capital, and thus vary from one study to another. Samson and Duxbury [2000] provide a technical comparison of pellet production in Canada using wood residue, switchgrass and willow. Switchgrass processing is projected to cost $\$44.54\text{-}\58.58 t^{-1} (in 2000 Canadian dollars), including bagging, but not including feedstock costs (with feedstock costs, the total is $\$90.54\text{-}\126.58 CAD). This study assumes switchgrass does not need to be dried prior to processing. The production rate is $45\text{-}70 \text{ lbs Hp}^{-1} \text{ hr}^{-1}$.

Mani et al. [2006] perform a similar study in the Pacific Northwest region of Canada. They include drying costs, unlike Samson and Duxbury [2000], and the total, including raw materials, is $\$51 \text{ t}^{-1}$ ($\$31 \text{ t}^{-1}$ not including raw material). The scale of production is 6 t hr^{-1} , or $45,000 \text{ t yr}^{-1}$.

Smeets et al. [2009] follows the supply chain of both miscanthus and switchgrass in Europe, calculating the costs of producing, processing and transporting each feedstock. Not including feedstock costs, their total pelletizing costs per ton are $\$32\text{-}\36 at 2010 exchange rates ($\text{€}26\text{-}\text{€}29$ in 2004 Euros) and $\$38\text{-}\44 ($\text{€}31\text{-}\text{€}36$ in 2004 Euros) in 2030. This cost varies according to local costs of labor and fuel, and includes drying. The simulated processing facility processes $80,000 \text{ t yr}^{-1}$.

There are economies of scale in production; higher levels of production spread out fixed costs to make production per ton less expensive. However, there is a trade-off. Thek and Obernberger [2004], Smeets et al.

[2009], and Samson and Duxbury [2000] describe the trade-off between processing facility size and transportation costs: higher levels of production require a larger amount of feedstock, this will have increasingly higher transportation costs the further it must travel to the facility. Sultana et al. [2010] find the optimal processing facility size for a Western Canada agri-pellet plant using wheat, barely, and oats to be 70,000, 150,000 and 150,000 t yr⁻¹, respectively, for each feedstock.

3.3 Survey-Based Literature: Motivation to Produce

The previous literature provides us with an understanding of the economics of production. Survey-based literature helps guide the content of our survey of producers and non-producers of bioenergy feedstocks and provide us with an understanding of the other factors that may influence the decision to produce biomass feedstock crops. As Jiang and Swinton [2009] point out, many studies concerning biomass production focus on the technical potential of cropland in the U.S., rather than the behavior of farmers when faced with dynamic production decisions. The technical potential is important in evaluating policy, they argue, but it is the decision of the producer that ultimately limits the supply, rather than the technical potential.

Villamil et al. [2008] investigated potential biomass producers in the Midwest U.S. They conducted a mail survey in order to describe the information channels and needs that potential producers have. The study approached the cultivation of miscanthus as a technological innovation, and used Roger’s innovation-decision model to understand adoption and non-adoption. In this model, determinants of adoption include age, experience, and education level. Villamil et al. [2008] did find significant differences in experience and farm size among potential adopters and non-adopters, but in other demographic aspects, the two groups were identical.

Moving beyond demographics, several key studies have examined the role of social and environmental attitude in the farmer’s decision-making process for technological innovation. Pannell [1999] created a model to assess the issues and challenges in adoption of “new and complex” farming systems. Some of the challenges to adoption include 1) developing a system that is more profitable than previous systems 2) assessing the profitability of the new system and 3) overcoming uncertainty about the system. Pannell [1999] articulates the goals of the farmer to be multi-dimensional and that the farmer seeks to fulfill his goals, be they social, environmental, and/or economic.

Valdivia and Poulos [2009] found the decision-maker’s attitude to be a significant factor in their analysis of interest in creating a riparian buffer and forest farming. Beedell and Rehman [1999] found that it is important, in attempting to articulate the farmers decision-making process, to assess the motives and goals

of the farmer *as much as* traditional aspects, such as the economics, policy context, and services and infrastructure available.

In studies concerning energy crop production in the UK, Sherrington et al. [2008] and Mattison and Norris [2007] both stress that in order to understand the supply side of potential energy crops, researchers need to understand multiple components of the farmers decision. Sherrington et al. [2008] tried to fill the gap in the literature of the producers decision to grow energy crops by conducting focus groups and articulating the significant issues that arise. Most of the farmers surveyed grew energy crops (primarily willow, and some miscanthus) as a method of diversification and many of them contract with others for the establishment and harvesting of energy crops.

The overall consensus of the UK focus group interviews was that the main factor affecting the farmers decision to grow or not grow energy crops is the potential financial return. Farmers that have already adopted energy crops speculated that they would reap larger financial benefits by being early adopters. However, there were also important secondary factors, which include ideological beliefs concerning climate change and fossil fuel dependency and the desire to scale back daily involvement on the the farm, which energy crops allow more readily than other crops.

3.4 Survey-Based Literature: Motivation to Consume

Europe has a history of higher fuel prices and more strict greenhouse gas emissions legislation, and therefore have a more developed market for biomass used for home heating. There are several relevant survey-based studies that have described these markets and can enlighten our understanding of the U.S. market for biomass for home heating.

Jablonski et al. [2008] use market segment analysis to empirically study the potential demand for biomass in the UK residential market. Currently less than 1% of UK residential heat generated comes from biomass. While other biomass energy consumption sectors have been growing quickly (transportation and industrial sectors, specifically), even with governmental intervention, this sector is growing slowly, and Jablonski et al. [2008] try to identify why.

The framework used in Jablonski et al. [2008]’s study focuses on the intersection of three distinct measurements of potential: technical, economic, and implementation potential. Technical potential covers what is physically feasible under assumptions concerning technology, economic potential refers to the fraction of the market that could be economically competitive, and implementation potential covers social, political and policy constraints that may limit implementation.

Segmenting the market into homogenous groups of consumers allows Jablonski et al. [2008] to assess the different potentials for each group and to make more specific recommendations about the market. For this study, Jablonski et al. [2008] separate the market into groups based on the development characterization (new/retrofitted), area characterization (rural/urban), displaced fossil fuel, and proximity to gas grid. Literature review and personal interviews led the researchers to these drivers as the key market segmenting characteristics.

Assumptions are then made concerning the aforementioned potentials of each segment, and several scenarios are simulated to find the most potential profit. The four scenarios compared are pellets replacing natural gas and oil and bio-oil replacing natural gas and oil. Their results show that increasing the number of pellet boilers in rural and urban settings has the highest technical potential, and could increase the biomass pellet demand by 50%; it is recommended as a target for policy. As for economic potential, Jablonski et al. [2008] find that the profitability gap is the largest for the displacement of natural gas (the cheapest source of residential heat, as in the U.S.) and recommend a steep increase in fossil fuel prices (specifically natural gas) as the most efficient way to increase biomass energy demand.

Rather than focus on *potential* consumers, Nyrud et al. [2008] conducted a descriptive study of *current* improved wood stove consumers in Norway. They used surveys to assess the success of the governmental subsidy for the purchase of improved wood stoves. Recognizing that consumer demographics, preferences and attitude help to determine consumption patterns of energy, the study attempts to link the attitude of a consumer to the behavior of the consumer. Wood heating has traditionally been popular form of heating in Norway, although electricity has now become the dominant form. Due to increasing concern about the dependency on electricity, the government began a program to subsidize new, improved wood stove sales. They offer a subsidy of up to 30% of the price of the stove, which is similar to the recent U.S. tax credit enacted through the EPA.

Nyrud et al. [2008] found that the consumer's satisfaction with the technology was the most influential determinant of future use. Satisfaction was influenced by time and effort required, subjective norm (or the approval of society), perceived heating effect, and subsidy. Environmental issues were also a relevant issue, as consumers believed their actions were beneficial for the environment. All of these conclusions illustrate the way in which consumption decisions extend beyond net present values.

In another study describing ways to increase consumption of bioenergy products for home heating, Verma et al. [2009] qualitatively study the issue of quality labeling in Belgium. They believe that the market in the EU suffers from lack of information and promotion of the available governmental incentives. They infer that the high cost of adoption has an influence over the willingness to utilize the technology and that incentives

play a “key role“ in developing the biomass pellet market. If consumers assume the entrance costs are high and are ignorant of government incentives, an easy way to increase consumption is through education.

Verma et al. [2009] also believe that a ‘Belgian Quality Label’ will help to win trust from the consumers, as they cite local regulatory labels in other EU nations that have been shown to increase consumption. Fielder [2004] agree that more stringent labeling and quality control measures will help the pellet market expand in European nations.

In a comparative study, Fielder [2004] assess the pellet-based heating systems of Sweden, Germany and Austria. Currently, Sweden has the most users, with at least 6% of residential heating fuel coming from pellets. This is in part due to higher costs of alternative fuels in Sweden and lower costs of pellet boilers, as well as the ease of transition to the new technology: former oil-based boilers were easily converted. Notably, all three countries have a history of governmental assistance and regulation concerning the market for pellet fuel.

Mahapatra and Madlener [2007] more closely examined the pellet industry in Sweden to find out the extent of market penetration that pellets have had, as well as the barriers to entry that exist. They found that the pellet industry struggled until the national carbon tax was enacted in 1991, making fossil fuels more expensive, and perhaps leading to the comparatively high rate of biomass consumption. At the time of publication, pellet fuels were cheaper than traditional fuels, but still had not been as widely adopted as Mahapatra and Madlener [2007] thought they should be, considering the economics of pellet consumption. Mahapatra and Madlener [2007] attributed this to several possible reasons: lack of information and education, including doubts about the availability and dependability of pellet heat, using a “folk“ economic comparison rather than an accurate economic comparison (i.e. not considering detailed cost-benefit analysis, only monthly or annual savings), not being able to try the product prior to purchase, and the change in habits and home design that a new system requires. Adoption at an institutional level, they found, was more widespread, as existing coal-fired technology could more easily be retrofitted to accept pellets.

3.5 Conclusion

Of the three biomass feedstocks described, production literature has been focused on switchgrass, with miscanthus and corn stover only recently receiving attention as potential biomass pellet feedstocks. Of the three, miscanthus studies have typically described higher yields and lower production costs than switchgrass or corn stover, especially when the studies focus on the Midwestern U.S. Cost of production of miscanthus

ranges from \$36-\$198 t⁻¹, cost of production of switchgrass ranges from \$9.94-\$151 t⁻¹, and corn stover production costs range from \$6.80 - \$122.83 t⁻¹.

Existing pellet production literature describes the approximate costs of each step of production and the economies of scale of production. Production costs per ton ranges from \$31 to \$59 per ton of pellets, depending on the study.

Survey-based literature about the motivation to produce biomass feedstocks describes the factors that are not typically included in cost-benefit analysis, such as producers' demographics, attitude, and beliefs. Similarly, survey-based consumption literature were generally in agreement in identifying factors beyond economics, such as access to information, education, and culture as some of the main barriers of technological adoption. In countries where the prices of nonrenewable fuels are comparatively higher than renewable fuel, adoption is generally more widespread. Several studies agreed that an efficient way to fairly increase the cost of nonrenewable fuels, thus increasing adoption of renewable fuel technology, is a carbon tax. Government assistance for the initial costs of conversion increases adoption, but needs to be coupled with educational programming to ensure awareness, consumer satisfaction and continued adoption.

The biomass pellet consumption literature is also decidedly focused on European markets. The cost of biomass pellets varies across the landscape due to natural differences in climate and soil, as well as differences in infrastructure, law, and policy. Similarly, the market for biomass pellets varies geographically as well, due to many things, including cost of traditional fuels and renewable fuels, and the local climate, culture and policy. This research will enhance the literature by focusing on production and residential biomass consumption in the Midwestern region of the United States. Being able to compare the simulated costs of production with actual pellet production cost data will also provide a unique perspective.

Studies that have focused on the feedstock production and pellet production typically focus on the perspective of producers. This study is unique in also approaching the market from the perspective of the consumer.

Chapter 4

Case Study/CBA

Our goal is to analyze the consumer’s decision to use biomass pellets and the incentives that affect the decision. Since costs for each step are not in the market, we will compile the costs using previous research. We will then compare the costs of using biomass feedstock pellets to the cost of using traditional fuels for residential home heating. We assume a dual heating system is necessary for using biomass pellets, necessitating the purchase of a new furnace. All costs are annualized.

First, using the previously described literature, we can calculate the potential costs of producing the three biomass feedstocks (miscanthus, switchgrass, and corn stover). The cost of production includes the price of seed or rhizomes, chemical inputs, equipment, the costs of harvest, and the transport and storage of the harvested product. We assume there is a cost of land, or an opportunity cost in planting biomass feedstock, because the farmer is giving up potential profit from other crops in planting the alternative biomass feedstocks. We assume the highest profit alternative for Illinois farmers is a corn-soy rotation; the foregone profits from not planting a corn-soy rotation will be the opportunity costs. We compare the production costs in Khanna et al. [2008] to the actual production costs at the Dudley Smith Farm trial.

After the production costs for each feedstock are described, we will detail the costs of processing the pellets. These costs must all be based on trials and models, as there are no dedicated commercial processing plants in Illinois. We will make assumptions and alterations in order to apply the models and trials to Illinois. We will also compare these costs to the actual pelletizing costs experienced in Central Illinois at the Dudley Smith Farm trial.

After calculating the production and processing of biomass feedstocks, we will describe the economics of consumption of the biomass pellets in a residential setting. As described earlier, there are several ways to heat a home using biomass feedstock, with varying costs and labor requirements. For this case study we will be using the average price of a new biomass furnace that is capable of heating an entire home (100,000 Btu capacity), including installation.

4.1 Production

Table 6 shows, in 2007 prices, annualized costs of production per hectare. Khanna et al. [2008] is the basis for the calculation of state-wide averaged costs of production of miscanthus and switchgrass, and Chen [2010] is the basis for the costs of corn stover production. The costs of production are annualized for the lifetime of the respective crop (15 years for miscanthus, 10 years for switchgrass, and one year for corn stover), using a 4% discount rate. The opportunity costs are included to reflect the costs of switching production out of the most profitable crop rotation (corn and soy) in Illinois and into biomass pellet feedstock crops. The opportunity costs are annualized as well. Opportunity costs are lower for corn stover because a corn crop is still harvested and salable; the only opportunity cost for corn stover lies in the increased yield that will be forgone from not including a soybean rotation, notwithstanding soybean profits. All projections are based on optimistic assumptions; all costs have been converted from 2007 dollars to 2009 dollars.

We also show the effect of a current policy that has been enacted as of 2009, the Biomass Crop Assistance Program, which lowers the cost of production through government subsidies. The program provides 75% of establishment costs for the first two years and two years of matching payments up to $\$45 \text{ t}^{-1}$, as well as two years of opportunity cost payments. This policy will be discussed in depth in Section 4.5: Policy Analysis.

The total farm-gate production costs for miscanthus is $\$59.92 \text{ t}^{-1}$. The production costs for switchgrass are $\$92.25 \text{ t}^{-1}$. Finally, the total production costs for corn stover are $\$101.66 \text{ t}^{-1}$.

We can compare the costs of production of miscanthus from Khanna et al. [2008] with the actual costs of production from the University of Illinois' Christian County Extension office, as shown in Table 7. Overall production costs at the Dudley Smith Farm are higher than those estimated in Khanna et al. [2008], and yield is lower than the estimated average yield in Illinois. This is because the increase in acreage in 2005 and 2008 brought a decrease in yield as miscanthus takes 2 years for establishment; the first two yields are expected to be much lower than the optimal projected yield. Two acres of miscathus were in their third year in 2009, but four acres were still in the establishment phase, leading to lower average yields. Yields are expected to climb in the next two years, until all 6 acres are at optimal production. Because the first year had quite different costs than the subsequent two years, both the three year and two year averages are given in Table 7. The two-year average cost of production for miscanthus is $\$125.97 \text{ ton}^{-1}$, which is much higher than Khanna et al. [2008]'s baseline estimated cost of $\$59.92 \text{ ton}^{-1}$ (which, like the Dudley Smith estimate, does not include transportation or opportunity costs). The high-end cost estimates in Khanna et al. [2008]'s sensitivity analysis are, however, similar to the Dudley Smith average costs. Storage, harvest and maintenance costs at the Dudley Smith farm trend downward, as they are expected to continue to do as infrastructure grows in Illinois.

4.2 Transportation

Post-production, the biomass feedstock must be transported to a processing facility, which can be a significant percentage of overall production costs. In addition to milage-based transportation costs, a handling cost for loading and unloading the biomass should be expected. It is difficult to model transportation costs as they generally depend on many variables, including trip distance, fuel prices, type of biomass, and the number of round-trips made.

The costs specific to biomass transportation are the focus of Searcy et al. [2007]’s paper. Investigating various types of biomass, they divide the cost into Distance Variable Costs (DVC) and Distance Fixed Costs (DFC) for each. The DFC are dependent on the type of biomass (specifically, the density and volume of the feedstock: round bales vs. wood chips, for example). The DFC include handling, such as loading and unloading, and are not dependent on the distance travelled. The DVC are the costs that are directly related to the distance travelled. Their estimate for grass and straw, in 2004 U.S. dollars, is $\$16.39 \text{ t}^{-1}$ ($\$18.61 \text{ t}^{-1}$ in 2009 dollars).

Returning to our data from three years of pellet production from miscanthus harvested from trial plots at the Dudley Smith farm, we found that the transportation of biomass feedstock bales to a pellet production facility had an average variable cost of $\$.70 \text{ t}^{-1}$, per mile, roundtrip or $\$.43$ per ton per Km, roundtrip. This cost is estimated based on a scenario where there is no backhaul. If there were a backhaul, we could expect costs to decrease by about 60% (Letterly [2009]).

If we assume the distance from production to processing to be 100 Km, using this average, there will be an added cost of $\$43.40 \text{ t}^{-1}$. Fixed costs, or handling costs, include loading and unloading bales before and after transport, and were found to be approximately $\$4.00 \text{ bale}^{-1}$ or $\$12.00 \text{ t}^{-1}$ per trip in Christian County, in 2009 dollars. Combined transport and handling costs in Christian County, Illinois, then, averaged $\$55.40 \text{ t}^{-1}$. It is assumed that the lack of infrastructure for transporting biomass is the reason it is currently so expensive; we will assume in this study that the cost of transporting biomass will decrease to the cost estimated by Searcy et al. [2007].

Table 8 compares Searcy et al. [2007]’s costs to the costs from the Dudley Smith Trial. Table 9 shows Searcy et al. [2007]’s cost converted to 2009 dollars and added to the total production cost. The total production cost for miscanthus is $\$78.53 \text{ t}^{-1}$, switchgrass is $\$110.86 \text{ t}^{-1}$ and corn stover is $\$120.27 \text{ t}^{-1}$.

4.3 Biomass Pellet Processing

The process of turning biomass into pellets can be broken down into three parts: drying, grinding and densification. First we will use the method in Mani [2005] and Mani et al. [2006] to approximate pellet production costs in Illinois, and then we will compare those to our preliminary data from the Dudley Smith trial.

The energy consumed during each process of pellet production can vary widely according to the particular processing plant, feedstock, and the desired outcome. In Mani [2005] and Mani et al. [2006], they calculated the total energy consumption, environmental emissions and costs of pelletizing various biomass crops in the Pacific Northwest. They found that a “typical operation“ consumes 300-3500 MJ for drying, 100-180 MJ for grinding, and 100-300 MJ for densification. Additionally, there are general energy requirements necessary for running a production facility. Their results vary according to the type of biomass feedstock that is being converted (for example, the moisture content, the density, and the size of the raw product) and according to the local fuel and labor costs. In Mani et al. [2006], the total processing cost is $\$51 \text{ t}^{-1}$, including feedstock costs (in 2003 dollars), using coal as the fuel to dry the feedstocks, and with a yearly production of 45,000 t yr^{-1} .

Mani et al. [2006] focuses on the processing of wood waste biomass into pellets, which requires drying the feedstock from a 40% moisture level to a 10% moisture level. We will assume for our study that the biomass feedstock only needs to be dried from 15% to 10%, which will require one-sixth of the energy in Mani’s study. Mani found the drying energy requirements using coal as the drying fuel, to be 2813 MJ/ton. That means that 469 MJ/ton will be required by biomass feedstock such as miscanthus and switchgrass. We assume coal is the fuel used to dry the feedstock. Further energy costs include electricity, which is used primarily for the grinding and densification processes, and diesel, which is consumed by heavy machinery in the production, including fork lifts and dump trucks. Taking the mean fuel requirements from Mani [2005] in MJ/ton, we will use Illinois fuel prices to calculate the approximate cost of energy required to process pellets.

Added to the cost of fuel are the fixed costs of running the facility, including, capital, storage, and personnel. Personnel includes staff in production, administration and marketing. Staff in production includes two people to operate the bagging operation if one-third of the pellets are bagged. The production rate is 6 tons/hour, 24 hours a day, 310 days a year (or about 45,000 tons/year).

In Mani et al. [2006], fixed capital costs have been discounted based on a lifetime of the machinery between 10 and 25 years, depending on the equipment. For the cost of capital, the interest rate is assumed to be 6%, maintenance is 2% of the cost, except for the pellet and hammer mills, for which the maintenance

is calculated at 10%, due to the intensity of use. The total cost of capital per ton of biomass pellets produced is \$6.42. The total cost of storage and personnel per ton of biomass pellets produced is \$14.48. The total production cost, therefore, is \$37.99. These costs have been converted to 2009 prices from 2004 prices. Table 10 compares these costs with the actual two-year averaged costs of pellet production for the Christian County miscanthus trial.

The Dudley Smith Farm trial pellet production costs are higher than the costs in Mani et al. [2006]. Again, the costs of production are expected to decrease as the infrastructure improves; currently processing facilities are able to charge a premium because there is very little competition.

Finally, we can combine the production, transport, and processing costs to find the total cost of one ton of biomass feedstock pellets, as shown in Table 11. Total cost of miscanthus pellets are \$116.52 t⁻¹, switchgrass pellets are \$148.85 t⁻¹, and corn stover pellets are \$158.26 t⁻¹.

4.4 Consumption of Biomass Pellets for Home Heating

The total cost of biomass pellet fuel can now be compared to traditional fuel sources so that we can investigate the decision to consume biomass pellet fuel. First we used U.S. Census Bureau information to find the average amount of energy used to annually heat a home: 72.69 GJ or 68.9 mBTUs (Cen). The cost of this amount of energy can then be compared across each fuel type. After a comparison of the fuel-only cost in Table 12, we take into account the annualized costs of converting the home to accept biomass pellet fuel, which includes the cost and installation of the furnace.

Table 12 clearly shows that miscanthus is the cheapest fuel for home heating, given our assumptions. Miscanthus is over \$400 cheaper, annually, than the current popular choice for home heating: natural gas (81% of consumers in Illinois use natural gas to heat their homes in 2000, according to the Energy Information Administration). In fact, all biomass feedstocks in this study (miscanthus, switchgrass, and corn stover), including shelled corn are less expensive than natural gas. In a Canadian study concerning the economics of residential home heating using biomass (switchgrass and wood pellets), Samson and Duxbury [2000] had similar results: biomass fuel was at least 28% cheaper than traditional heating fuels (fuel oil, natural gas, and electricity). However, this price covers only the cost of fuel. In order to use this fuel for home heating, consumers must purchase a furnace that specifically accepts biomass feedstock.

Nine leading manufacturers offer similar models at similar prices; the average BTU maximum is 100,000 and the average price is \$4,098. Installation costs will vary greatly according to the design and current system of the home. For this study we will assume installation to be \$2,000, or about 50% of the price. To

calculate the present value of the furnace cost, we use a lifetime of 20 years, 4% cost of capital, and annual maintenance charges of \$50, or about .8% of the cost of the furnace. This results in an annualized cost of owning a furnace of \$498.68.

Table 12 shows that including the cost of a new furnace, miscanthus biomass pellets are now about 18% more expensive than natural gas. However, compared to all other nonrenewable fuels, all three types of biomass pellets are actually *less* expensive than the estimated annual heating costs. This is significant: according to the Energy Information Administration, only 20% of rural households have access to natural gas. About 34% of rural households use electricity to heat their homes, 24% use propane, and about 10% use fuel oil or wood, while the rest report using kerosene. All three types of biomass pellets are less expensive than each of those fuels. This means that consumers in rural areas without access to natural gas would be, according to these estimates, more likely to find biomass pellets economically competitive. Furthermore, many farms require heating in multiple buildings, for which biomass pellets might also be the most economically competitive, if choice is limited to propane, electricity, or fuel oil.

The EIA also reports that almost half of rural residents in the U.S. have secondary heating sources (EIA), which supports our assumption that the cost of a new furnace and installation can not be assumed to take the place of a traditional fuel heating appliance and should be assumed to be an addition to the cost of traditional fuel heating appliances.

There are two other renewable heating options that a consumer may consider in making the decision about home heating: geothermal heating and cooling and solar powered heating and cooling. An estimate for the cost of geothermal heating from GeoIllinois, a local geothermal provider, states that average annual heating costs are just over \$500 (for a 2,000 sq. ft. home), and the system requires very little maintenance and has a relatively long life. Installation and initial capital investment will vary depending on whether or not the unit is being retrofitted or installed in a new building. The system does not require a backup heating appliance. There is also a \$3000 subsidy for the installation of a system, similar to the subsidy for biomass pellet burning appliances.

Solar energy is quite difficult to estimate as solar intensity varies by location and home design and cost will vary depending on total energy usage in the home. If connected to the grid, the system has the possibility of selling power back to the electric company, but if it is not connected to the grid, the excess power is stored in batteries; each system will have different annual costs. There are also subsidies offered for solar appliance purchase and installation.

4.5 Policy Analysis

We will now assess the effects of the previously described policies on the costs of heating using each fuel. Table 14 shows the annual heating costs under each policy. BCAP is a USDA Farm Service Agency program put in place to subsidize the transition to biomass feedstock production. The program provides reimbursement for 75% of the establishment costs for the first two years and \$1 for each \$1 paid by an approved conversion facility for each dry ton, up to \$45 per ton, for two years. The current BCAP program also pays farmers the estimated opportunity costs for two years; this would lower the annualized opportunity costs slightly. For this study, opportunity costs are assumed to be the constant. BCAP lowers production costs by 16%-46%, as seen in Table 6.

The total farm-gate production costs for miscanthus is \$59.92 t⁻¹ without BCAP assistance and \$35.13 t⁻¹ with BCAP. The production costs for switchgrass are \$92.25 t⁻¹ without BCAP and \$77.90 t⁻¹ with BCAP. Finally, the total production costs for corn stover are \$101.66 t⁻¹ without BCAP and \$55.18 t⁻¹ with BCAP assistance. The cost of the least expensive renewable fuel (miscanthus) is still higher than the least expensive non-renewable fuel (natural gas), but the difference is now smaller: miscanthus pellets are, annually, \$80 more expensive than natural gas.

The U.S. EPA’s Energy Star Program, as a part of the American Recovery and Reinvestment Act, is offering tax credit up to 30% or \$1500 of the cost of a biomass stove, insert, furnace or water heater. With a furnace with a price of at least \$4000, this essentially amounts to a \$1500 subsidy for the purchase of a new furnace. This lowers the annualized cost of the furnace to \$388.31, using the assumptions stated previously of a 20 year life, \$50 annual maintenance and 5% cost of credit. The tax credit lowers the furnace cost, providing an incentive to consume biomass pellets. The degree of the effect is similar to the degree of the effect of BCAP; there remains about an \$80 gap, annually, between the cheapest non-renewable fuel and cheapest renewable fuel (with non-renewable fuel being cheaper). Combined, BCAP and the tax credit are likely to decrease annual home heating costs using renewable fuel enough for it to compete with even the cheapest non-renewable fuel.

The last policy that we will examine is carbon pricing. We use “high” and “low” estimates of \$25 and \$50 per ton of emissions. The emissions per GJ from non-renewable fuels are generally much higher than renewable fuels, as seen in Table 1. The carbon tax, then, will increase traditional fuel costs at a higher rate than biomass pellets, providing increasing incentive to consume renewable fuels. This can be seen in Figure 6, which shows the effects of carbon taxes on the annual home heating costs (which includes the cost of the furnace). As the carbon tax increases, renewable fuel sources become the least expensive options.

Table 13 shows the effects of all policies on the annual heating cost of renewable biomass pellets, with a

comparison to the non-renewable fuels.

4.6 Sensitivity Analysis

Table 16 shows the sensitivity analysis that illustrates how changes in each of the variables affect the final annual cost of consuming biomass pellets. The changes are shown in percentage change from the baseline annual cost in order to more clearly illustrate the *change* rather than the *cost*.

When corn and soy prices increase, unsurprisingly, all feedstocks increase, due to the increased opportunity costs. Switchgrass increases at a higher rate due to its lower yield (11% versus 2% and 3%); the opportunity costs are higher per ton, compared to the other two feedstocks. The same is true when corn and soy prices decrease: switchgrass costs are more dramatically lowered.

When the yield of each feedstock is increased the annual cost decreases, and vice versa. The changes are more dramatic for corn stover when yields increase (-11% versus -5% and -7%) because the yield is low in the baseline (3.6 tons/hectare). When pelletizing costs increase 25%, the annual cost increases, and vice versa as well. The rate of change is very similar for all feedstocks at around 4%.

A 25% increase in transportation costs increases the annual cost by around 2%. A 25% increase in furnace costs increases the annual cost for each feedstock by 10-12%, with a corollary change due to decreased furnace costs.

The sensitivity analysis illustrates several important points. The yield that is used to make these calculations is very important. Lower yielding feedstocks are more dramatically affected by exogenous changes, such as the prices of corn and soy. The effects of the changes in the cost of the furnace show that it is a large component of the annual cost, whereas changes in the cost of pelletizing show that it is a small component of the annual cost. Increased yields will significantly decrease cost. The high-end production costs (when yield decreases by 25%), are \$1,115.35 yr⁻¹ for miscanthus, \$1297.01yr⁻¹ for switchgrass, and \$1,436.69 yr⁻¹ for corn stover.

4.7 Social Costs and Benefits

This cost-benefit analysis did not include some important social costs and benefits. Particulate matter, for example, is emitted during combustion of both renewable and non-renewable fuels, and is an air pollutant that can cause health and environmental damages. The amounts of these damages (but not the monetary cost) have been estimated in the context of heating fuel choice by Chen et al. [2010]. In their simulation, both coal and biomass have measurable particulate emissions, but biomass emits much less particulate matter

than coal. Another study has attempted to measure the gross annual damages from particulate air pollution in the U.S. in relation to health and adult mortality rates (Muller [2007]). Thus, there is a measurable social cost of particulate emissions, as well as measurable benefits from using renewable fuels rather than non-renewable fuels.

Other social costs and benefits that are not included are the effects of land-use changes on the economics and environment of Illinois, and the political effects of shifting the economics and geography of fuel use to more local sources. Land-use changes may include social costs, such as the effects of mono-cropping biomass feedstocks on land that was formally more ecologically diverse, leading to reduced biodiversity. Land-use changes may also include social benefits such as the reduced amount of chemical inputs that are required by biomass feedstock crops in comparison to commodity crops. Smeets et al. [2009], for example, studied the effects switching from commodity crops to miscanthus and switchgrass in Europe, and found substantial social benefits in the form of increased biodiversity. The effects of shifting imported fuel to local sources include costs and benefits in taxation, as well as more difficult to measure costs and benefits, such as heightened energy security and independence.

Chapter 5

Survey

5.1 Introduction

Our survey of rural households in Western Missouri included producers and non-producers of biomass feedstock, as well as consumers and non-consumers of biomass feedstock pellets for home heating. The cost-benefit analysis of using biomass pellets for home heating provides economic analysis based on break-even costs, but as the consumption literature illustrates, the decision to consume renewable energy for home heating is often more complex than simple economics. The survey is intended to go beyond the economics of consumption and production to fully articulate the factors involved in the decision to consume and produce biomass. Show Me Energy was chosen as the nearest biomass feedstock processing facility to Illinois.

5.2 Show Me Energy

The Show Me Energy Cooperative in Centerview, Missouri currently has over 500 members that have each bought a share in the cooperative in exchange for the right to sell a certain amount of feedstock to the plant. The processing plant accepts a wide range of feedstock material, including many different kinds of grasses. The facility produces pellets that are then sold back to the producers at wholesale costs, or are sold to industrial clients that co-fire the biomass pellets with non-renewable fuel.

5.2.1 New Generation Cooperatives

Show Me Energy is a “new generation” cooperative of biomass feedstock producers. While many elements of these cooperatives are similar to classic agricultural cooperatives, there are several key differences, which, depending on the situation, can prove to be advantageous.

Downing et al. [2005] reviewed several new generation cooperatives in the agricultural sector that were established with help from the U.S. Department of Energys Biomass for Rural Development Initiative. New Generation Cooperatives are especially suited for the renewable energy sector where bioenergy is the

primary product, they argue. This is in part due to the end-users needs: utility companies are interested in dependable delivery of exact quantities of a consistent product over long periods of time.

Traditional agricultural cooperatives generally operate under the definition given by the USDA, as “a user owned and controlled business from which benefits are derived and distributed equitably on the basis of use or as a business owned and controlled by the people who use its services” (Flynn [2000]). The New Generation Cooperative (hereafter NGC) is no different. NGCs differ primarily in the membership, rules, and regulations that affect the payout of dividends. Traditional cooperatives allow open membership, where producers can pay annual dues and become members at will; there is no limit in the cooperative as to how many members the cooperative can have (although there may be rules about the ratios of members to non-members).

New Generation Cooperatives, however, have a closed membership structure that limits the number that may join. Members are required, at the outset, to purchase shares. In this way NGCs avoid the free rider problem of traditional cooperatives. The shares then require a certain amount of supply to the cooperative (for example, one share might buy the right to sell the cooperative 5 tons of biomass a year). The amount of investment in the cooperative is tied to the amount of business the member is allowed to conduct. The cooperative decides ahead of time how much supply it will require and sells shares based on those numbers. This increases capital in the formation of the cooperative; it alleviates the problem of raising capital in the beginning, when share purchase is not required for membership. Instead of building equity over time, NGCs begin with a large amount of equity.

This also brings up the issue of supply; a NGC structure works well when cooperatives need a steady, constant supply over time. Traditional cooperative structure generally requires producers to market all output through the cooperative, and can have wide fluctuations of supply, as weather and other effects influence production. With NGCs, the supply is decided and limited in the beginning and thus there is no need to worry about over- or under-supply.

The Iowa Law Review (Flynn [2000]) describes the differences between NGCs and traditional cooperatives as offensive versus defensive. NGCs are offensive in that they are groups of farmers uniting to take back the value-added share of the market previously in the hands of processors. Traditional cooperatives are defensive in that they exist merely as a way to deal with market imperfections.

5.3 Survey Design

A modified version of Dillmans’s tailored design method (Dillman [2000]) was used to both design and administer the survey. Several researchers with previous survey design experience at the University of Illinois revised the survey. Representatives from the National Agricultural Statistical Survey (NASS) in Missouri contributed revisions as well. Finally, the survey was pre-tested at the annual board meeting at Show Me Energy. Seven participants read the survey and contributed comments regarding structure, wording and content. The participants were all Missouri biomass producers. Several small changes were made as a result. The final survey was administered by mail from the NASS Missouri office. It is included in the Appendix.

After the first survey was sent, we sent reminder postcards and replacement surveys twice. Contact information was provided for participants so that they were able request additional surveys if necessary. We followed Dillman [2000]’s suggestions for building trust by using the University’s name and explicitly stating our adherence to the Institutional Review Board’s policies. Participants were clearly told of their rights and responsibilities and were given the opportunity to contact the IRB using a collect call. For Show Me Energy members, we also included a letter from the general manager on Show Me Energy letterhead stating his support for the survey and his adherence to privacy policies.

The survey was divided into six sections. The basic design is based on Dillman [2000]’s suggestions, with a two-column format: the left column for questions and the right column clearly marked for answers.

The first two sections asked for basic demographics concerning the primary decision maker and the farmland, using both fill-in-the-blank questions and multiple-choice questions. The second section contained six statements that participants were asked to rate on a whole number scale of 1 to 5, where 1 is “agree”, 3 is “neutral”, and 5 is “disagree”. The participants were asked to evaluate each statement and decide if they agree, disagree or are neutral. The statements concern energy crops, climate change, and economic speculation concerning carbon pricing. This section was included with the intention of gathering information about the producer’s attitude and beliefs. As described previously, evidence shows that a producer’s decision will be based not only on economics, but also on beliefs and values.

The fourth section has two parts: part one is a spreadsheet that allows the participant to describe their production. It is divided into acres in CRP, pasture, livestock, and crop production. It included questions about the type of livestock, crops and crop yield. The second section asks participants about the changes in production that have taken place or will possibly take place as a result of biomass energy crop production.

The fifth section also has two parts: the first part asks the participants for further details concerning biomass production, including Show Me Energy membership, harvest methods, and BCAP payments. The second part contains eight factors regarding production decisions that the participants are asked to rate on

a whole number scale of 1 to 5, where 1 is “very important” , 3 is “neutral”, and 5 is “very unimportant”. Similar to the previous section containing statements that were evaluated, this section allows us to gauge the attitude, beliefs and values specific to the biomass producers.

The final section included questions about consumption of biomass pellets. Participants were asked about their homes and whether or not they used biomass pellets for heating. If they did, they were asked several more questions concerning the details of the home heating structure and economics. This section provides us with a more complete profile of the consumer of biomass pellets.

5.4 Sample Selection

Show Me Energy Cooperative and the National Agricultural Statistical Survey assisted in designing our sample population. The Cooperative provided NASS with their membership database, totaling 368 members. The Cooperative has since expanded membership to over 500, but this survey was conducted prior to the expansion. After duplicate addresses, multiple shares, and out-of-state addresses were dropped, the total number of members was 273.

NASS then matched a non-member sample as closely as possible to the demographics of the member sample. Using their own database of Missouri farmers, they sampled 1200 non-members that were in a 100-mile radius of the Show Me Cooperative, which included 48 counties. They did not include locations outside of the Missouri state line (as Show Me Energy has very few out-of-state members), and dropped counties that were partially within the 100-mile radius as well. The sample was drawn from only the farmers in the NASS database that had previously planted corn, wheat, or hay or had cattle. The commodities were chosen to most closely mirror the member sample, and no minimum nor maximum was used, as members had a wide range of sizes of farms and values for those commodities.

The total database of 38,625 records was sorted by county and by gross value of sales, in order to get a representative sample across all counties and all size groups. Likewise, in each county, systemic sampling was used to select a representative sample of the population of farms in that county. In order to ensure representation of all economic classes across the state, NASS systemically sampled the population using Gross Value of Sales (GVS). Systemic sampling involves choosing every n^{th} element from a sorted list (in this case, highest GVS to lowest GVS). This method ensures that the sample will contain representation from across the range of a selected variable, and reduces the chance of selecting a biased sample.

5.5 Survey Results

As stated previously, 273 Show Me Energy members were sent surveys and 1,200 non-members were sent surveys, for a total of 1,473 participants. We over-sampled the non-members because we anticipated lower participation in that group. The members were sent a letter from their General Manager encouraging participation and showing support for the research; we anticipated that the members would be more likely to participate than non-members. We account for the over-sampling of non-members by adding a weight variable to our calculations. The post-stratification weight variable is described by Bethlehem [2009]:

$$d_i = \frac{N_h/N}{n_h/n}$$

where N_h is the population size of strata h in population N and n_h is the sample size of strata h in sample n . For members the weight is

$$(273/38,625)/(273/1,473) = .04,$$

and for non-members, the weight is

$$(38,352/38,625)/(1,200/1,473) = 1.22.$$

This weight variable is then included in all estimations and calculations, as appropriate.

The mean of certain variables is compared between the two groups (members and non-members), taking into account the weight variable, and tested using the adjusted Wald test. The null hypothesis is that the mean of each group is the same. We then use the F-statistic distribution table to find out the probability that the F-statistic falls outside of the distribution, according to the degrees of freedom and level of significance. If the F-statistic falls outside of the distribution, this means that the null hypothesis, (that the mean of each group is the same) can be rejected at a specified certainty level. If the F-statistic falls within the distribution where the probability is quite high (10% or higher), then the null hypothesis cannot be rejected and we must accept that the means are statistically the same. We have reported the p-value, which tells us the level of significance at which the null hypothesis can be rejected. A p-value less than .10 is generally used to reject the null hypothesis with confidence.

Our final response rate was 23.49% overall (342 total participants), with 42.86% response rate from members (117 participants) and 19.08% response rate from non-members (225 participants).

5.6 Respondent Characteristics

5.6.1 Demographics

The general results of the survey are shown in Table 17. Respondents were overwhelmingly male, born between 1915 and 1983, and the mean age among all respondents is 60. The mean number of children is just over 2. The mean years of experience and years farming the same land are 30 years and 26 years, respectively. The percent of the farm that is owned outright is around 80% and the mean size of the farm is 546 acres.

In terms of education, a majority of respondents finished high school or earned a G.E.D., and over half have taken at least some college courses. Over half of respondents are split between full- and part- time farmers, and about a third are either hobby farmers or retired farmers. Respondents were allowed to identify with more than one political ideology, so the total is larger than the number of respondents. A majority chose conservative, republican, and/or independent, while about a fourth of the population identified with democrat, liberal, or socialist.

5.6.2 Farm Characteristics

Of the 342 total respondents, 96 have land enrolled in the CRP, 255 have pasture, 224 have livestock, and 159 farmers plant crops. The average amount of land in CRP is 31.52 acres. There is an average 188 acres in pasture. The majority of livestock are beef cattle, with a small percentage of horses, dairy cattle, and goats. The average number of livestock is 73. The average number of acres in crops is 497, and the majority of the crops are corn, soy, wheat, and hay.

5.7 Members of Show Me Energy and Non-Members

Now that we have an idea of the general population of participants, we can investigate the similarities and differences among members and non-members of Show Me Energy. Respondents were overwhelmingly male for both members and non-members, as evident in Figure 1. The mean age for members and non-members is significantly different; the mean age for members is 56 and for non-members is 61.

The mean number of children is statistically the same for both groups, at just above 2. The mean years of experience and years farming the same land are also statistically the same for members and non-members, at around 30 years and 26 years, respectively.

The mean size of the farm is statistically different between the two groups: members typically have

larger farms, compared to non-members: 800 acres compared to 468 acres. Another statistically significant difference between the two groups is the percentage of the farm that is owned outright: members own less of their land than non-members (82% versus 88%).

In terms of education, members have a higher percentage of college-educated farmers, which can be seen in Figure 3. A higher percentage of members are full-time farmers than non-members, while more non-members are hobby farmers or retired farmers. These differences can be seen in Figure 2. Members identified more often with “conservative” and “republican” than non-members, as shown in Figure 4. A higher percentage of members are self-described members of environmental organizations. A higher percentage of members also claim farm income as the primary income, and are more likely to rent acres. Members answered positively more often as to whether their neighbors produced biomass. A higher percentage of members have employees, although the mean number of employees is statistically the same for both groups.

The survey included 6 statements concerning the environment and climate change. The results are shown in Table 19. Three statements show statistically different means between the members and non-members: “Biodiversity leads to a more healthy ecosystem,” “Demand for energy crops will grow in the future,” and “Production of energy crops will increase farm profitability.” Members agreed more with all three statements, compared to non-members. These differences are illustrated in Figure 5.

5.7.1 Members Only

We asked only members of Show Me Energy to answer several questions concerning their production decision. Question 10 in Section 5 asked “How influential are the following in your decisions about the number of acres in biomass production?” and listed eight possible influences, which members rated from 1 (Very Influential) to 5 (Very Unimportant). Sixty members responded, and the results can be seen in Table 25. It is clear that on average, biomass price, anticipated future biomass price, and anticipated future demand for biomass were the three most influential aspects of the eight possible selections (all scoring under 2 on average). It is important to note that the mean of all eight is below 3, meaning all eight were, on average, at least somewhat important to producers.

Members were asked how they harvested the biomass, and the results are listed in Table 18. The majority of respondents own their own equipment (61%). Most others hire others to harvest (25%) or share equipment (11%).

Over half of reporting members began producing biomass in 2006 and 2007. Most members began producing biomass in the same year that they became members. Members produce a mean of 35 tons of biomass per year, at an average price of \$42 per ton. Twenty-two members (19% of members) claim they

will receive BCAP payments this year.

5.8 Consumers of Biomass Pellets for Home Heating

Table 24 shows the similarities of consumers and non-consumers of biomass pellets. All means are statistically the same for consumers and non-consumers. The scale statements concerning economics and the environment show similarities and differences between consumers and non-consumers of biomass pellets. Table 20 shows that consumers tend to agree more with the statement: “Demand for energy crops will grow in the future”. All other statements are statistically the same.

We asked consumers and non-consumers of biomass pellets questions that can help shed light on the decision to use biomass pellets for home heating. First, we asked non-consumers to identify why they choose not to use pellets. Respondents were allowed more than one answer. Table 21 shows the most common reasons include “inconvenience” and “cost”. “Storage space” is the third most commonly identified reason to not use biomass pellets, followed by “smell” and “other”, and, lastly, “concern about air pollution”. We allowed participants to write in their own response as well, which also helps us understand the decision. The most commonly written response was “use wood” and, secondarily, “availability”. Several respondents cited the infrastructural demands of installing the new system in responding “not set up for it”, and several cited the initial cost of the stove and installation. There were a couple participants that were concerned about their home insurance policy not allowing the use of a biomass pellet stove or furnace, and several were concerned with the mess in the house.

Then, we asked consumers to describe the way in which they use biomass pellets. Table 22 shows the type of appliance used, type of facility heated, and the previous source of heat. The majority of consumers use a stove for secondary home heating. Propane is the most common previous source of heat, followed by electricity and wood. Only one consumer reported natural gas as the previous source of heat.

Finally, the specifics regarding the cost and amount of pellets consumed annually help complete the profile of consumers of biomass pellet fuel, as seen in Table 23. The average price paid for pellets per ton is \$189, and the average amount used annually is 3.23 tons. The average cost per year is \$565, and the average age of the appliance is 3 years. The size of the facility heated varies from 500 sq. ft. to 4300 sq. ft. The cost of the appliance and installation varies as well, from \$600 to \$14,000.

Chapter 6

Conceptual Framework: Decision Modeling

Following Rahm [1984]'s framework for modeling the decision of the producer, and Davey [2008]'s application of the framework, we can construct a utility function for the producer's decision:

$$U_{Ti} = X_i\alpha_T + e_{Ti}$$

where X_i is a vector of observable characteristics, such as age, acreage, and location for producers $T=1$ and non-producers $T=0$, α_T is a vector of parameters, and e_{Ti} is a vector of error terms. Thus, the i th firm will become a biomass feedstock producer if U_{1i} is greater than U_{0i} . Similarly, we can use the same model for the consumer's decision using a vector of similar characteristics for consumers, $T=1$ and non-consumers, $T=0$. The i th consumer will consume biomass if U_{1i} is greater than U_{0i} .

The variable description is found in Table 26, and the summary statistics for the variables are listed in Table 27. The dependent variables, or regressands, that we have chosen for production and consumption are binary, or dichotomous variables. This means that our regressand is qualitative and not quantitative, and we are seeking to find the probability of a value of the regressand, rather than a quantitative value of the regressand. For this reason, we will use a probability model for our regressions.

Probability models include the linear probability model (LPM), the logit, and the probit. The linear probability model (LPM) is the simplest, as it allows ordinary least square estimation. However, there are several problems inherent to the LPM model, such as the non-normality of disturbances: the disturbances actually follow Bernoulli distribution and present heteroskedasticity.¹

The problem of heteroskedasticity means that the estimates will not have minimum variance, and will thus not be efficient. A large sample size may overcome this problem, but our sample size is limited in this case, and cannot thus overcome this problem.² Another problem of the LPM model is that the regressand

¹A simplified regression can be described as $Y_i = \beta_1 + \beta_2 X_i + u_i$, and the disturbances can be described as $u_i = Y_i - \beta_1 - \beta_2 X_i$, and Bernoulli distribution is described as $E(Y_i) = 0(1 - P_i) + 1(P_i)$. If the equation follows Bernoulli distribution, then the values of the disturbances, as well, follow Bernoulli distribution and can take one of two values: $1 - \beta_1 - \beta_2 X_i$, OR $-\beta_1 - \beta_2 X_i$. Therefore, u_i is not normally distributed. It then follows that the mean and variance for this type of equation are not normally distributed, and as with the Bernoulli distribution, the variance is a function of the mean. In other words, if the mean is p , then the variance is $p(1 - p)$, which means the variance is heteroskedastic.

²This can be overcome, however, by using a method similar to *weighted least squares*, or WLS, where the entire equation is divided by $\sqrt{w_i} = \sqrt{E(Y_i/X_i)[1 - E(Y_i/X_i)]}$. This is done by a two step process where OLS is run first to obtain Y_i and w_i estimates. These estimates are then used to transform the data as described.

is not limited by the model to values of 0 and 1, as in the logit and probit.³

While these problems are surmountable using several techniques including increasing sample size, our sample size is limited to a small sample, and thus, the LPM model is not a good fit. Furthermore, as the name of the model suggests, it is linear, and this means that it assumes constant marginal effect. In this case, several variables are hypothesized to be non-constant in their marginal effects, and thus, a non-linear model would be a better fit.

To address this non-linearity in marginal effects, it is logical to use a cumulative distribution function (CDF): either the logistic (logit model) or normal (probit model) distribution function. Both models produce similar results using maximum likelihood estimation; the main difference is in the shape of the CDF: the logit model has slightly fatter tails than the probit model. Both models allow for non-linearity, and increasing and decreasing marginal effects. The logit model is mathematically more simple, and allows a greater number of post-estimation tests; therefore, the logit model is used for both the production and consumption regressions.

The logit model uses the logistic cumulative distribution function (Λ):

$$U_{Ti} = F(\mathbf{x}, \beta) = \frac{e^{\mathbf{x}'\beta}}{e^{\mathbf{x}'\beta} + 1} = \frac{1}{1 + e^{-(\mathbf{x}'\beta)}} = \Lambda(\mathbf{x}'\beta) = \text{Prob}(Y = 1|\mathbf{x}), \text{ where } \mathbf{x} = \beta_1 + \beta_2 X_2 \dots + \beta_k X_k$$

The coefficients that are estimated are interpretable as the log-odds; they represent the change in the logit as the variable changes. The results may be more easily understood in the context of marginal effects, which can be estimated at the mean of a continuous variable, or for the discrete change of a binary variable from 0 to 1. From Greene [2008], the marginal effects are:

$$\frac{\partial E[y|\mathbf{x}]}{\partial \mathbf{x}} = \Lambda(\mathbf{x}'\beta)[1 - \Lambda(\mathbf{x}'\beta)]\beta$$

In order to explain the amount of biomass that a producer decides to produce, we run a Heckman two-step procedure using the Inverse Mills' Ratio. The Inverse Mills' Ratio (IMR) is necessary in order to account for selection bias. When only observed positive production data is used for the regression, and zero production is, in effect, "censored" by a latent variable, regression coefficients may be inconsistent. The Heckman two-step procedure accounts for the latent variable, and provides consistent coefficient estimates.

To run a Heckman two-step regression, first, a probit regression is run where the dependent variable is a binomial that represents production of biomass feedstocks (1) or no production (0). The independent variables used in this study are the same as the variables used in the third logit regression (Model 3) to explain the dependent variable *members*. The Inverse Mills Ratio is constructed using the ratio of the probability density function over the cumulative distribution function of the regression.

The second step usually uses the IMR as an instrument in an ordinary least-squares (OLS) estimation. In this case, the dependent variable (*Tons Per Year*) can not be negative; it must be positive or zero. The

³This can be overcome by assuming negative results equal 0 and greater than 1 results equal 1.

negative binomial model, as well as the Poisson count model both fit this requirement. The negative binomial model is used because it allows more robust variation. The dispersion parameter (α) is significantly greater than zero, which signifies that the negative binomial regression is a better fit than the Poisson model. A mean dispersion is used in the negative binomial regression, rather than the constant dispersion.

At least one variable must be included in the first probit regression that is not included in the second regression; in this case, several variables are included in the first regression that are not included in the second regression. The variables that are not included are assumed to be important in determining whether or not a farmer becomes a biomass producer, but not important in determining the amount of biomass the producer decides to produce.

The Inverse Mills' Ratio is defined in Greene [2008] as

$$\begin{aligned}\lambda(\alpha) &= \phi(\alpha)/[1 - \Phi(\alpha)] && \text{if truncation is } > a, \\ \lambda(\alpha) &= -\phi(\alpha)/\Phi(\alpha) && \text{if truncation is } < a, \\ \text{where } \alpha &= (a - \mu)/\sigma, \text{ and } \phi(\alpha) \text{ is the standard normal density.}\end{aligned}$$

6.1 Modeling the Producer's Decision

Because producing biomass for pellet production currently necessitates joining the Show Me Energy Cooperative in Missouri, as there are no known alternative markets near Centerview, Missouri, we use the respondent's membership as the binary variable for production. After the binary production regression is run, we use the results to construct the Inverse Mills Ratio (IMR). We then include the IMR as an additional term in a least-squares regression where the dependent variable is the amount of biomass produced annually.

The acreage of the farm (*Acres*) is included because we believe that production decisions are based partly on physical farm characteristics. It is projected that larger farms will be more likely to join Show Me Energy, because they have more production, more land, and therefore the relative risk of changing production and marketing strategies is lower. There could also be economies of scale, which might lower overall production costs for larger farms. Larger farms might also have a larger capacity to invest in a crop strategy that is perceived to be riskier.

The type of farm production is also believed to influence the production and marketing decisions of the farmer. Because the pasture and livestock variables are likely to be correlated, we use a dummy variable (*Have Livestock*) where 1 means the farm has livestock, 0 means there is no livestock. Livestock could have a positive or negative effect on membership in Show Me Energy; livestock farmers may be more likely to

have biomass crops already in rotation, but they may also have more of a need to retain the crop for the livestock. Several other production variables are included as well, such as the number of employees (*Number of Employees*), a dummy variable for farms where the farm income is the primary household income (*Farm Income is Primary Income*), and a dummy variable for full-time farmers (*Full-Time Farmer*). Having more employees may make certain production strategies easier or more economically viable. If the farm income is not the primary income, or the producer is not a full-time farmer, this could mean that the producer has already diversified their income sources, and may be less likely to diversify into a different crop, such as biomass. If the farm income is the primary income or the producer is a full-time farmer, the producer may be likely to diversify into various production strategies.

Characteristics of the farmer will also influence the decision making process, as evident in Valdivia and Poulos [2009], Beedell and Rehman [1999], Pannell [1999], Luzar and Diagne [1999], and Greiner et al. [2009], to name several. As shown in the description of our survey statistics, the populations of members and non-members contain differences in characteristics. For this reason, we include the farmer’s age (*Age*), the number of years farming (*Years Farming*), and self-described political association (*Conservative and Republican*), and a dummy variable representing membership in environmental organizations (*Member of Environmental Org.*):1 for member, 0 for non-member). Education is included as well; a dummy variable(*Bachelor’s Degree or more*) is used to denote participants that have a bachelor’s degree or more education (1) or less than a bachelor’s degree (0).

Farmers that are younger may be more likely to make longer-term investments in the farm and in the land, such as planting a perennial crop that takes several years to mature; however, older farmers may be more experienced and may be more willing to adopt a new strategy. The number of years farming may increase the likelihood to adopt a non-traditional crop, as expertise may lead to higher levels of confidence and risk-taking. Political association was included to capture differences in political persuasion as they are correlated with production strategies. Education was included because we predicted that more educated producers might be more willing to adopt new technologies.

We believed there to be a spatial component to the decisions to produce and consume bioenergy, both in knowledge diffusion (word-of-mouth) and due to transport costs. Using the participant’s stated county, we constructed several variables based on location: one for residents of the same county as the Show Me Energy Cooperative (*Johnson County*), and one for residents of all counties adjacent to Johnson County (*Nearby to Johnson County*).

The statements concerning climate change, biodiversity, and the economic potential of biomass were based on a Likert scale from 1 to 5. A dummy variable was extracted for all participants that answered ”1”

for each statement, meaning that they "strongly agreed."

For the regression where the amount of biomass in production is the dependent variable, we included only selected variables from the logit regression. The variables we included were chosen under the assumption that they would effect the decision to produce biomass. This relies on the assumption that not all of the factors that affect the decision to produce biomass necessarily effect the decision of *how much* biomass to produce. For example, having a neighbor that also produces biomass is assumed to have a positive effect on membership in Show Me Energy, but is not assumed to affect the amount of biomass that is produced.

We propose that the age, employment status, farm size, number of employees, and whether or not the farm income is the primary income, will all affect the decision of how much biomass to produce. The age of a farmer may be, again, related to the willingness of the farmer to make longer-term investments in perennial crops that take several years to mature. The employment status and primary income dummy are both related to diversification and whether or not the farmer has already diversified income sources. The acreage of the farm will limit the amount of biomass that it is possible to produce. The number of employees might make the farmer more likely to produce more biomass as labor is less constrained. The livestock dummy variable is ambiguous: it may make the producer produce more or less biomass. The location variable *Johnson County*, may increase the biomass production, as transportation costs are lower, making overall production costs lower.

While we can't directly observe the cost-benefit analysis of switching from a traditional crop to produce a biomass energy feedstock, these regressions can help to explain the indirect costs and benefits and improve our overall understanding of the decision, in terms of economics. For example, the cost of switching may increase as age increases, as the costs are spread out over a shorter time frame. Similarly, being an early adopter of a promising technology may be perceived as a benefit. Our regressions will show which facets of the production system and producer effect the decision to produce, as well as the decision of how much biomass to produce.

6.1.1 Results: Producer's Decision

For the first regression, where membership in Show Me Energy is the dependent variable, we estimate three models, and the results can be seen in Table 28. Model 1 is the baseline model, and it includes demographic variables as well as farm production variables. Model 2 includes the addition of spatial variables *Nearby to Johnson County* and *Johnson County*. Finally, Model 3 includes all variables from Model 2 as well as the six "agree/disagree" statements.

Traditional tests of overall significance and goodness-of-fit are generally not applicable to complex survey

results due to the inclusion of weights. In order to compare the goodness of fit of each model, we use the test developed by Archer et al. [2007], `svylogitgof`, which is the F-adjusted mean residual test, and takes into account survey design weights. If we can not reject the null hypothesis, then the model is a good fit. P-values are reported in the results.

The F-adjusted test for overall goodness of fit for Models 1 and 3 allow us to reject the hypothesis that the model is not a good fit. The test result for Model 2 does not allow us to reject the hypothesis. However, all results are robust from Model 1 to Model 3, with signs and significance of coefficients relatively unchanged. Furthermore the sensitivity and specificity of each model show that they are increasingly accurate in prediction, both positively and negatively.

Using Model 3 as our final regression, we found that producers were less likely to join the cooperative and produce biomass feedstock as their age increases in all three models, but, as Models 2 and 3 show, are more likely to join as the number of years farming increases.

Being a member of an environmental organization is significant across Models 2 and 3, and has a positive effect on membership. When the farm income is the primary household income, membership likelihood increases in all Models.

Having a neighbor that is producing biomass is significant across all three Models and has a positive influence on the likelihood of membership. Producers that rent acres to others are more likely to be members in Model 1, but the variable is insignificant in Models 2 and 3. Having livestock on the farm decreases likelihood of membership in all Models.

The location dummy variables are both significant and positive in both Model 2 and 3. Producers that are located near Johnson County are more likely to join Show Me Energy and produce biomass, and producers located within Johnson County are even more likely to join. This can be seen in the marginal effects of each variable: being in Johnson county increases the odds of joining by nearly 20%, while being adjacent to Johnson County only increases the odds by 1.5%.

There are two significant "agree/disagree" statements: "Climate change is the result of human actions," and "Production of energy crops will increase farm profitability." In both cases, participants that "strongly agreed" with the statements were more likely to be members of Show Me Energy.

Being a full-time farmer (versus part-time, retired, or hobby), the size of the farm, the level of education, political views, number of employees, percentage of the farm owned, and whether the crops are produced on the farm are all insignificant in all three regressions.

6.1.2 Results: Amount of Biomass in Production

The IMR for the sample used in the OLS equation has a mean of 4.71, standard deviation of 2.58, minimum of $3.25e^{-08}$ and maximum of 11.65.

The IMR (*Mills*) is included in the negative binomial regression equation. The results of the models are shown in Table 29; Model 1 does not include spatial variable, Model 2 does. The p-value of the F-tests show that Model 1 is a slightly better fit; however, the model coefficients, significance and signs do not differ significantly.

The number of employees is positively correlated with the amount of biomass produced. All other variables: age, employment status, acreage, the farm income is the primary income dummy, the livestock dummy, and the location variable do not have significant effects on the amount of biomass produced. The sample size is quite small (N=33), which could be a reason for the low explanatory power of the model.

These results imply that the decision of how much biomass to produce annually is correlated with the number of employees on the farm. The decision is not necessarily related to the production structure of the farm (i.e. more or less livestock or crops), nor the characteristics of the farmer.

6.2 Modeling the Consumer's Decision

For the consumption of biomass, we asked respondents directly if they consume biomass pellets for heating (home or otherwise); this will be our binary dependent variable. Our independent variables will be the age of the home (*Age of Home*), the age (*Age*), environmental organization membership (*Member of Environmental Org.*), use of other renewable utilities (*Uses Renewable Utilities*), a dummy variable for location (*Johnson County*), and one of the previously described six "agree/disagree" statements: "demand for biomass will grow."

There is little research on the adoption of pellet-based heating technology, but we have used several other studies to guide the model. As it has been shown in this study, the initial investment in pellet technology is large; thus we predicted that residents would be more likely to make this investment if they were more invested in their home and their land. This is reflected in the variables concerning the age of the home, the age of the resident. It is also reflected in the dummy variable for the statement "demand for biomass will grow"; consumers that agree with the statement may be more likely to consume given that they believe they will be "early adopters" of an emerging technology and may also believe that prices will fall as demand grows.

It has been shown that a lack of familiarity and education can dissuade people from consuming pellet

fuel (in this study, as well as in Mahapatra and Madlener [2007] and Verma et al. [2009], among others). Therefore, it is believed that membership in an environmental organization and using other renewable utilities will have an influence on the use of biomass.

Similarly, as availability of biomass pellets is crucial to the decision to consume them, a spatial variable is included in the regression that is 1 for residents of Johnson county and 0 otherwise. Residents in the same county as Show Me Energy have the greatest access to biomass pellets for home heating, and thus are hypothesized to be more likely to use biomass pellets.

6.2.1 Results: Consumer's Decision

Table 30 shows the results of three models. Our first model is the baseline regressing; the second and third model incrementally add the location variable and one of the six "agree/disagree" statements. This statement was chosen because it was the only statement which showed significant and consistent correlation. Using the F-adjusted test for overall goodness of fit, we can see that the models have good fit. The sensitivity and specificity show that all three models can predict negative results, but can not accurately predict a positive result. However, there are two significant variables. In all models *Age* is significant and is negatively correlated with the consumption of biomass pellets. This implies that younger consumers are more likely to choose to consume biomass pellets. In Model 3, the dummy variable for consumers that strongly agree with the statement "demand for biomass will grow" is significant and positively associated with biomass consumption.

6.3 Conclusion

This study contributes to several areas of economic research, including literature about the production of biomass feedstock, processing of biomass feedstock pellets, and consumption of biomass pellets. It is unique in its focus on the Midwestern "Corn Belt" region of the U.S., adjusting elements of the cost according to the local conditions. As policy makers become increasingly interested in the potential efficacy of renewable energy incentives, studies such as this one can provide insight into the effects of policy on supply and demand of renewable energy. My policy analysis shows that it will take a combination of current policies and potential policies to make renewable fuels economically competitive with non-renewable fuels until production costs decrease.

There have been regional studies of the technical potential of bioenergy crops (Jiang and Swinton [2009]); however, production may not be limited by the technical potential, but rather the by the decision of the

producers to produce or not produce bioenergy crops. Producers cite the current and future economics of biomass as the most influential factors in making the decision to produce biomass (see Table 25), however, our research suggests that the decision is complex. Production may be limited by a number of different variables, such as the location of the farmer in relation to the processing facility, or the age and experience of the producer.

This study helped to shed light on not only the minimum break-even production cost that is necessary for Midwestern farmers to switch into energy crop production, but also the type of producer and production systems that have a higher likelihood of producing biomass. As our regressions show, younger farmers with longer experience farming are more likely to adopt biomass production. Farms that are larger, located near a market, or acknowledge that neighbors are producing biomass are all more likely to adopt. Producers of biomass feedstock for the cooperative Show Me Energy are optimistic about the future economics of energy crops (see Table 19 and Figure 5). Livestock farmers and farmers that are located further away from the processing facility are less likely to produce biomass. Most farmers did not report significant production changes when they began producing biomass for Show Me Energy; rather they rerouted their previous grass production towards the new market.

The results of the survey also support the results of the cost benefit analysis. Transportation costs are shown to be a significant cost in the final break-even pellet production cost, and the location of the producer is also significant in the regressions concerning production: those nearby, with lower transportation costs, are more likely to produce biomass. The significance of the production variable *Have Livestock* indicates that certain types of producers are less likely to produce biomass feedstock for pellet production, which may be related to differences in opportunity costs.

Consumption of biomass is difficult to explain with our small sample size ($N=31$) and poor goodness-of-fit scores for all regressions. However, the survey results shed light on the decision to consume: almost half of the consumers switched from propane to biomass pellets (see Table 22), which allows us to propose that they did not have access to cheaper fuels such as natural gas and wood. Thus, biomass pellets may be more competitive in rural markets where choice is limited.

According to our participants, the non-consumption of biomass is related to the inconvenience and perceived cost (both of the appliance and the fuel: see Table 21). Many non-consumers in our survey report having access to low-cost wood for secondary heating. So while natural gas may not be an option, there still exists an inexpensive fuel that is difficult for biomass to economically compete with. However, without the option of natural gas or low-cost wood, our cost-benefit analysis shows that renewable pellets are economically competitive, even without subsidies. Consumers without access to natural gas, nor their own

wood, are more likely to consume biomass fuel, as our cost-benefit analysis showed as well. Most consumers report using biomass to heat another facility or in conjunction with another heating system in their home. Thus, according to the survey, as well as our cost-benefit analysis, biomass pellets are more likely to be a top choice among consumers that are interested in heating auxiliary buildings or drying corn; i.e. to supplement their secondary heating needs, rather than replace their primary heating source.

Biomass feedstock production has been associated with environmental benefits; however, in general, motivations behind being involved in production *and* consumption tend to be more economic than environmental. Furthermore, both consumers and producers, on average, tended to disagree with the statements “Climate change is the result of human actions” and “I am concerned about climate change.” This helps to rule out climate change concern as underlying motivation for production or consumption.

This study has shown the conservative, break-even cost of production of biomass feedstock pellets using three different feedstocks in the Corn-Belt region of the U.S. The effects of current and potential policy are shown and policy implications have been explored. The survey results help to illustrate and support the cost-benefit analysis, while also revealing more about the motivations of production and consumption.

To return to the questions presented in the introduction, we have shown that the policies in place do substantially lower the cost of biomass pellets, making them competitive with natural gas, under our assumptions. Without the policies, natural gas is substantially less expensive than biomass pellets. Biomass fuel would be competitive without the policies only to consumers without access to natural gas, i.e. rural consumers. Carbon pricing has the effect of increasing the cost of non-renewable fuel at a much higher rate than non-renewable fuels, making biomass fuel increasingly competitive. Sensitivity analysis shows that substantial increases in production costs or decreases in yield will have noteworthy effects on the annual home heating cost.

Opportunities for further survey research include a more thorough and geographically diverse survey. A more thorough survey would include a larger sample size, and would address the problem of non-response with more persistent follow-up. An improved survey would ask for more information concerning the differences in options for home heating among rural and urban households; this would be useful in constructing the potential market for renewable biomass fuel. A more geographically diverse survey could also address similarities and differences among energy crop producers and consumers from different cultures and climates. As production of biomass energy crops becomes more widespread and infrastructure and crops become more established, it will be interesting to revisit the costs of producing and processing feedstock pellets at the Dudley Smith Farm, as well as elsewhere.

Table 1: Greenhouse Gas Emissions from Production Per GJ

Crop	Kg/hectare	Tons CO₂-eq./GJ
Miscanthus	794.45	.002
Switchgrass	1194	.007
Corn Stover	120	.002
Corn(shelled)	2357	.090

Table 2: Greenhouse Gas Emissions from Production and Processing Per GJ

Fuel	Tons CO₂-eq./GJ
Miscanthus	.005
Switchgrass	.011
Corn Stover	.006
Corn(shelled)	.094
Wood Pellets	.007
Natural Gas	.059
Electricity	.001
Propane	.066
Fuel Oil	.082

Table 3: Switchgrass Production Literature

Author	Location	Type	Yield	Discount Rate	Cost of Land	Transport	Storage	Total Cost	Notes
Sladden et al. [1991]	Alabama	8 varieties	6.76-34.60 t ha ⁻¹	unspecified	No	No	No	\$9.94-\$50.89 t ⁻¹	1990 dollars
Turhollow [1994]	Midwest	unspecified	14.4 t ha ⁻¹	6%	\$154 ha ⁻¹	No	Yes	\$48 t ⁻¹	1989 dollars
Hallam et al. [2001]	Iowa	Cave-in-Rock	11.13-11.60 t ha ⁻¹	unspecified	\$197.08-\$284.17	\$4.20 t ⁻¹	Yes	\$38.9t-1-47.65 t ⁻¹	1993 dollars
Duffy [2001]	Iowa	unspecified	4 t acre ⁻¹ (9.88 t ha ⁻¹)	8/9%	\$75 acre ⁻¹ (\$185 ha ⁻¹)	No	Yes	\$264.59 acre ⁻¹ (\$66.15 t ⁻¹)	2000 dollars
Epplin et al. [2007]	Tennessee	unspecified	12.3 t ha ⁻¹	unspecified	\$10.77 t ⁻¹	\$13 t ⁻¹	Yes	\$48-67t ⁻¹	2007 dollars
Perrin et al. [2008]	Upper Plains	unspecified	7 t ha ⁻¹	10%	\$64-222 ha ⁻¹	No	Yes	\$59.10 t ⁻¹	2003 dollars
Khanna et al. [2008]	Illinois	Cave-in-Rock	7.01t ha ⁻¹ (5.78 t ha ⁻¹ annualized)	4%	\$192.76 ha ⁻¹	\$55.39 ha ⁻¹	Yes	\$98.19 t ⁻¹	2003 dollars
Smeets et al. [2009]	Europe	unspecified	12-20 t ha ⁻¹	unspecified	€10-€232 ha ⁻¹	€11-€20 t ⁻¹	Yes	€43-€100 t ⁻¹	2004 dollars
Mooney et al. [2009]	Tennessee	Alamo	13.8 t ha ⁻¹	5.4%	(\$12-\$287) ¹	(\$14-\$25) ¹		(\$53-\$124) ¹	2010 dollars
James et al. [2010]	Michigan	Cave-in-Rock	9 t ha ⁻¹	5%	\$168 ha ⁻¹	\$3.56 L ⁻¹	No	\$43.93-\$68.60 t ⁻¹	2009 dollars
Jain et al. [2010]	Illinois	Cave-in-Rock	14.57 t ha ⁻¹	4%	\$148	No	No	\$115 t ⁻¹	2009 dollars
					\$73-\$82 t ⁻¹	No	Yes	\$117-151 t ⁻¹	2007 dollars

¹Converted from 2009 Euros to 2010 dollars at an exchange rate of 1€ to 1.2364 US dollars.

Table 4: Miscanthus Production Literature

Author	Location	Yield	Discount Rate	Cost of Land	Transport	Storage	Total Cost	notes
Huisman et al. [1997]	Europe	12 t ha ⁻¹	unspecified (7% machinery)	966 ECU ha ⁻¹ (\$773 ha ⁻¹) ¹	No	Yes	119 - 161 ECU t ⁻¹ (\$95-\$129 t ⁻¹) ¹	1997 ECU
Bullard [2001]	Europe	18 t ha ⁻¹		No	No	No	45-72 ECU t ⁻¹ (\$36-\$58 t ⁻¹) ¹	1997 ECU
Heaton et al. [2004]	Illinois	33 t ha ⁻¹	3%	\$341 ha ⁻¹	No	No	\$38 t ⁻¹	1997 dollars
Styles et al. [2008]	Ireland	8.2-15.2 t ha ⁻¹	5%	No	No	Yes	€37-€48 t ⁻¹	2002 dollars
Khanna et al. [2008]	Illinois	35.8t ha ⁻¹	4%	\$192.76 ha ⁻¹	Yes	Yes	(\$46-\$59) ²	2007 Euros
Smeets et al. [2009]	Europe	15-25 odt ha ⁻¹	unspecified	€10-€232 ha ⁻¹ (\$12-\$287) ²	€11-€20 t ⁻¹ (\$14-\$25) ²	Yes	€55-€106 t ⁻¹	2010 dollars
James et al. [2010]	Michigan	22.4 t ha ⁻¹	5%	\$138t ⁻¹	No	No	(\$68-\$131) ²	2003 dollars
Jain et al. [2010]	Illinois	39.97 - 40.26 t ha ⁻¹	4%	\$31-\$43 t ⁻¹	No	Yes	\$46-\$198t ⁻¹	2004 dollars
							\$69-\$106 t ⁻¹	2009 dollars
								2007 dollars

¹Converted from European Currency Unit to \$U.S. dollar at the 1997 exchange rate of 1 ECU = \$1.25 dollars

²Converted from 2009 Euros to 2010 dollars at an exchange rate of 1€ to 1.2364 US dollars.

Table 5: Corn Stover Production Literature

Author	Location	Yield	Cost	Notes
Hallam et al. [2001]	Iowa	5.7-8.6 t ha ⁻¹	\$6.80-\$34.77t ⁻¹	1993 dollars
Gallagher et al. [2003]	Corn Belt	889.4 t mi ⁻² (3.43 t ha ⁻¹)	\$16-\$18 t ⁻¹	1997 dollars
Larson et al. [2010]	Illinois	3.82 t ha ⁻¹	\$66t ⁻¹	2007 dollars
Chen2010	Illinois	3.6 t ha ⁻¹	\$122.83 t ⁻¹	2003 dollars

Table 6: Cost of production with and without BCAP assistance

Cost items (\$ ha ⁻¹)	Miscanthus ¹	Miscanthus With BCAP	Switchgrass ¹	Switchgrass With BCAP	Corn Stover ²	Corn Stover With BCAP
Fertilizer	40.42		57.39		28.63	
Chemicals	1.27		4.16			
Seed	23.69		15.69			
Interest on op. inputs	4.58		5.41		2.00	
Storage/drying/crop ins.	87.67		23.91		222.18	
Machinery	673.59		222.44			
Total Operating Cost (2007 dollars)	968.93	491.02	328.99	248.87	252.81	91.10
Total Operating Cost (2009 dollars)	1002.58	508.07	340.42	257.51	261.59	94.26
Yield	19.95	19.95	5.78	5.78	3.6	3.6
Opportunity Cost	192.76	192.76	192.76	192.76	104.39	104.39
Break-even delivered cost (2009 \$ t ⁻¹)	59.92	35.13	92.25	77.90	101.66	55.18

Table 7: Dudley Smith Miscanthus Production

	Harvest Year			3 Year Average 2007-9	2 Year Average 2008-9
	2007	2008	2009		
Acres	2	2	6		
Yield (tons)	8	17	36		
Tons/Acre	4	8.5	6	6.17	7.25
Cost Per Ton					
Maintenance	\$92.13	\$43.94	\$25.43	\$53.64	\$34.39
Storage	\$100	\$26.80	\$20.83	\$49.21	\$23.82
Harvest	\$100	\$79.41	\$56.11	\$78.51	\$67.76
Total Cost Per Ton	\$292.13	\$149.57	\$102.37	\$181.36	\$125.97

¹Khanna et al. [2008]²Jain et al. [2010]³Opportunity costs are based on a corn price of \$80.68 per ton and a soy price of \$200.72, and a corn yield of 10.81 tons per hectare using a corn-soy rotation and 9.51 using a corn-corn rotation and a soy yield of 3.14⁴(Operating Cost_{Feedstock} + Opportunity Cost_{Corn-Soy}) / Yield_{Feedstock} = Breakeven Farmgate Price_{Feedstock}

Table 8: Transportation Costs

Study	Feedstock	Variable Costs	Fixed Costs	Total for a 100 km Round-trip	Currency
Searcy et al. [2007]	Straw/Stover	\$0.12 t km ⁻¹	\$4.39 t ⁻¹	\$16.39 t ⁻¹	2004 dollars
Dudley Smith Trial	Miscanthus	\$0.43 t km ⁻¹	\$12.00 t ⁻¹	\$55.01 t ⁻¹	2009 dollars

Table 9: Production Costs Including Transportation

Feedstock	Farm-gate (\$ t ⁻¹)	Transport (\$ t ⁻¹) ¹	Total (\$ t⁻¹)
Miscanthus	\$59.92	\$18.61	\$78.53
Switchgrass	\$92.25	\$18.61	\$110.86
Corn Stover	\$101.66	\$18.61	\$120.27

Table 10: Actual and Simulated Pellet Production Costs

Mani et al. [2006]					Christian County Trial
	Fuel	Fuel Required (MJ)	Price Per MJ ²	Cost Per Ton	
Pelletizing - Energy					
	Coal	469	0.0016	\$.75	
	Electricity	404	0.0309	\$12.49	
	Diesel	206	0.0188	\$3.86	
				\$17.09	
Pelletizing - Capital Costs				\$6.42	
				\$23.50	\$30.00
Storage and Personnel				\$14.48	\$26.81
Total Processing Costs Per Ton				\$37.99	\$56.81

Table 11: Total Production, Transport and Processing Costs

Feedstock	Farm-gate (\$ t ⁻¹)	Transport (\$ t ⁻¹)	Processing (\$ t ⁻¹)	Total (\$ t⁻¹)	Per GJ
Miscanthus	\$59.92	\$18.61	\$37.99	\$116.52	\$7.24
Switchgrass	\$92.25	\$18.61	\$37.99	\$148.85	\$9.10
Corn Stover	\$101.66	\$18.61	\$37.99	\$158.26	\$10.63

¹Searcy et al. [2007]'s total, updated to 2009 U.S. dollars²Based on EIA's three-year averages for Illinois

Table 12: Baseline Annual Costs to Heat an Average Home

Energy Source	Price	Price per GJ	Annual Cost (72.69 GJ)	Furnace Cost	Total Annual Cost
Electricity ¹	\$.11/kWh	\$32.63	\$2248.54		\$2,248.54
Propane ¹	\$2.21/Gallon	\$24.15	\$1664.07		\$1,664.07
Fuel Oil (No. 2) ¹	\$2.60/Gallon	\$18.77	\$1292.94		\$1,292.94
Natural Gas ¹	\$12.82/1000 Ft. ³	\$12.16	\$837.68		\$837.68
Wood Pellets ²	\$225/Ton	\$13.72	\$945.27	\$498.68	\$1,443.96
Corn Stover ³	\$158.26/Ton	\$10.63	\$772.69	\$498.68	\$1,230.95
Switchgrass ⁴	\$148.85/Ton	\$9.10	\$661.65	\$498.68	\$1,160.33
Miscanthus ⁴	\$116.52/Ton	\$7.24	\$526.43	\$498.68	\$1,025.11
Corn (Shelled) ⁵	\$107.14/Ton	\$8.06	\$772.58	\$498.68	\$1,271.26

Table 13: Policy Comparison of Annual Heating Costs (US \$)

Fuel	Market Price	BCAP	Tax Credit	Carbon Tax \$25	Carbon Tax \$50
Miscanthus - Production	270.71	158.72	270.71	280.12	289.53
Processing and Transport	260.78	260.78	260.78	260.78	260.78
Furnace Cost	498.68	498.68	388.31	498.68	498.68
Total	1025.11	913.12	914.74	1034.52	1043.93
Switchgrass - Production	410.04	346.29	410.04	429.05	448.06
Processing and Transport	260.78	260.78	260.78	260.78	260.78
Furnace Cost	498.68	498.68	388.31	498.68	498.68
Total	1160.33	1096.57	1049.95	1179.33	1198.34
Corn Stover - Production	496.27	269.38	496.27	506.68	517.08
Processing and Transport	260.78	260.78	260.78	260.78	260.78
Furnace Cost	498.68	498.68	388.31	498.68	498.68
Total	1271.26	1044.36	1160.89	1281.67	1292.07

Table 14: Annual Heating Costs Under All Policies Compared to Non-Renewable Fuels (US \$)

	Miscanthus	Switchgrass	Corn Stover	Natural Gas	Electricity	Propane	Fuel Oil
Annual Cost	\$812.16	\$1005.21	\$944.40	\$938.52	\$2249.54	\$1783.94	\$1442.71

¹According to the EIA database: <http://www.eia.doe.gov/>; if Illinois averages are not available, Indiana averages are used

²Fithian, Illinois manufacturer's quote, October 2009

³Jain et al. [2010]

⁴Khanna et al. [2008]

⁵based on a price of \$3 per bushel

Table 15: Sensitivity analysis of biomass pellet production.

Feedstock	Baseline Annual Cost	Corn and Soy Prices +25%	Corn and Soy Prices -25%	Yield +25%	Yield -25%	Pelletizing Costs + 25%	Pelletizing Costs - 25%	Transportation + 25%	Cost of Furnace +25%	Cost of Furnace -25%
Miscanthus	\$1025.11	3.77%	-3.77%	-5.28%	8.80%	4.19%	-4.19%	2.05%	12.16%	-12.16%
Switchgrass	\$1160.33	11.30%	-11.30%	-7.07%	11.78%	3.64%	-3.63%	1.78%	10.74%	-10.74%
Corn Stover	\$1271.26	2.78%	-2.78%	-11.78%	13.01%	3.65%	-3.65%	1.79%	9.81%	-9.81%

Table 16: Sensitivity analysis using low- and high-end production estimates.

Feedstock	Baseline	Low-end Production Estimate (per ton)	Low-end Annual Cost	High-end Production Estimate (per ton)	High-end Annual Cost
Miscanthus	\$1025.11	\$39	\$917.06	\$151	\$1648.98
Switchgrass	\$1160.33	\$36	\$923.20	\$198	\$1421.50
Corn Stover	\$1271.26	\$7	\$808.18	\$123	\$1374.36

Table 17: Respondent Characteristics

	Members Number (% of Mem.)	Non-Members Number (% of Non-Mem.)	Total Number (% of Total)	Adj. Wald p-value
Participants	117 (34%)	229 (66%)	346	
Male	109(93%)	204(89%)	313(90%)	.1290
Female	7(6%)	19(8%)	26(8%)	.1290
Less than High School	3(3%)	12(5%)	15(4%)	.5479
High School/G.E.D.	27(23%)	81(35%)	108(31%)	.0239
Some College	26(22%)	47(21%)	73(21%)	.4651
Bachelor's Degree	44(38%)	49(21%)	93(27%)	.0351
Graduate Studies	14(12%)	33(14%)	47(14%)	.2312
Full-Time Farmer	59(50%)	53(23%)	112(32%)	.0001
Part-Time Farmer	38(32%)	75(33%)	113(33%)	.8579
Hobby Farmer	10(9%)	52(23%)	62 (18%)	.0032
Retired Farmer	8(7%)	43(19%)	51(15%)	.0042
Conservative	54(46%)	85(37%)	139(40%)	.5233
Republican	40(34%)	63(28%)	103(30%)	.2239
Independent	34(29%)	66(29%)	100(29%)	.5819
Democrat	21(18%)	48(21%)	69(20%)	.4127
Liberal	2(2%)	5(2%)	7(2%)	.5980
Socialist	0(0%)	2(1%)	2(1%)	.1574
Environmental Org. Members	14(12%)	17(8%)	31(9%)	.1606
Farm Income is Primary Income	49(42%)	40(17%)	89(26%)	.0004
Rent Acres	28(24%)	35(15%)	63(18%)	.0554
Neighbors Produce Biomass	37(32%)	11(5%)	48(14%)	.0000
Have Employees	29(25%)	36(16%)	65(19%)	.4058
Mean [St. Err.]	Members	Non-Members	Total	
Age	55.79 (1.26)	61.19 (0.96)	56.06 (1.19)	.0007
Number of Children	2.18 (0.13)	2.20 (0.12)	2.18 (0.123)	.9095
Years of Farming Experience	30.73 (1.53)	30.80 (1.26)	30.74 (1.45)	.9703
Percent of Farm Owned	82.24 (2.82)	88.48 (2.07)	82.55 (2.69)	.0765
Years Farming Same Land	26.97 (1.70)	27.32 (1.18)	27.99 (1.61)	.8634
Farm Size	800.6735 (89.21)	468.08 (102.09)	783.57 (84.79)	.0148
Number of Employees	.51 (0.15)	.37 (0.07)	.50 (.14)	.4058

Table 18: Response to the question: How do you harvest biomass?

Positive Responses	
Own your own equipment	37
Rent equipment	1
Share equipment with others	7
Hire others to harvest	15
Other scenario	1

Table 19: Mean score for members and non-members

	Mean [St. Err.] (1 = Agree, 5 = Disagree)			Adjusted Wald Test p-value
	Members	Non-Members	Total Average	
Climate change is the result of human actions.	3.43[.13]	3.41[.11]	3.48[.12]	.7557
I am concerned about climate change.	3.10[.12]	2.95[.11]	3.11[.12]	.3276
Biodiversity leads to a more healthy ecosystem.	1.96[.09]	2.39[.09]	1.99[.09]	.0022
Carbon offsets will be economically valuable in the future.	2.86[.14]	3.04[.10]	2.89[.13]	.3203
Demand for energy crops will grow in the future.	1.89[.09]	2.30[.08]	1.93[.08]	.0019
Production of energy crops will increase farm profitability.	2.03[.09]	2.68[.09]	2.09[.09]	.0000

Table 20: Mean score for consumers and non-consumers

	Mean [St. Err.] 1 - Agree, 5 - Disagree		Adj. Wald p-value
	Consumers	Non-Consumers	
I am concerned about climate change.	3.24 [.34]	2.92 [.12]	.3834
Climate change is the result of human actions.	4.13 [.26]	3.37 [.11]	.0072
Biodiversity leads to a more healthy ecosystem.	2.80[.45]	2.34[.09]	.3231
Carbon offsets will be economically valuable in the future.	3.16[.34]	3.04[.10]	.7454
Demand for energy crops will grow in the future.	1.46[.13]	2.38[.09]	.0000
Production of energy crops will increase farm profitability.	2.14[.23]	2.72[.09]	.0207

Table 21: Factors influencing non-consumption

What factors influenced your decision not to use pellets for home heating? (Check all that apply)	
	Total Count (308 Non-Consumers)
Inconvenience	107
Concern about air pollution	3
Storage Space	30
Cost	90
Smell	14
Other, Blank	23
Other, Filled in by User:	
Use wood	23
Availability of pellets	11
Not set up for it	9
Cost of Stove/Furnace	9
Insurance	3
Mess	2
Never thought about it	8
No Answer	126

Table 22: Consumer Description

	Total Consumers: 34 (19 non-Members, 15 Members)
Type of Appliance:	
Stove	19
Furnace	4
Insert	7
Other	1
Function of pellet heating:	
Home Heating	21(6 Primary Heat)
Heating Another Facility	13
Farm-related Facility	3
Other	2
Previous Fuel:	
None	1
Natural Gas	1
Propane	16
Electric	7
Wood	8
Other	0
Political Views:	
Conservative	16
Republican	9
Independent	8
Democrat	3
Liberal	1
Socialist	0
Type of Farmer:	
Full-time	13
Part-time	14
Hobby	5
Retired	0

Table 23: Statistics of consumption of biomass pellets.

	Mean [St. Err.]	Min.	Max
Cost of Appliance and Installation	\$ 3340 [2600]	\$600	\$14,000
Size of Facility (Sq. Ft.) [St. Err.]:	2344 [434.11]	500	4300
Age of Appliance:	3 yrs.[.29]	1 yr.	30 yrs.
Price of Pellets Per Ton	\$189 [29.99]	\$100	\$450
Quantity of Pellets Per Year (tons)	3.23 [.60]	1	8
Total Cost of Fuel Per Year	\$565 [71.30]	\$400	\$1600

Table 24: Statistics of consumers and non-consumers of biomass pellets.

	Mean [St. Err.]		Adj. Wald
	Consumers	Non-Consumers	p-value
Age of Home	36 [10.16]	38 [2.36]	.7820
Acres	304 [89.53]	490 [108.58]	.1893
Years Farming Current Land	21 [3.92]	28 [1.20]	.1020
Percent of Home Owned	85% [7.95]	89% [2.09]	.6658
Age	56 [2.68]	62 [.98]	.0454

Table 25: Influences of biomass production decision: members

How influential are the following in your decisions
about the number of acres in biomass production?

	Average Score [Linearized St. Err.] (1 = Very Important, 3= Neutral, 5 = Very Unimportant)
Capacity to store grass	2.66 [.17]
Capacity to transport grass	2.13 [.14]
Capacity of my labor force to produce crop	2.58 [.17]
Land Availability	2.35 [.17]
Biomass Price	1.60 [.13]
Anticipated future price of biomass	1.63 [.13]
Anticipated payments for carbon offsets	2.50 [.20]
Anticipated demand for biomass for biofuel production	1.66 [.12]

Table 26: Variables used in regression

Variable Name	Description
age	Age of participant
Years Farming	Number of years of farming experience of Participant
Full-Time Farmer	1 if farming is their full-time job, 0 otherwise
Member of Environmental Org.	1 if participant is a self-identified member of an environmental organization, 0 if not
Acres	Number of acres owned by participant
Farm Income Is Primary Income	1 in the farm production is the primary household income, 0 if not
Bachelor's Degree or more	1 if they answered positively for "some college", "Bachelor's degree", or "graduate studies", 0 otherwise
Conservative and Republican	1 if Participant identified with any or all "conservative" or "republican", 0 otherwise
Neighbor Produces Biomass	1 if Participant identified a neighbor producing biomass, 0 otherwise
Number of Employees	Number of Employees
Percent of Farm Owned	percentage of the farm that is owned outright
Rents Acres to Others	1 if Participant rents acres to other farmers, 0 otherwise
Have Livestock	1 if Participant reported livestock on the farm, 0 otherwise
Have Crops	1 if Participant reported crop production on the farm, 0 otherwise
Total Livestock	total number of livestock reported
Total Crop Acres	total number of acres planted in crops (corn, soy, wheat)
Nearby to Johnson County	1 if Participant resides in one of the 8 counties that border Johnson County (Show Me Energy's county), 0 otherwise
Johnson County	1 if participant is located in Johnson county, 0 otherwise

Table 27: Summary statistics of variables used in regression

Variable Name	Mean	(Std. Dev.)	Min.	Max.	N
Dependent Variables					
Members	0.379	(0.486)	0	1	256
Tons Per Year	33.784	(64.969)	0	400	44
Use Biomass	0.098	(0.297)	0	1	256
Independent Variables					
Age	59.15	(12.401)	27	86	260
Home Age	40.235	(31.37)	0	163	243
Years Farming	30.9	(15.248)	3	70	259
Full-Time Farmer	0.358	(0.48)	0	1	260
Member of Environmental Org.	0.088	(0.285)	0	1	260
Acres	602.715	(1173.476)	1.5	14680	256
Farm Income Is Primary Income	0.301	(0.459)	0	1	256
Bachelor's Degree or more	0.465	(0.5)	0	1	260
Conservative and Republican	0.638	(0.481)	0	1	260
Neighbor Produces Biomass	0.177	(0.382)	0	1	232
Number of Employees	0.42	(1.127)	0	12	251
Percent of Farm Owned	86.056	(26.076)	0	100	252
Rents Acres to Others	0.174	(0.38)	0	1	259
Have Livestock	0.692	(0.462)	0	1	260
Have Crops	0.915	(0.279)	0	1	260
Nearby to Johnson County	0.242	(0.429)	0	1	260
Johnson County	0.096	(0.295)	0	1	260

Table 28: Logit Regression Results [Dependent Variable= Membership in Show-Me Energy]

Variable	Model 1 Coefficient (Std. Err.)	Model 2 Coefficient (Std. Err.)	Model 3 Coefficient (Std. Err.)	Model 3 MFX
Age	-0.094*** (0.022)	-0.120*** (0.029)	-0.151*** (0.039)	-0.001
Years Farming	0.033 (0.020)	0.057* (0.024)	0.064* (0.032)	0.000
Full-Time Farmer	-0.425 (0.765)	-0.219 (0.792)	-0.203 (0.918)	-0.001
Member of Environmental Org.	1.294 (0.673)	1.668* (0.790)	2.132* (0.901)	0.022
Acres	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000
Farm Income is Primary Income	1.588* (0.752)	1.661 (0.888)	1.933* (0.898)	0.013
Bachelor's Degree or More	0.274 (0.462)	0.224 (0.487)	0.130 (0.569)	0.000
Conservative and Republican	-0.332 (0.434)	-0.238 (0.463)	0.193 (0.499)	0.001
Neighbor Produces Biomass	2.394*** (0.650)	2.404*** (0.652)	2.535*** (0.721)	0.032
Number of Employees	-0.044 (0.300)	0.193 (0.220)	0.167 (0.270)	0.001
Percent of Farm Owned	-0.002 (0.009)	0.005 (0.011)	0.012 (0.012)	0.000
Rents Acres to Others	1.231* (0.565)	0.970 (0.654)	0.600 (0.733)	0.003
Have Livestock	-0.993* (0.475)	-1.174* (0.550)	-1.411* (0.614)	-0.008
Have Crops	-0.866 (0.709)	-1.132 (0.740)	-1.207 (0.751)	-0.007
Nearby To Johnson County		1.918*** (0.507)	1.929*** (0.515)	0.015
Johnson County		4.262*** (0.747)	4.534*** (0.905)	0.222
Strongly Agrees: "Climate change is the result of human actions."			2.441* (1.002)	0.028
Strongly Agrees: "I am concerned about climate change."			-1.233 (0.756)	-0.003
Strongly Agrees: "Production of energy crops will increase farm profitability."			2.603** (0.997)	0.028
Strongly Agrees: "Biodiversity leads to a more healthy ecosystem."			-0.467 (0.681)	-0.001
Strongly Agrees: "Carbon offsets will be economically valuable in the future."			-0.364 (1.314)	-0.001
Strongly Agrees: "Demand for energy crops will grow in the future."			-1.235 (0.868)	-0.003
constant	1.190 (1.264)	0.728 (1.458)	1.542 (1.485)	
N	216	216	216	
% predicted + correctly	23%	30%	34%	
% predicted - correctly	85%	85%	85%	
F-adj. Test	.90	82.07	1.435	
p-value	.5260	3.287e-63	.175	

†for p < .10, * for p < .05, ** for p < .01, and *** for p < .001

Table 29: Heckman Two-Step Estimation Results [Dependent Variable= Tons of Biomass Produced by Members]

Variable	Model 1 Coefficient (Std. Err.)	Model 2 Coefficient (Std. Err.)
Mills	-0.235 (0.123)	-0.156 (0.143)
Age	-0.001 (0.013)	-0.011 (0.018)
Full-Time Farmer	-0.311 (0.461)	-0.619 (0.607)
Acres	-0.000 (0.000)	-0.000 (0.000)
Farm Income is Primary Income	0.080 (0.608)	0.372 (0.700)
Employees	1.022* (0.440)	0.998* (0.422)
Have Livestock	-0.220 (0.389)	-0.242 (0.382)
Johnson County		0.557 (0.547)
constant	3.843*** (0.589)	3.990*** (0.676)
lnalpha constant	0.044 (0.389)	0.017 (0.399)
N	33	33
F(7,26) (8,25)	1.63	1.53
Prob > F	.1716	.1973

[†]for p < .10, * for p < .05, ** for p < .01, and *** for p < .001

Table 30: Logit Regression Results: [Dependent Variable= Consumption of Biomass for Residential Home Heating]

Variable	Model 1 Coefficient (Std. Err.)	Model 2 Coefficient (Std. Err.)	Model 3 Coefficient (Std. Err.)
Home Age	-0.002 (0.013)	-0.002 (0.013)	-0.001 (0.014)
Age	-0.040* (0.020)	-0.039 [†] (0.020)	-0.034 [†] (0.020)
Member of Environmental Org.	0.153 (1.206)	0.139 (1.203)	0.077 (1.192)
Uses Renewable Utilities	0.267 (0.822)	0.253 (0.822)	-0.037 (0.789)
Johnson County		-0.968 (0.722)	-1.011 (0.728)
Strongly Agree: "Demand for biomass will grow."			1.312* (.574)
cons	0.058 (1.126)	0.004 (1.138)	-.757 (1.343)
% predicted + correctly	5%	5%	5%
% predicted - correctly	94%	94%	94%
N	242	242	242
F-adj. test	1.33	1.83	2.44
p-value	0.2593	0.1078	0.0264

[†]for p <.10, * for p <.05, ** for p <.01, and *** for p <.001

Figure 1: Respondents by Gender

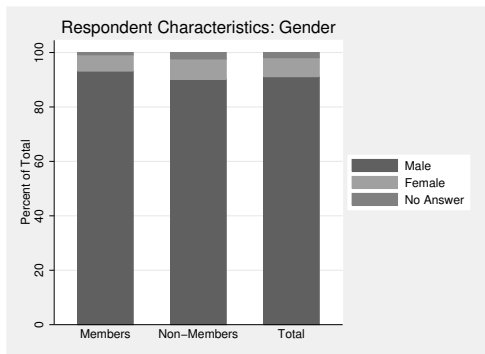


Figure 2: Respondents by Employment Status

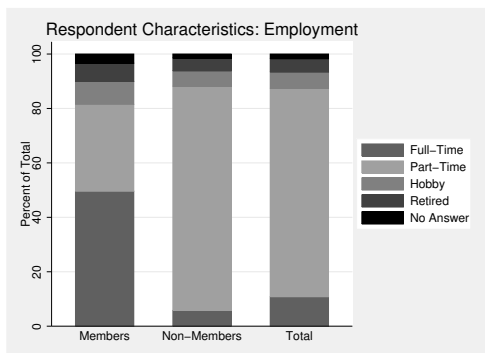


Figure 3: Respondents by Education Level

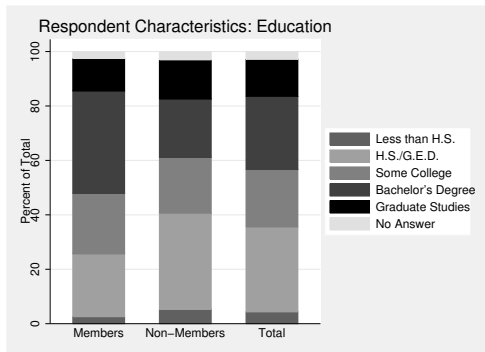


Figure 4: Respondents by Politics

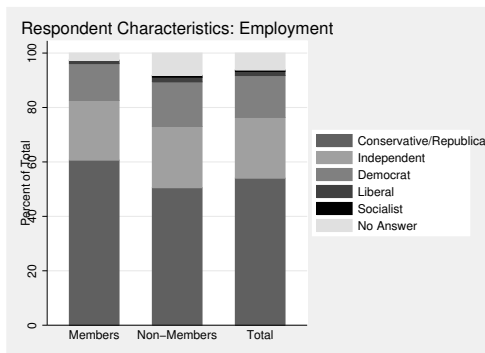


Figure 5: Environmental and Economic Statements: Mean Scores

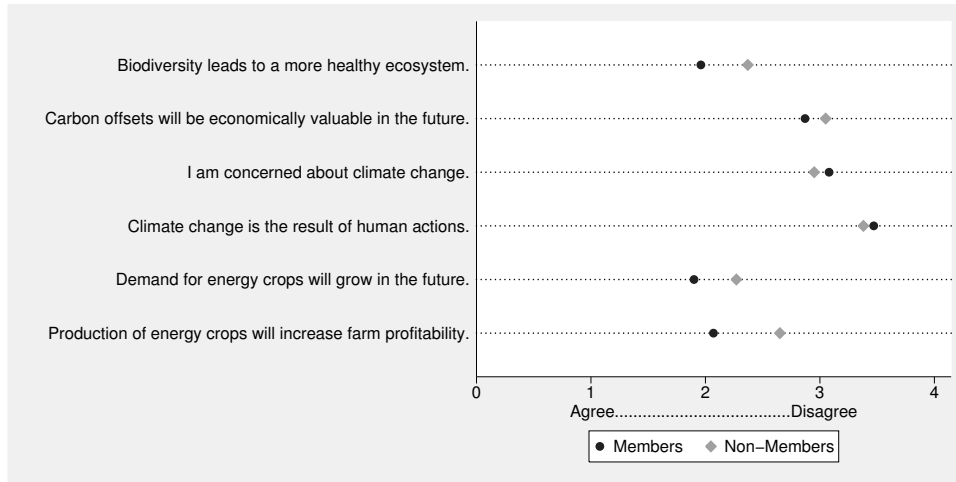


Figure 6: Effects of Carbon Tax on Annual Home Heating Costs

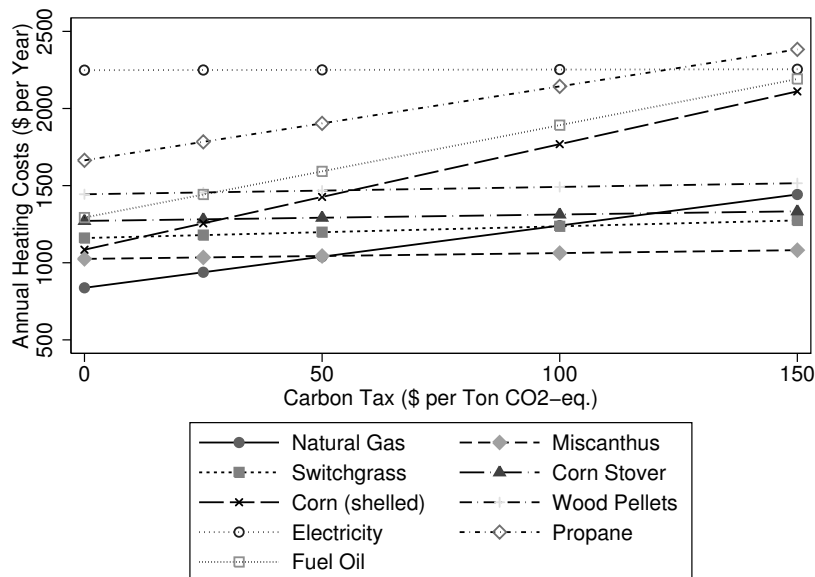


Figure 7: Map: Total Participants

Number of Participants in Surveyed Counties in Missouri

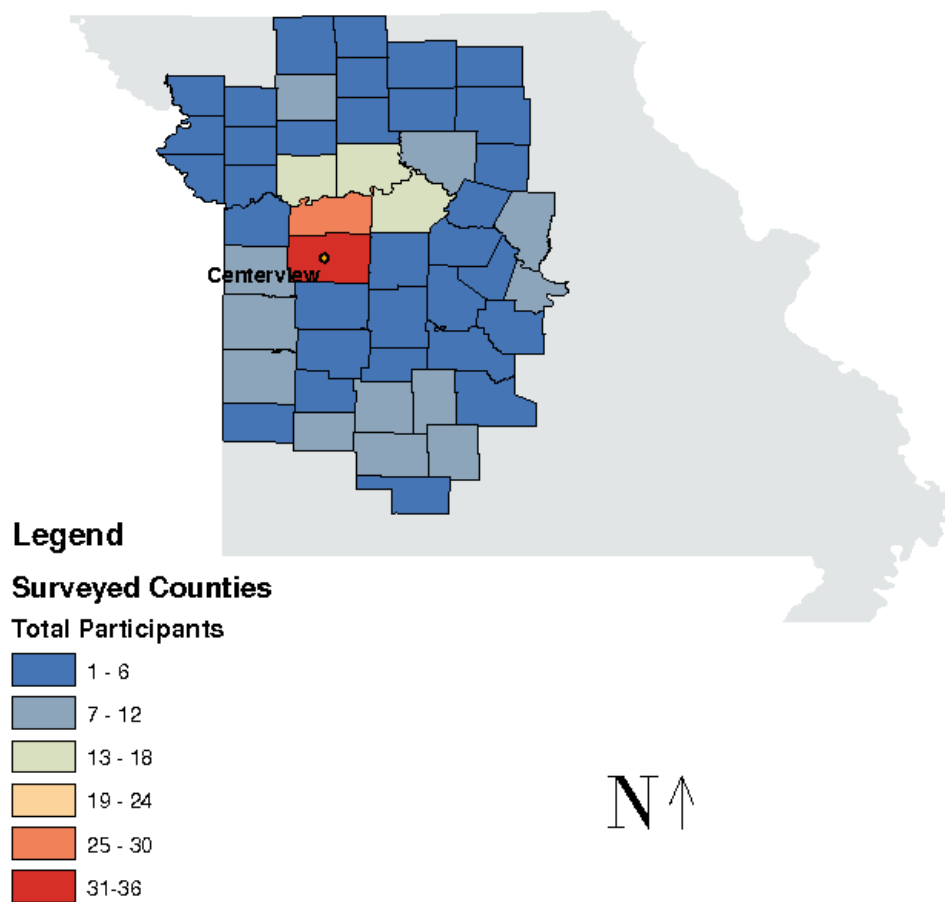


Figure 8: Map: Members as a Percentage of Total Participants

Percentage of Participants that are Members in Surveyed Counties in Missouri

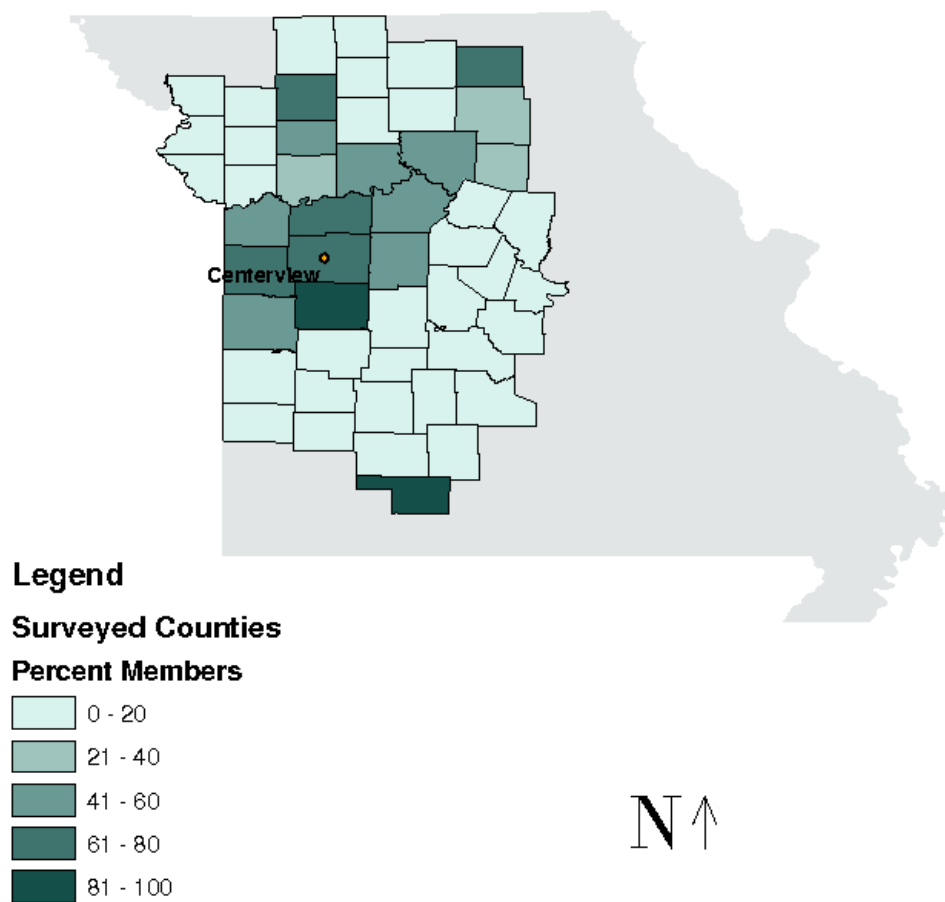


Figure 9: Map: Non-Members as a Percentage of Total Participants

Percentage of Participants that are Non-Members in Surveyed Counties in Missouri

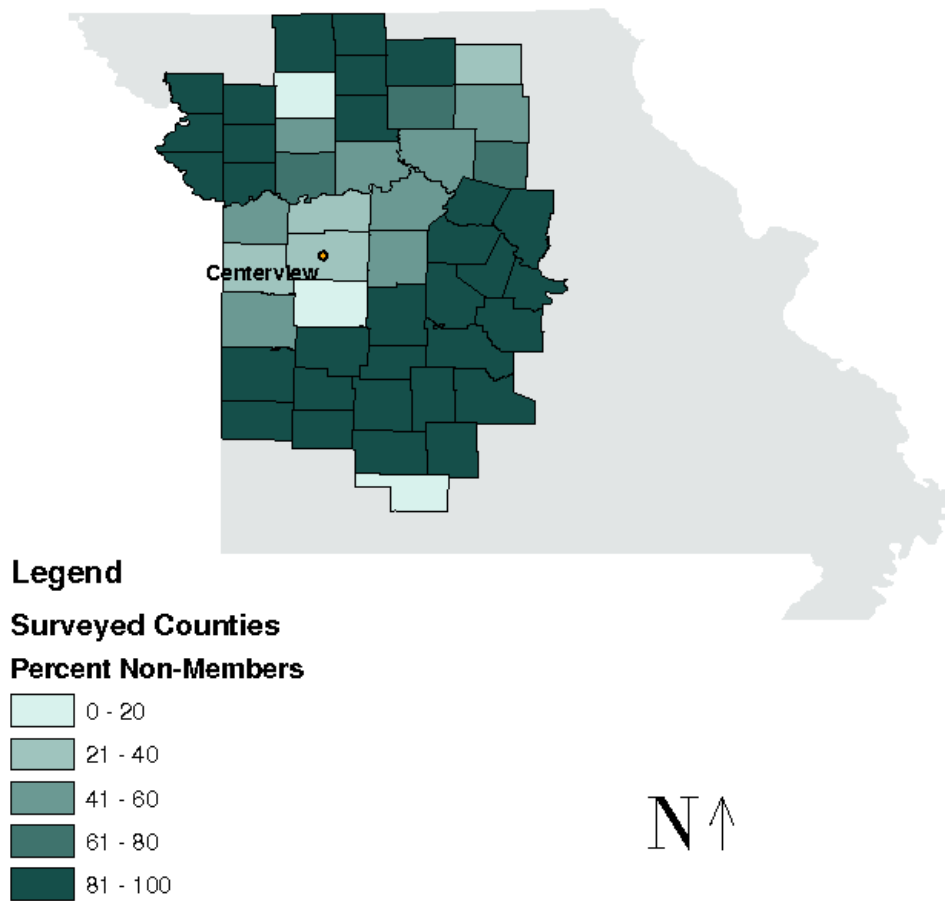


Figure 10: Map: Consumers as a Percentage of Total Participants

Percentage of Participants that are Consumers in Surveyed Counties in Missouri

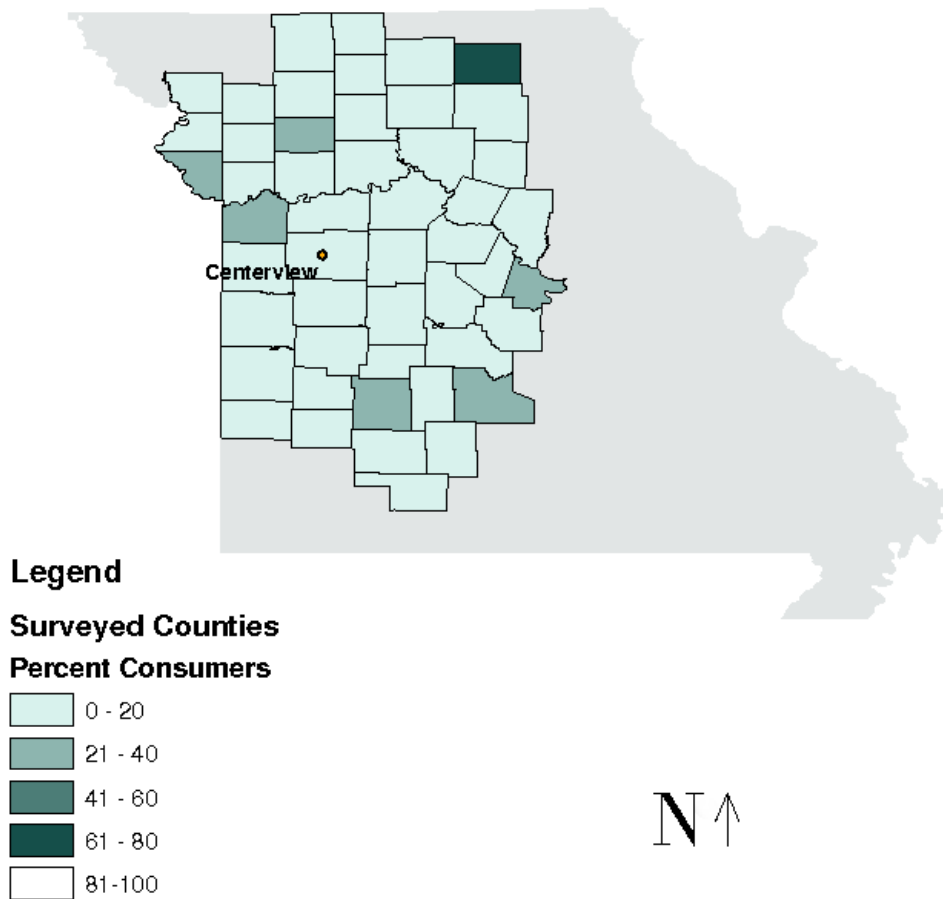
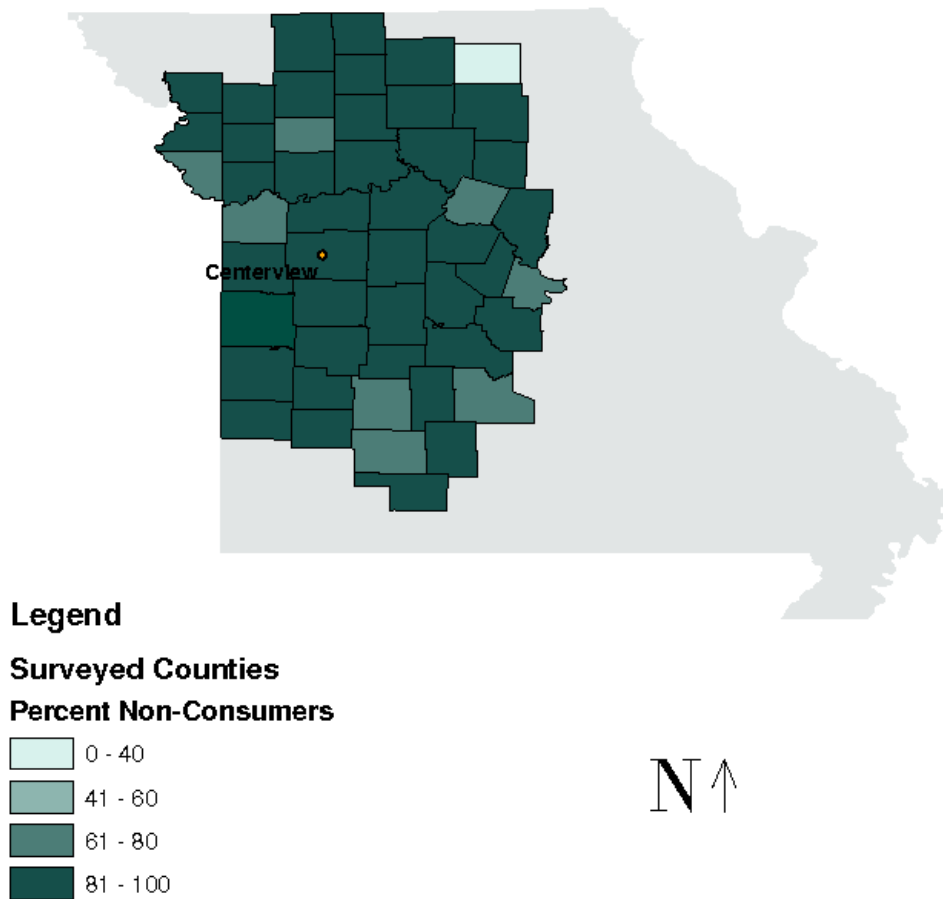


Figure 11: Map: Non-Consumers as a Percentage of Total Participants

Percentage of Participants that are Non-Consumers in Surveyed Counties in Missouri



Appendix A

Appendix: Survey

Biomass Energy Crop Production and Pellet Purchase

1 Demographics

Please provide background information about yourself. All answers are confidential and will not be linked to your identity or address.

1. Year you were born: -----
2. Gender: ☐ Male
☐ Female
3. Highest education level attained: ☐ Less than high school
☐ High school or G.E.D.
☐ Some college
☐ Bachelors degree
☐ Graduate degree
4. Total number of years you have been farming: -----
5. Are you a: ☐ Full time farmer
☐ Part-time farmer
☐ Hobby farmer
☐ Retired farmer
6. Are you the primary decision-maker concerning farm production? ☐ Yes
☐ No
7. Number of children: -----
8. Are you a member of any environmental or conservation organizations? (not including trade organizations) ☐ Yes
☐ No
If **yes**, please list them: -----

9. Zip code of farmland: -----
10. County of farmland: -----
11. Political Views: (check all that apply) ☐ conservative
☐ independent
☐ democrat
☐ republican
☐ liberal
☐ socialist

2 Farm Information

Please provide your answers as applicable for the year 2009.

1. What percentage of the farm assets (including land, crops and livestock) do you own? _____%
2. What year did you first begin farming this land? _____
3. Number of acres you farm: _____ **Acres**
4. Number of employees on the farm: _____ **Employees**
5. Is the farm income the primary household income?
☐ Yes
☐ No
6. Do you rent acres of land to another producer?
☐ Yes
☐ No
 If **yes** how many acres of land do you rent to others? _____ **Acres**

3 Opinion

For each statement, please circle the number which best corresponds with your assessment:

	Agree		Neutral		Disagree
The current rate of climate change is the result of human actions.	1	2	3	4	5
I am concerned about climate change.	1	2	3	4	5
Biodiversity leads to a more healthy ecosystem.	1	2	3	4	5
Carbon offsets will be economically valuable in the future.	1	2	3	4	5
Demand for biomass energy crops will grow in the future.	1	2	3	4	5
Production of biomass energy crops will increase farm profitability.	1	2	3	4	5

4 Farm Production

Please describe your farm:

CRP:	_____Total acres in 2009
Pasture:	_____Total acres in 2009 Do you interseed pasture? Yes No
Livestock:	_____ Total Head in 2009 _____ Head of beef cattle _____ Head of dairy cattle _____ Head of _____ _____ Head of _____ (please describe)
Crops:	_____ Total acres in 2009

	Acres	Yield/Acre
Biomass energy crops		
Soybeans		
Corn		
Wheat		
Alfalfa		
Other:		
Other:		

If you produced grass **in 2009**, please describe:
 (for example, if you have alfalfa planted for seed **and** biomass, circle both.)

Grass:	For: (circle all that apply)	Acres	Yield/Acre	Since what year
	pasture / forage / seed / biomass			
	pasture / forage / seed / biomass			
	pasture / forage / seed / biomass			
	pasture / forage / seed / biomass			

1. Do neighboring farms produce biomass energy crops? ☐ Yes
☐ No

If **yes**, what is the distance to the nearest neighbor
 producing biomass energy crops?-----**miles**

2. If you **are not currently** producing biomass energy crops, are you likely to produce them in 2010? ☐ Yes
☐ No

If **yes**, -----**acres**

3. If you **are not currently** harvesting grass for biomass, are you likely to harvest it in 2010? ☐ Yes
☐ No

If **yes**, -----**acres**

If **no**, please complete these sentences:

"I would be likely to produce biomass energy crops if the price for biomass

is at least \$-----per short ton. At this price, I would plan to harvest,

at most, -----acres each year.

5 Biomass Production

If you do not produce biomass energy crops, please skip to Section 6.

1. Since which year have you been producing biomass energy crops? _____

2. Are you a member of the Show Me Energy Cooperative?

☐ Yes

☐ No

If **yes**, which year did you join Show Me Energy? _____

3. How many tons of biomass do you supply annually to Show Me Energy? _____

_____short tons

4. What was the average price **per short ton** that you received in 2009? \$_____

_____/short ton

5. Are you receiving Biomass Crop Assistance Program (BCAP) payments?

☐ Yes

☐ No

If **yes**, starting when? _____

6. Have you expanded planted acres of biomass energy crops in 2009,
compared to 2008?

☐ Yes

☐ No

If **yes**, by how many acres? _____

_____acres

If **yes**, which of the following describe the previous use of that land?

Check all that apply:

☐ CRP

☐ Pasture

☐ Crop

☐ Purchased new land

☐ Idle

☐ Other

7. Have you expanded the harvesting of crops specifically for biomass sales in 2009,
compared to 2008?

☐ Yes

☐ No

If **yes**, by how many acres? _____

_____acres

8. Have you reduced the number of livestock in 2009 compared to 2008
in order to produce biomass?

☐ Yes

☐ No

If **yes**, from _____head to _____head

9. When you harvest biomass, do you:

Check all that apply:

☐ Own your own equipment

☐ Rent equipment

☐ Share equipment with others

☐ Hire others to harvest

☐ Other scenario

10. How influential are the following in your decisions about the number of acres in biomass production?

	Very Important		Neutral		Very Unimportant
Capacity to store grass	1	2	3	4	5
Capacity to transport grass	1	2	3	4	5
Capacity of my labor force to produce crop	1	2	3	4	5
Land availability	1	2	3	4	5
Biomass price	1	2	3	4	5
Anticipated future biomass price	1	2	3	4	5
Anticipated payments for carbon offsets	1	2	3	4	5
Anticipated demand for biomass for biofuel production	1	2	3	4	5

6 Biomass Consumption

1. What year was your home built? _____

2. Do you own your home?

☐ Yes

☐ No

3. Do you use any other renewable utilities? (solar, wind, etc.)

☐ Yes

☐ No

4. Do you use biomass to heat your home or another facility on-site?

☐ Yes

☐ No

If no, what other factors influenced your decision not to use pellets?

Check all that apply:

☐ Inconvenience

☐ Concern about air pollution

☐ Storage Space

☐ Cost

☐ Smell

☐ Other_____

If the answer to Question 4 is **no**, then you have finished our survey. Thank you.

If the answer to Question 4 is **yes**, please answer the following questions:

6. Please describe the type of appliance you use:

☐ Stove

☐ Fireplace insert

☐ Furnace

☐ Other_____

7. What is the make/model? _____

8. What year did you install the stove/insert/furnace? _____

9. What is the pellet-based heating used for?

☐ Home heating

☐ Heating another facility

☐ Farm-related activity

☐ Other_____

If pellets are used for **home-heating**, is the furnace the primary heating source?

☐ Yes

☐ No

Appendix B

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