Energizing the Landscape:
An analysis of switchgrass production costs, commodity crop economics, and nascent gasification technologies in the United States.

A DISSERTATION
SUBMITTED TO THE FACULTY OF THE
UNIVERSITY OF MINNESOTA
BY

Thomas Alan Nickerson

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Jason D. Hill, Timothy M. Smith

August 2014

Acknowledgements

First and foremost, I would like to thank my advisors Jason Hill and Tim Smith. In many ways, you both helped shape me as a researcher, student, employee, and person. I am forever in your debt for the guidance you have provided me. I would also like to acknowledge Bill Lazarus and Gary Sands, who helped complete my examination committee. I appreciate all the work you have put in to help me through my research and the insight you gave to steer me through this process. I must also recognize my colleagues in BAE 309 and the NorthStar Initiative. You helped make my University of Minnesota experience unforgettable, and I will always cherish the memories. Finally, I would like to thank anyone else who helped me along my path as a PhD student. I am grateful for all your help and appreciate everyone who helped make this document possible, no matter the contribution.

Dedication

I dedicate this dissertation to my wife, Katie. Your support and guidance was invaluable throughout my graduate school career, and I cannot thank you enough for all you have done for me.

Abstract

The United States has set ambitious goals for bioenergy that, if met, would require the widespread production of additional sources of biomass on the landscape. In this dissertation, I explore three important economic aspects of the development of the bioenergy industry, namely switchgrass production costs, competition between switchgrass crops and existing commodity crops, and the use of biomass in emerging energy technologies. First, I derive near-term production costs, returns, and profitability of switchgrass (*Panicum virgatum*), a perennial bioenergy crop, across a region spanning 14 states. Costs vary across the region, ranging from less than \$300 ha^{-1} to more than \$1,400 ha^{-1}, yet switchgrass for bioenergy may be profitable in certain locations with commoditized switchgrass prices at or above \$50 Mg^{-1}. Second, I describe the financial profile of the two most prevalent commodity crops grown in the United States, corn and soybeans. I find both crops experience an increase in production costs across the entire study period, but these increases are outpaced by commodity prices, ultimately leading to higher operating profit margins. Furthermore, approximately half of all major corn and soybean producing counties have experienced, in at least one year from 2005 to 2011, a policy inefficiency in which crop insurance overcompensates for the loss of crops, which hinders the introduction of dedicated bioenergy crops on the landscape. Third, I assess the viability of solar-heated gasification systems and find that given current energy market conditions, financial incentives such as tax credits, bond yield reductions, or price subsidies would be necessary to generate a positive return over the life of facilities. In total, bioenergy in the United States will face substantial hurdles and will need to overcome industrial inertia in the agriculture and energy sectors. However, with the correct tools and incentives, it may be possible for bioenergy from switchgrass to become an increasingly important piece of the United States energy profile.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Introduction

Biomass for bioenergy is contentious. For some, it has the potential to become the most important source of energy for the United States since the transition from coal to petroleum. For others, it is a policy instrument used by the government to artificially drive up energy prices and depress the use of American fossil fuels. Biomass energy cannot be introduced without mention of the multifaceted debate about how it is produced, where it is produced, and what the final product is. Land is a fixed resource, and biomass for bioenergy is not currently grown in significant amounts anywhere in the country. Because of this, business as usual operations will not be sufficient enough to produce biomass for energy crops at a large scale. The use of underutilized or “marginal” lands that are either economically or physically unfit to produce value crops, such as corn or soybean, may be prime locations for biomass cropping systems because it would not cause bioenergy crops to compete with food sources, and would also allow producers to expand revenue generating potential on their lands. However, some argue that to meet the necessary fuel production requirements mandated by federal bioenergy policy, bioenergy feedstocks will have to displace some current commodity crop production, causing competition between food and fuel. Additionally, the viability of using energy crops to generate energy is a pressing issue in the debate over energy production in the United States. Between the conversion of feedstocks to liquid fuels for transportation fuels, the gasification of biomass into gases for transportation fuels and electricity generation, or the combustion of biomass for heat and electricity generation, understanding the economics behind the processes are important to recognizing the potential for biomass for bioenergy use.

This dissertation assesses the economics of bioenergy and commodity crop production, the impacts of policy on commodity crop economics, and the financial feasibility of nascent biomass gasification facilities that utilize solar energy for heat. These analyses contribute to conversations surrounding what will be necessary for bioenergy to become competitive in the agricultural industry, how commodity crop economics have experienced dramatic changes since the introduction of bioenergy production policies, and what economic climates are necessary for new bioenergy technologies to come online and remain financially solvent.

1.2 Switchgrass Economic Scenarios

The first section of this collection of studies looks at the economic costs associated with producing switchgrass in the United States for bioenergy. Specifically, it utilizes and analyzes data from production studies conducted throughout the central portion of the country, in states that are thought to be the best candidates for large-scale bioenergy production.[1–3] The study assesses switchgrass production in 14 states using data from 12 peer-reviewed or university trial studies that span from 2000 to 2011.

To begin this study, a spatially and temporally explicit database was constructed to enable a thorough analysis of switchgrass production potential. The two major questions to be answered in this study are: “What are the costs associated with producing switchgrass?” and “What costs are subject to the most potential change over time and do they have an outsized impact on production costs?“ Data from all 12 studies were organized and cost accounting and life-cycle costing methodologies were employed to create a real-value comparison analysis of switchgrass production over time. The end result of the database construction was a simulated 10 year stand of switchgrass first planted in 2011.

After the database was created, the data were analyzed to determine what the costs of production were across space and what the biggest drivers of total cost were within operations. Summary statistics were used to determine the spatial implications of switchgrass production across states, whereas sensitivity analyses were used to determine the intra-operational drivers of cost. Here, it was hypothesized that land rents would comprise a substantial portion of production costs. Because of this, two land types were assessed: cropland and pastureland. By looking at the rent prices for cropland and pastureland, both high and low land rent opportunity costs are captured.

It was discovered that there is a wide range of costs across the country. Areas in the northwest portion of the study area, the Dakotas and Nebraska, have lower costs than switchgrass production in areas of the Corn Belt. It was also found that producing bioenergy crops on cropland always results in a higher production cost for farmers than growing the same feedstock on pastureland. This is likely due to the opportunity costs of growing a crop on a more productive, higher quality land type. Finally, it was estimated that commoditized biomass prices of at least \$50 Mg^{-1} would be necessary for producers to realize a profit on switchgrass grown on land with pastureland rents and \$75 Mg^{-1} commoditized biomass prices would be necessary for farmers growing switchgrass on land priced as cropland to become profitable. It should be noted, however, that not all states see profits at these biomass prices as cropland grown switchgrass in Iowa needs biomass prices above \$150 Mg^{-1} to experience profits.

1.3 Commodity Crop Financial Analysis

The second study in this collection looks at the recent historical trends in commodity crop economics and the impact that crop insurance policy has on county-level profitability. Data from the USDA's National Agricultural Statistical Service and Economic Research Service were compiled to assess the changes that have occurred in corn and soybean production costs, returns, and ultimately profitability, in the last decade. Specifically, the years 2005-2011 are analyzed. The years are broken up into two time periods, the years immediately following the enacting of the Renewable Fuel Standard (2005-2008) and the years following the Great Recession (2009-2011).

The motivation behind this section was to assess how profitability had changed for producers in the face of increasing commodity prices. It was postulated that, even with increasing prices, if production costs had seen similar gains then producer profitability would not have increased over time. It was found that price increases drastically outpaced costs and profitability for producers of both corn and soybean increased at the county level across time periods.

This study also assessed the impact that crop insurance policy has on county level profitability. The profitability of corn and soybean production at the county was assessed before and after the inclusion of the appropriate crop insurance payments, or indemnities. After indemnities were incorporated, the counties were assessed to determine which had moves from experiencing a loss to realizing a profit, or being financially solvent before indemnities and seeing an outsized gain in profitability after indemnities. It was discovered that more than 10% of all counties experience these policy inefficiencies on an annual basis. Through these analyses it is hoped that the recent commodity crop economic scenarios will be better understood and that the inefficiencies in crop insurance policy will be highlighted and discussed in a reforming manner.

1.4 Solar Biomass Gasification Project Finance

The final component of this collection assesses the use of biomass feedstocks in energy production. This project looks at novel solar heated molten salt gasification systems that generate synthesis gas (syngas) from biomass for use as a substitute for natural gas or for conversion into transportation fuels.

This study is a project finance and policy analysis of the life-cycle of a gasification facility. It details the costs of engineering and design, raw materials for construction, the costs of construction, operations and maintenance costs, feedstock purchasing, and financials (e.g. taxes, depreciation, credit). Through these metrics is it possible to establish the life-cycle cost of the facility and determine what competitive prices for the product gas must be for the facility to become and remain profitable.

In addition to straightforward costs and returns, the facilities were also assessed under a variety of policy scenarios to determine what the impact of applying available policy levers to the facilities would bring. These policies include tax credits, production subsidies, and capital bonds. By exploring the changes that these policy levers create on gasification facility finances, it can be determined which, alone or in concert, may be necessary to facilitate the advancement of renewable energy technologies.

It was found that these new technologies have the potential to become profitable under the proper economic climate and with appropriate policy incentives enacted (i.e., tax credits, lowered bond yields, and production credits). Currently, natural gas prices are too low to allow these facilities to be competitive without additional action, but future facility success is not outside the realm of possibility.

1.5 Conclusions

The purpose of this collection is to describe some of the economic and policy scenarios surrounding the prospects for bioenergy crop incorporation on the landscape, how commodity crop production economics have changed in recent history and what some additional barriers to non-commodity crops may be, and the potential for financial solvency within bioenergy production facilities and how certain policy levers may increase financial feasibility in the long-term.

Bioenergy is entering its way into the national fuels conversation. Through the production of dedicated biomass crops, the use of conventional crop waste, and commodity crop product, the renewable fuel marketplace is becoming a larger player in the United States fuel mix. It is hoped that these studies will contribute in a meaningful way to the discussion surrounding bioenergy and will help to inform future researcher and decision makers on how to move forward in this exciting area of energy generation.

Chapter 2

A regional approach to assessing the economics of switchgrass biomass production in the United States through the analysis of production costs, returns, and profitability

Abstract

Meeting the United States bioenergy mandates will require that large amounts of biomass be grown across the nation. Here we derive near-term production costs, returns, and profitability of switchgrass (*Panicum virgatum*), a perennial bioenergy crop, using budgets from 12 university extension publications and peer-reviewed studies across 14 states. We assess costs on two different land rent prices, cropland and pastureland. Costs vary across the region, ranging from less than \$300 ha^{-1} to more than \$1,400 ha^{-1}. With estimated biomass prices of \$0, \$25, \$50, \$75, \$100, \$125, and \$150 Mg^{-1} and with annual yields ranging from approximately 3 Mg ha^{-1} to 28 Mg ha^{-1}, we find that production in less than one third of the states is profitable at biomass prices of \$75 Mg^{-1} or less for biomass grown on cropland. For pastureland, one half of states have profitable operations at \$75 Mg^{-1} for biomass. From this, we hypothesize that further economic incentives will be needed to create incentive for producers to be willing to implement switchgrass into their farming operations.

2.1 Introduction

Through policy and research, the impetus to place more perennial grasses on the landscape for environmental and economic benefit has intensified.[4,5] Switchgrass (*Panicum virgatum*) is one species of perennial grass that has been thought of as a viable candidate for bioenergy production in the United States.[2,6–8] As a result of switchgrass production, it is thought that significant volumes of transportation fuel, specifically cellulosic ethanol, could be generated for use.[2,3] Doing so would reduce the reliance on fossil fuels for transportation and would increase domestic energy security through the production of energy on American soil. The Renewable Fuel Standard (RFS2), updated in 2007, calls for the production of 136MM liters of domestic biofuel to be produced by 2022. Of this 136MM liters, 60.6MM liters are to be derived from cellulosic materials.[3] However, switchgrass is not currently grown in significant quantities and there are no existing commercial-scale processing facilities producing biofuels from non-corn stover cellulosic materials.

There are many predicted environmental benefits to an increased amount of switchgrass on the landscape.[5,8–12] However, to become a viable source of alternative energy, switchgrass must also compete economically with conventional crops and land uses.[13,14] Strong economic competition of switchgrass with conventional crops is inescapable as producers are likely already utilizing those lands in a manner which is best for their operation.[14] Furthermore, in the event that idle lands are placed back into production, they may face consideration for the production of additional commodity crops.[15] Initiating the production of switchgrass is a large undertaking and understanding the economics of switchgrass production is important to the incorporation of cellulosic biofuels into the transportation fuel supply.

Generally, perennial crops are assumed to be the feedstock of choice in a bioenergy cropping regime.[3,5,16] Whether these perennial crops are monocultures (*Panicum virgatum*, *Miscanthus giganteus*, short rotation woody crops) or polycultures of diverse species (natives, prairie), the candidate species are well suited to a majority of the United States.[5,16] Biomass crops have potential to produce resources that can yield energy while not removing supplies from food markets. This can be done through the utilization of non-prime and idle agricultural land.[17] Recent literature suggests that the choice of whether to plant monoculture or polyculture bioenergy species is a decision to be made on an individual farmer basis; and that the current level of knowledge and available incentives are not sufficient to drive farmers toward bioenergy crops.[18,19] The assurance of a stable market, potential for profit, and technical assistance for new crops seem to be of utmost importance to the farmers in question.

Due to the nature of the plant lifespans, agronomic practices for dedicated bioenergy crops would differ greatly from current practices for annual row crops. Every growing season is essentially a new start with annual crops. Conversely, perennial crops will undergo an establishment year, followed by a series of production and maintenance years. In the event that there is catastrophic crop failure, annual crops can start anew the next season. Perennial crops must also start over, but will go through the establishment phase again.

Scale is important in bioenergy production analysis. As a new share of the agricultural sector, it is important to analyze the larger system without overgeneralizing so that accurate predictions can be postulated. By only assessing the farm level, there are many economic questions that may not be properly addressed. The same can be said for only addressing the situation at a national level. With this study, a spatially-guided regional approach is taken to show broader trends in the biofuel production sector, while not applying a blanket analysis across a large portion of the country. The goal of this methodology is to present spatially relevant data while also providing an assessment of the overall feasibility of large-scale perennial biomass production.

The study area for this analysis is the middle portion of the United States. The states included in this study include: Arkansas, Kansas, Illinois, Iowa, Michigan, Minnesota, Mississippi, Nebraska, North Carolina, North Dakota, Oklahoma, South Dakota, Tennessee, and Virginia. This section of the country is an ideal switchgrass production location for a variety of reasons, including: a majority of the country's farming infrastructure is located within this region; many of the institutions that research the growth and production of switchgrass crops are located there; and switchgrass is a native species throughout the entire area.

Producing switchgrass for biofuels will require overcoming a great deal of agricultural and transportation fuel production economic inertia.[13] In determining whether a biofuel industry could be successful, it is important to understand the economic components that comprise the system. As stated, the objective of this study is to create an enterprise budget database that encompasses the costs of producing switchgrass for bioenergy on lands that have cropland and pastureland rent price structures. There are three main goals that stem from the creation of this database. The first is to produce 10-year stand life amortized costs for each land-value category and study location in real 2011 dollars, which will help describe the near-term economic conditions for switchgrass production. We aim to discover what the costs to grow switchgrass are across the nation under a series of expert-determined best management practices. The second goal is to conduct a sensitivity analyses to assess the individual impacts of cost variables on the total production cost. This analysis will allow for greater understanding of the drivers of switchgrass production economics. Through the creation of spatial production cost datasets it is possible to generate predictions about what the future of switchgrass production may be. The third goal is to assess the profitability of switchgrass at a variety of biomass price points and determine at which price points a 10-year switchgrass stand would become profitable in various locations. We hypothesize that switchgrass yield will be the largest driver of overall profitability, offsetting areas of high cost.

There are a number of switchgrass studies that exist in the literature, and most of them assess the potential for biomass yield and environmental benefits.[1,7–10,20–25] The intention of this study is to contribute to the discussion surrounding the economics of bioenergy production in the United States through the use of switchgrass as a feedstock. Primarily, this study will focus on the production costs of switchgrass throughout the major agricultural production region of the country.

2.2 Methods

2.2.1 Database Components and Creation

Data for the regional enterprise budgets were gathered from peer-reviewed and university studies conducted throughout the United States.[12,13,26–34] This database is comprised of data from 12 studies over 14 states that temporally spans from 2000 to 2011 (Table 2.1).

Table 2.1 Peer-reviewed and university based sources used in this analysis.

States	Source
Arkansas	*Popp, 2007*[27]
Illinois	*Khanna et al., 2008*[12]
Iowa	*Duffy, 2008*[35]
Kansas	*Holman et al., 2011*[34]
Michigan	*James et al., 2010*[13]
Minnesota	*Lazarus, 2010*[31]
Mississippi	*Busby, 2007*[32]
Nebraska	*Perrin et al., 2008*[26]
North Carolina	*Green and Benson, 2008*[29]
North Dakota	*Perrin et al., 2008*[26]
Oklahoma	*Griffith et al., 2010*[33]
South Dakota	*Perrin et al., 2008*[26]
Tennessee	*University of Tennessee, 2009*[30]
Virginia	*Eberly, 2007*[28]

The included primary studies were chosen for their recent contribution to the literature and their complete analysis of switchgrass production costs. To qualify, a study must have taken place within the Unites States, as well as have established values for establishment and production year seed, fertilizer, chemicals, and harvest. Studies that did not include these variables independently from one another (i.e., multiple costs aggregated into one variable) or provide a specific location were not included.[7,21,36,37] This was done to allow analysis of the individual components of the overall cost. Additionally, papers in this study assess non-irrigated switchgrass plots. Papers were omitted from this study if they utilized irrigated plots in their analysis.[38,39] Resulting costs are calculated at the farm-gate (i.e., transportation costs are not included). Costs encapsulate an entire cycle of switchgrass production over a 10-year horizon, including a one-year establishment cost, which captures costs for the initial set-up of the crop, and a nine-year production cost series that characterizes the annual costs of operation for the remainder of the stand length. We used the data from these studies and integrated cost accounting assumptions to address time variances and operating procedures to ensure time-appropriate results for the production of switchgrass across the study area.

Ten of the twelve studies used in this analysis assess the growth of switchgrass in during a specific time frame in a state that is appropriate for switchgrass production.[12,13,27–30,32,33,35,40] These studies did not note a specific location within the state, but are instead aggregations of individual plots and year-specific financial data from across the respective states, in areas that would be suitable for growing switchgrass.

The other two studies used in this analysis assess multiple locations within study states.[26,34] These studies utilized and reported data from geographically specific university test plots and analyzed the data used in the direct production of these plots. To ensure an equal comparison to the other ten studies used in this analysis, the multiple point-specific data within each state were aggregated to provide a single set of cost data for the state.

Full life-cycle costs for switchgrass production were reported in all twelve studies. Every study had costs associated with the establishment year and with production years. As mentioned, it was part of our selection criteria for the studies used in this analysis to have data for both establishment and production years. Additionally, since we look at these data on a spatial level, we took into account the fact that each study had its own management practices. The way in which each study managed their switchgrass plots were assumed to be appropriate and were accepted as reported.

2.2.2 Financial Analysis

Costs associated with the individual studies are presented in nominal values, but are converted to real 2011 dollars for the creation of an equivalent-value economic dataset.[41] This was done to ensure an equal comparison of costs that had occurred across varying time periods. Without the transformation of nominal to real dollars, the purchasing power of the US dollar would be temporally misrepresented.

As mentioned, there are two distinct time periods in this analysis, the establishment year and the series of production year costs. The establishment-year costs comprise the expenditures associated with the initial year of growth. Following the establishment year, a database including nine years of production-year costs was created. These values make up the annual maintenance and harvest costs for the crop. Costs associated with the establishment year are: seed, fertilizer, pesticide (e.g. herbicides, insecticides, and pesticide), lime, machinery (e.g. depreciation and maintenance, application of seed, fertilizer, pesticide, etc.), and land rent. While the management practices between the establishment year and production years are different, many of the same cost variables may be utilized in both periods. For example, re-seeding within the first two production years is not uncommon; therefore seed, fertilizer, and lime costs must be included in production year budgets. The variables associated with the production-year costs are seed, fertilizer, pesticide, lime, machinery, land rent, and harvest (Table 2.2).

The individual studies within the larger analysis all have their own management techniques and estimated production costs. We assume that these techniques and costs are appropriate for the time and location of each switchgrass stand. Across all studies we see a series of trends in the costs for producing switchgrass. In all studies, land prices make up a substantial portion of the annual production cost in both establishment and production years. This is not unexpected, as land prices are one of the major drivers of agricultural production costs across the country.

Table 2.2 All production costs (ha^{-1}) for the establishment (EY) and production (PY) years used in the original studies, shown in nominal study year dollars. Within each column the costs are ranked with increased shading corresponding to increased costs.

State	Original Year	EY Seed	EY Fertilizer	EY Lime	EY Pesticide	EY Machinery	PY Seed	PY Fertilizer	PY Lime	PY Pesticide	PY Machinery	Harvest	Rent
AR	2006	$148.26	$102.92	$81.54	$26.32	$107.86	$0.00	$124.54	$0.00	$4.69	$25.11	$160.54	$247.11
IL	2003	$106.67	$30.15	$56.83	$17.89	$44.12	$2.96	$51.61	$1.58	$1.98	$18.29	$257.14	$78.04
IA	2008	$111.20	$50.16	$155.68	$19.13	$70.55	$0.00	$135.54	$0.00	$19.13	$32.49	$319.53	$197.68
KS	2007	$106.58	$0.00	$0.00	$0.00	$383.24	$4.15	$309.96	$0.00	$0.00	$383.24	$81.78	$135.91
MI	2008	$140.85	$118.61	$0.00	$66.72	$98.84	$0.00	$164.99	$0.00	$3.81	$1.63	$194.89	$264.40
MN	2010	$190.27	$150.73	$0.00	$172.97	$88.96	$0.00	$172.53	$0.00	$0.00	$172.80	$46.63	$98.84
MS	2010	$321.24	$90.34	$43.24	$12.45	$619.69	$0.00	$167.91	$0.00	$15.49	$105.29	$514.08	$216.22
NE	2000	$65.11	$11.00	$0.00	$25.92	$35.76	$2.13	$42.23	$0.00	$9.59	$20.34	$98.49	$176.13
NC	2008	$222.39	$393.39	$93.90	$16.06	$115.13	$0.00	$287.31	$18.78	$0.00	$144.95	$181.20	$142.09
ND	2001	$78.23	$0.00	$0.00	$41.93	$47.20	$0.00	$30.96	$0.00	$16.63	$18.71	$81.75	$81.58
OK	2010	$74.13	$29.01	$0.00	$45.76	$175.54	$0.00	$74.33	$0.00	$0.00	$42.72	$251.73	$111.20
SD	2001	$100.45	$0.00	$0.00	$43.76	$56.64	$0.00	$33.88	$0.00	$14.70	$19.08	$121.56	$140.91
TN	2008	$181.62	$227.34	$0.00	$100.52	$85.67	$0.00	$340.02	$0.00	$34.59	$85.67	$266.16	$169.27
VA	2007	$203.86	$57.33	$40.15	$0.00	$170.23	$0.00	$346.74	$26.51	$0.00	$108.01	$157.90	$111.20

We also see that in certain states there are outsized differences in certain cost components. For example, in Mississippi and Kansas we observe large costs associated with the operation of machinery. In Kansas we see larger than usual machinery costs, however these costs are considered the result of normal regional farming operations and there is nothing of note causing increased costs. It should be noted that the Kansas State University study does include both irrigated and non-irrigated yield estimates and costs in their study and only non-irrigated data were used.[34] In Mississippi we see large establishment-year machinery costs and production-year harvest costs due to the methodology used to assess machinery. The method used in the original study provides a cost for equipment through an annual amortized cost, not hours used in a process. This was done to highlight the entirety of the fixed costs associated with equipment. It takes into account not only the operating time, but also the time when the machinery sits idle, while payments must still be made.[32] However, this methodology lends more cost to equipment than the other studies used in this analysis, especially in the establishment year. The other studies only look at the hours the equipment is operated and generate a cost based on actual running time. The method of hourly operation captures the cost of machinery only during operation and requires an assumption of hours operated per year to create an accurate cost.

In North Carolina it is noted that establishment year fertilizer costs are substantially greater than in other years. This is because the management techniques in the state call for high levels of fertilizer application in the establishment year, whereas many other studies do not require much, if any, fertilization in year one.[29] Higher fertilizer costs in Kansas, Tennessee, and Virginia are due to increased use of fertilizer, as compared to other states. In Virginia, the same management methods for warm season hay were used for switchgrass.[28] In the final budget for this analysis, however, the original study management techniques are utilized but the adjusted prices for fertilizer are not. All studies are subject to the same fertilizer prices.

The costs of production are much lower in Nebraska, North Dakota, and South Dakota than in other states. Part of this is due to the time value of money and that the original studies were published in 2000 dollars, when nominal prices were low. Additionally, the management techniques called for in these studies were relatively lean as compared to other studies in this analysis. For instance, the only costs borne in the establishment year are land, pesticide, seed, and the accompanying machinery costs for seed and pesticide application. When looking at production year costs, fertilizer costs remain relatively low because of application rates applied in certain locations of the study. Harvest costs are also low because they are partially dependent on yield and yields in this portion of the country are low, relative to other states.[26]

Illinois and Iowa experience higher than average harvest costs. These realized increases are due to two compounding factors. Harvest costs are associated with yield and both these states see higher yields, resulting in higher harvest costs. Additionally, the harvest of switchgrass, particularly large amounts of switchgrass requires custom machinery to handle the workload. The additional cost for hiring custom operations is higher than typical farming operations, however custom operators are used because it results in a lower overall cost than each individual operator owning the necessary equipment to complete these tasks on their own. Coupling the higher yields with the need for custom equipment raises the cost associated with harvesting biomass.[12,35]

In all cases, we see that major differences in production costs are driven by spatially explicit differences in management techniques. Costs for the goods vary over time, but the amounts of fertilizer, seed, and machinery times used account for a majority of the cost implications for switchgrass production. Knowing how the cost components vary in the original studies allows us to be able to more accurately predict what the future costs associated with switchgrass production may be.

Throughout the study we operate under two spatial assumptions. The first is that raw material costs do not vary across space. That is, inputs such as seed, fertilizer, pesticide, and lime do not have costs that vary across regions. This differs from inputs that are not raw materials, such as machinery and labor, which do have costs that vary across space. We assume that raw materials experience nationwide pricing because they are substitutable products. The second spatial assumption is that labor and machinery costs are subject to variable pricing because of differences in labor force, labor opportunity costs, depreciation factors, and weather. Because labor costs are dependent on both the supply and demand for work, pricing depends on not only the number of available workers in the area, but also the other opportunities those workers may be eligible for and would cause competition for available employees. Machinery costs would vary across space due to depreciation and maintenance costs. In general, depreciation values remain relatively consistent across the entire area of study, as those costs are assessed under Federal IRS code. However, outside effects on machinery, including time in operation and weather may create a variety of maintenance schedules that may cause a wide-array of costs.

Because establishment costs are a one-year cost, they are reported as provided from the budget of the primary studies. However, some production costs had multiple year entries. If multi-year costs were reported as a single number then it was assumed that the cost was borne annually over the stand life. If there was more than one reported production year cost for a variable then an average of the years was calculated to create a production-year cost. The production-year costs were then multiplied by the number of production years (nine) to calculate a total production-year cost. The total production cost for a 10-year stand is the sum of the calculated production year costs and the single establishment year cost.

Table 2.3 All production costs (ha^{-1}) for the establishment (EY) and production (PY) years used in this study. These values differ from Table 2.2 in that they are adjusted to be in real 2011$, and have had adjustments to 2011 fertilizer and land prices as reported by USDA NASS. The fertilizer and land prices used in this analysis are 2011 USDA NASS prices, which were chosen because these two variables have seen substantial increases during the time period of the original studies (2000-2011). Within each column the costs are ranked with increased shading corresponding to higher costs.

State	EY Seed	EY Fertilizer	EY Lime	EY Pesticide	EY Machinery	PY Seed	PY Fertilizer	PY Lime	PY Pesticide	PY Machinery	PY Harvest	Crop Rent	Pasture Rent
AR	$162.74	$196.05	$89.50	$28.89	$118.39	$0.00	$133.00	$0.00	$5.16	$27.55	$176.24	$216.22	$39.54
IL	$128.21	$43.93	$68.31	$21.50	$53.03	$3.56	$61.16	$1.90	$2.38	$21.98	$309.06	$452.20	$79.07
IA	$114.20	$51.52	$159.88	$19.64	$72.45	$0.00	$250.52	$0.00	$19.64	$33.37	$328.16	$484.33	$113.67
KS	$113.74	$0.00	$0.00	$0.00	$409.01	$4.42	$318.22	$0.00	$0.00	$409.01	$87.28	$124.79	$39.54
MI	$144.75	$0.00	$0.00	$68.57	$101.58	$0.00	$85.99	$0.00	$3.90	$1.68	$200.30	$222.39	$61.78
MN	$192.96	$85.28	$0.00	$175.42	$90.22	$0.00	$214.26	$0.00	$0.00	$175.25	$47.30	$333.59	$53.13
MS	$325.81	$115.89	$43.86	$12.63	$628.49	$0.00	$223.38	$0.00	$15.72	$106.80	$521.37	$232.28	$43.24
NE	$83.67	$0.00	$0.00	$33.31	$45.94	$2.74	$64.94	$0.00	$12.31	$30.34	$126.60	$370.66	$35.21
NC	$228.57	$393.14	$96.49	$16.51	$118.31	$0.00	$241.03	$19.30	$0.00	$148.87	$186.09	$161.85	$59.31
ND	$97.68	$0.00	$0.00	$52.36	$58.93	$0.00	$45.96	$0.00	$20.78	$26.19	$102.07	$127.26	$33.36
OK	$75.19	$47.27	$0.00	$46.41	$178.04	$0.00	$107.91	$0.00	$0.00	$43.34	$255.31	$72.90	$28.42
SD	$125.38	$0.00	$0.00	$54.63	$70.70	$0.00	$73.71	$0.00	$18.36	$36.15	$151.76	$195.21	$39.54
TN	$186.66	$95.95	$0.00	$103.31	$88.04	$0.00	$134.65	$0.00	$35.56	$88.04	$273.55	$196.45	$46.95
VA	$217.58	$126.52	$42.85	$0.00	$181.67	$0.00	$340.61	$28.29	$0.00	$115.27	$168.53	$111.20	$44.48

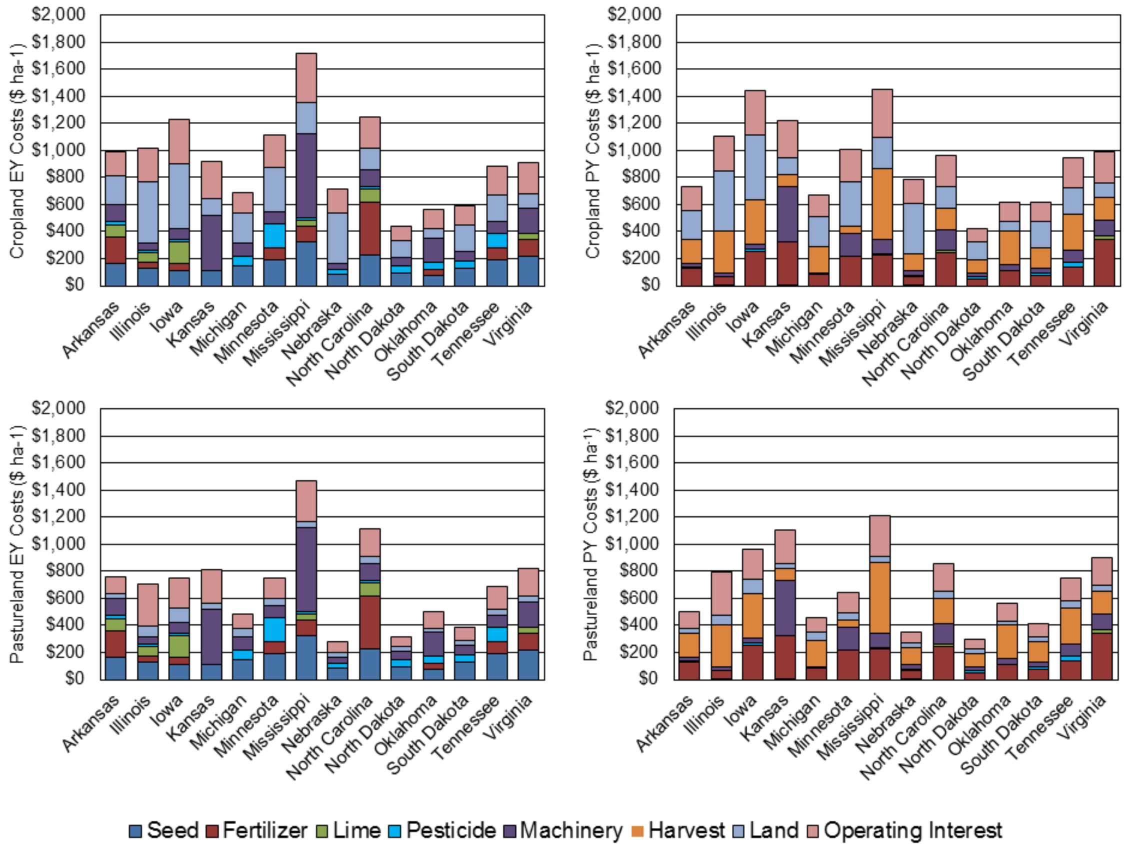


Figure 2.1 The establishment year and production year costs (ha^{-1}) associated with the growth of switchgrass for bioenergy within each state for both cropland and pastureland rents.

The cost data used in this study are shown in Table 2.3 and in Figure 2.1. These costs are used to determine the full life-cycle costs for a 10 year stand of switchgrass. As mentioned, the costs in this study are broken into two time periods, establishment and production years. The costs for both the establishment and production years are made up of seed, fertilizer, lime, pesticide, machinery, and harvest. For some states, in some years, the management practice does not call for the use of a certain input. In these cases the value for that input is zero. Additionally, Perrin et al., 2008 embedded the cost of fertilizer, seed, and pesticide application into those respective inputs. Therefore, the value for machinery for the Perrin et al., 2008 study states (Nebraska, North Dakota, South Dakota) was calculated by using the machinery cost portion for the aggregated study (28.2%) and subtracting that out from cost components that utilize machinery (seed, fertilizer, and pesticide application) and allocating that difference to the machinery cost component.[26] Finally, an additional cost variable is included for the amortized cost. The operating interest cost for the life cycle of the stand is calculated by multiplying the total cost of the establishment year and production years by the interest rate used in the amortization equation. It is the cost associated with holding assets and debt. Therefore it is considered a non-operating cost that is not included as part of the raw inputs but is included in the amortization calculation.

It is assumed in this study that most annual operating costs, including machinery, labor, and pesticide costs increase at the rate of inflation year after year. These components were converted to real 2011 dollars using a time-value of money conversion factor.[41] Conversely, fertilizer and land prices have increased significantly in excess of inflation between the years of the original studies and the simulated 2011 stand establishment year. To account for the fertilizer price changes, 2011 fertilizer prices were obtained from the USDA Economic Research Service (USDA-ERS) and were input into the database to accurately reflect the increase.[42] Nitrogen fertilizer price was assumed to be equivalent to 44-46% urea, unless explicitly stated in the primary study.[43] To account for the change in land rents, land rent values from the USDA National Agricultural Statistical Survey (NASS) for cropland and pasture land were gathered for 2011 and applied to replace the original study-year land rents.[44] NASS values provide a more detailed look at the expense difference to farmers for producing crops on land with cropland rent value and pastureland rent value. An additional assumption in this analysis is that the non-land costs for switchgrass production between the different rent prices are equivalent.

We look at the difference between cropland and pastureland rents because there is discussion that switchgrass and other energy crops may be grown on marginal land or land that is currently un- or under-utilized.[5,45] Because this land is currently unused, it may be subject to lower rent prices than land that is currently producing crops. However, it is also thought that to meet RFS2 goals, some bioenergy crops will need to displace commodity crops or that commodity crop prices will cause expansion onto under-used lands, potentially causing an increase in land rent.[46,47]

We also operate under the assumption that yields and production costs will not vary by land type. Previous research has indicated that no substantial yield or cost differences are seen between land types when best-practice management techniques are utilized.[1,25,48] Additionally, the largest drivers of greater long-term switchgrass yield are suggested to be rainfall or irrigation and nitrogen application.[11,24,25,34,38,48]

To generate an accurate and equivalent stand-life approximation for switchgrass for all studies in this article, temporal aspects of the production economics must be included; in accounting for these, a rate of 3% is assumed. This rate is used to calculate operating capital interest and to simulate the rate of inflation over time. In choosing to use funds for one activity, there is an “opportunity cost” or loss in ability to use those funds for any other activity. The operating capital interest aims to capture the costs of these choices. With this rate it is possible to create an equal-part, or amortized, cost for production over the specified time period.

The end result of this portion of the study is an amortized production cost database for a 10-year stand of switchgrass beginning in 2011 at multiple locations throughout the study area for both cropland and pastureland priced rents. These costs provide an approximation of switchgrass production for farmers and allow for further analysis of costs across space.

2.2.3 Uncertainty and Sensitivity

To determine the impact of individual switchgrass production cost components on the overall amortized production cost, a sensitivity analysis was performed on the cost components. A sensitivity analysis is used, in-part, to determine the influence of individual variables within an equation. To perform this analysis we used Monte Carlo simulation. The Monte Carlo method involves the repeated calculation of an equation using samples of random variables to observe potential patterns within the data. By running these calculations over many thousands of iterations, it is possible to begin discerning patterns within the data and determining which variables are most impactful on the equation, as well as determining which outcomes are most likely.

The sensitivity analysis was executed in Oracle Crystal Ball. Crystal Ball is a third-party Excel add-in that is primarily used for predictive spreadsheet modeling. The spreadsheet databases that were generated for this study were used in this sensitivity analysis. In the beginning, random variables for each cost component had to be determined. This was done by fitting probability distributions to the data. In all independent cost component cases, the triangle distribution was used. This was done due to the lower number of inputs per cost component (one per state). The minimum, mean, and maximum value for each cost component was input into the model distribution.

Once the assumptions for each cost component was set, the equations for cropland and pastureland amortized costs were calculated and the resulting amortized costs were designated as forecast variables. When the cost components and equations were defined, the program was run over 10,000 iterations to determine which cost components are most impactful in driving switchgrass production amortized costs.

Outputs from the runs were then analyzed using Crystal Ball to determine the amortized production cost variation created by changes in the value of each independent variable, while all other independent variables are held constant. The analysis was done to assess the overall variation at 10% (+/-) cost changes for each variable. Additionally, the cumulative explained variation of each independent variable on the amortized cost was calculated. The explained variation is reported as a percentage to highlight the impact of each variable, as well as show how much of the overall model variation is explained by all the cost components, given the model setup.

2.3 Results and Discussion

2.3.1 Overview

The costs of production for switchgrass are highly variable across space. Portions of the ‘Corn Belt’ region have consistently high costs (Illinois, Iowa, and Missouri) in comparison to the northern Great Plains (North Dakota, South Dakota, and Nebraska). Unsurprisingly, both the mean and median values for biomass grown on cropland are greater than for pastureland, which is a lower-value land. The mean annual stand cost for switchgrass grown on cropland is \$869 ha^{-1}, whereas the mean cost on pastureland is \$646 ha^{-1}. The median annual stand cost for switchgrass on cropland is \$892 ha^{-1}, compared to \$586 ha^{-1} for pastureland. Cropland costs across all locations span a range of \$1,033 ha^{-1}, the low price being \$402 ha^{-1} in North Dakota. The highest cost for cropland switchgrass production is in Mississippi, at a cost of \$1,435 ha^{-1}. The lowest costs for pastureland switchgrass production can be found in North Dakota, at \$285 ha^{-1}. The highest cost for pastureland switchgrass, like cropland switchgrass, is found in Mississippi at \$1,206 ha^{-1}.

2.3.2 Uncertainty and Sensitivity

Individual costs components for switchgrass can have substantial effects on the final amortized cost. The enterprise cost budgets for switchgrass grown on the two land types were analyzed to determine which cost components were most important in the total cost structure. In this analysis it was determined that the most impactful cost components between the two rent classifications were similar, albeit with slight differences. Four of the twelve variables in each land-type scenario were found to contribute to more than 98% of the variation in the amortized cost of production. For switchgrass grown on land that had a pastureland rent, the cost that contributed most to the amortized cost variance was harvest. This was followed by production-year machinery costs, then by production-year fertilizer costs, and production-year land rent. The costs surrounding switchgrass grown on land with cropland rents were similar to pastureland switchgrass, except that production-year land rent was the most impactful independent variable on amortized cost. Land rent was followed by harvest, production-year fertilizer, and production-year machinery costs, respectively.

As part of the analysis on switchgrass crop production, sensitivity analyses were performed to assess the impact of increases or decreases in the pricing of individual inputs to the system. By looking at the individual components of the costs in more detail it becomes easier to see how pricing changes over time may affect the production of crops. Each independent variable was increased or decreased in price by 10%. The other independent variables in the system were held constant during this time. This method was employed for both cropland and pastureland land types. As shown in Fig. 2.2, a 10% increase in production-year rent price, harvest, production-year fertilizer, and production-year machinery for switchgrass grown on cropland resulted in changes of 2.6%, 2.5%, 1.7%, and 1.6% to the annual per hectare production costs. A 10% decrease in each cost component resulted in a decrease amortized cost of 2.7%, 2.7%, 1.7%, and 1.7%, respectively. Switchgrass grown on pastureland experiencing a 10% increase in harvest costs, production-year fertilizer, production-year machinery costs, and production-year rent, resulted in changes of 3.2%, 2.2%, 2.1%, and 0.8% to the amortized cost. A 10% decrease in cost components resulted in 3.3%, 2.2%, 2.1%, and 0.8% respective decreases in the amortized production cost.

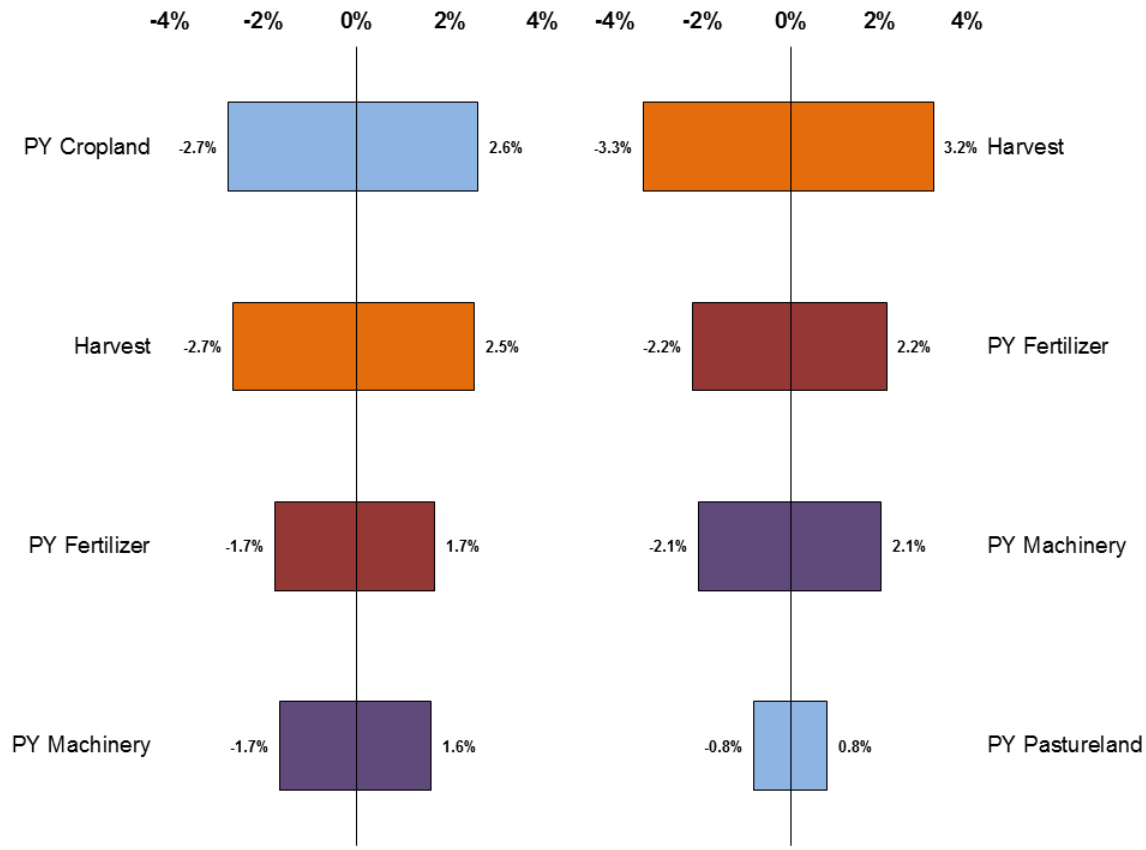


Figure 2.2 Tornado plots representing the cost variables comprising 98% of the model for the amortized per acre cost of switchgrass grown on land with cropland and pastureland rents. These variables are the most sensitive to pricing changes. A 10% change in the individual cost component would result in a change in the total amortized cost of the percent shown. Model contains all independent variables; the top 4 in each case make up 98% of variation.

Yields 2.3.2

Each individual study included estimated yields for switchgrass grown over the life of the stand. The studies each provided their own estimates for yields, and these numbers were fit to meet the specifications of this analysis. In this study we operate under two main assumptions. The first is that there is no harvest in the first year. Some original studies claim that there is the possibility for year one harvest.[26] However, to maintain continuity throughout all growing areas we decided that the low yields seen in the establishment year are not cost effective enough to warrant harvest. The second assumption is that there is a consistent annual yield over the remainder of the stand life. Individual studies may present gradual increases in yield over time while others provide a constant yield over the stand life. To account for this we simply provide a stand-life average annual yield for all ten years of the stand. This helps to account for the costs of establishment, even when no harvest is occurring. Fig. 2.3 shows the annual average yield (Mg^{-1}) for each state in the analysis. We see that more southern states, like Mississippi, Tennessee, Illinois, and Arkansas experience higher annual yields. This is in contrast to more northern states, like the Dakotas, Nebraska, and Minnesota, which see more depressed yields.

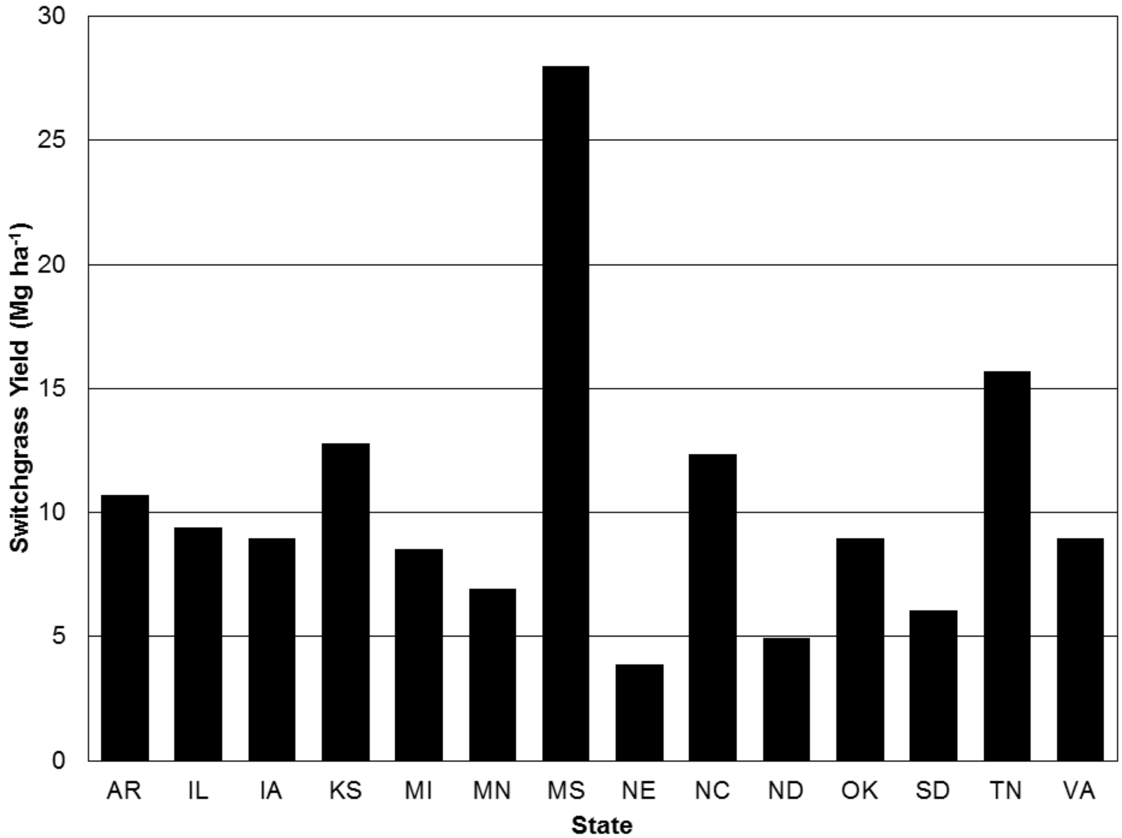


Figure 2.3 Average annual biomass yields by state (Mg), this analysis assumes no harvest in year one. These values are the result of the annual realized yields averaged across the entire 10 year stand life. This was done to ensure that the full cost/yield ratio would be taken into account for the life of the stand.

Costs 2.3.3

Assessing the costs associated with the production of switchgrass is important to understanding the potential viability of the industry. We attempt to normalize costs by land utilization and production output. By doing this, it is possible to see which states experience the lowest cost of operation in growing switchgrass (Fig. 2.4 and Fig 2.5). To do this we use the two equations. To assess the cost of producing switchgrass (ha^{-1}) (Fig. 2.4) we calculate the amortized cost of growing switchgrass. Here we used our 10 years stand life, the stand-life cost of production, and a 3% depreciation rate. To determine the cost of producing switchgrass (Mg^{-1}) we use the equation $C_p = C_{ha}/Y_{ha}$, where C_p is the amortized cost of production, C_{ha} is the cost to produce a hectare of switchgrass, and Y_{ha} is the yield of biomass ($Mg\ ha^{-1}$).

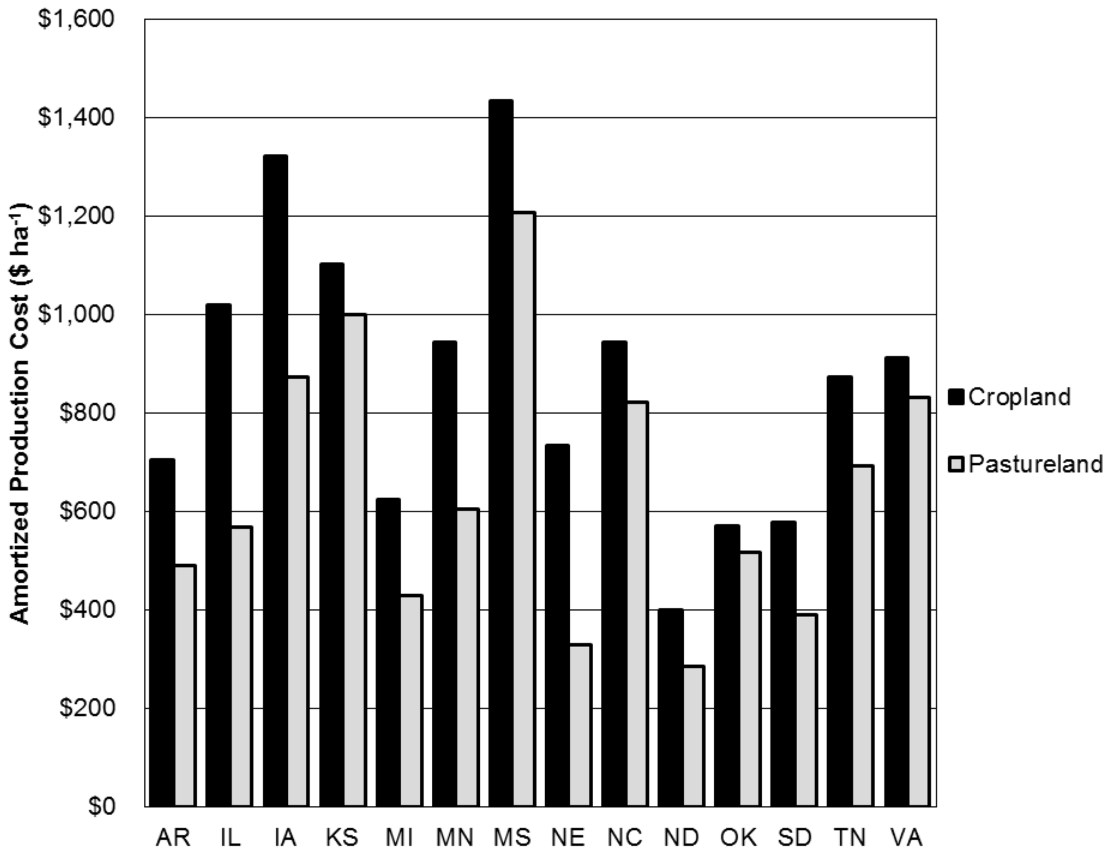


Figure 2.4 Total amortized production cost ($\$\ ha^{-1}$) of switchgrass grown in each state over the life of the stand, land rents included. The inputs included in the amortized cost are: seed, fertilizer, lime, pesticide, machinery, harvest, and land. These inputs are calculated over the establishment and production years.

Through this analysis we find that the states of Arkansas, Michigan, Mississippi, and Tennessee have the best cost-to-yield ratios. Iowa, Virginia, Illinois, Minnesota, and Nebraska are the most expensive in which to produce switchgrass (Mg^{-1}) (Fig. 2.5). This would suggest that the low cost states experience the most financially optimal management methodologies to produce switchgrass while the other states become increasing expensive.

Embodied in the prices of cropland and pastureland rents are the uses and opportunity costs of land.[49] Cropland is more expensive than pastureland because the value of the product that can be produced on the land is greater than that of the product produced on pastureland. Crops tend to be grown on lands of higher physical quality than pastureland. Because these lands are capable of producing high returns for farmers, the demand for these lands are increased, which increases the price. By utilizing the best land to grow the highest value products, farmers are trying to maximize their earning potential. Land that is less productive is better suited to plant species of lower value and higher environmental resilience.

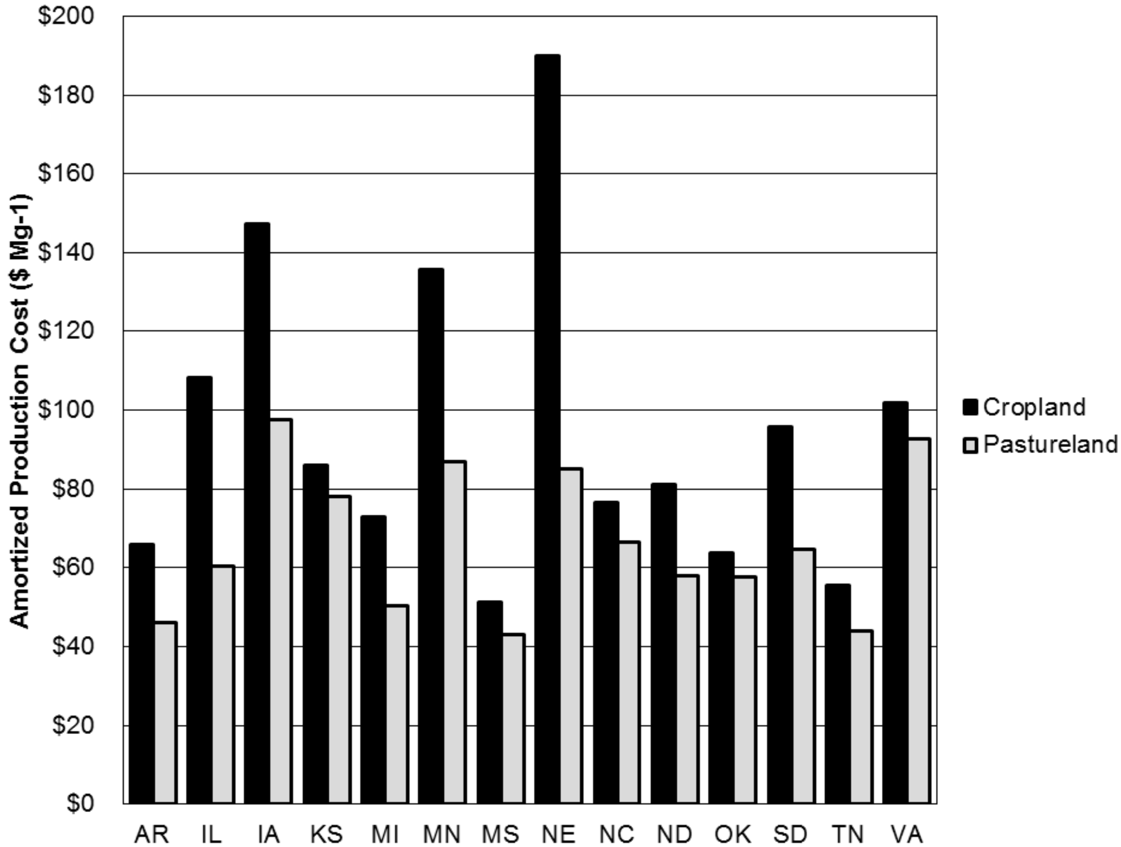


Figure 2.5 Annual amortized production cost ($ Mg^{-1}) of switchgrass grown in each state over the life of the stand. The inputs included in the amortized cost are: seed, fertilizer, lime, pesticide, machinery, harvest, and land. These inputs are calculated over the establishment and production years.

The difference between the prices of land types can be seen in Figs. 2.4 and 2.5, where the state-level annual amortized production cost (ha^{-1} and Mg^{-1}, respectively) for each land rent type is shown. Because this study assumes that production procedures between land types are identical, the figure helps to capture the difference in land rent cost. The difference in price between prime and sub-prime production land can have a substantial difference in total production cost. In some states there are smaller discrepancies (less than 25%) between the cropland and pastureland production costs. These states include: Kansas, Mississippi, North Carolina, Oklahoma, and Virginia.

However, in other states there is commonly a larger difference (greater than 25%) seen. The states that experience this larger difference include: Arkansas, Illinois, Iowa, Michigan, Minnesota, Nebraska, North Dakota, South Dakota, and Tennessee. The states that experience smaller differences between cropland and pastureland rent tend to be states that do not produce large quantities of commodity crops that would generate increased land value. However, this is in contrast with the states that do see a large difference between cropland and pastureland rents, which are mainly located within the Corn Belt, where higher value crops are produced on the landscape, increasing the opportunity cost of growing other items.

The price of cropland has increased (in real 2011 terms) by more than 86% per acre since 2000, when the first studies used in this analysis began.[44] A large portion of this increase occurred after the installation of the Energy Policy Act of 2005, which spurred the first iteration of the RFS2. Some existing studies point to the increased commodity prices and demand in corn for ethanol via RFS2 as a major driver of cropland prices.[50–52] Interestingly, while the rent price for cropland has increased, the price premium for cropland as compared to pastureland has steadily decreased since 2000.[53] That is, even as cropland prices have risen, the increase in the value of an acre of pastureland has risen at a rate greater than that of cropland. If cellulosic ethanol production becomes more commonplace, it is unlikely that farmland prices will decrease. This is due, in part, to the fact that areas of farmland within 50 miles of an ethanol plant can see an increase of \$371 ha^{-1} over comparable lands elsewhere.[53]

Fertilization of crops is another major component of agricultural operations. To ensure consistent, high yields, producers typically fertilize their crops. In the case of switchgrass, the major fertilizers used by farmers are nitrogen, phosphorus, and potassium (potash).[8,10,29,40] Nitrogenous fertilizer prices are loosely tied to fossil fuel prices, and as the price of fossil fuels began to rise over the last decade, so did a major component of agricultural production.[54] Additionally, the increase in agricultural production throughout the late 2000s and early 2010s caused a sharp increase in demand for fertilizers. The rise in demand, coupled with the rise in fertilizer raw material prices triggered a massive uptick in fertilizer prices over the period in which the original switchgrass budget studies were conducted. According to the USDA-ERS, since the time of the first studies used in this analysis (2000) through the baseline year in this analysis (2011), nitrogenous fertilizer prices have increased 290% and phosphate fertilizers have increased 305%.[42] If this trend holds, fertilizer and land will continue to make up a significant majority of switchgrass cost budgets for the foreseeable future.

Costs associated with labor also make up a large portion of costs for producers. In this study these costs would be attributed to application, harvest, and machinery purchase and repairs. These costs can be closely linked to the opportunity costs associated with labor, the price of equipment, and maintenance. However, like land costs and unlike costs for fertilizer, seed, or machinery, labor costs are typically tied to geography. In areas where the demand for labor is high, there will be more competition for employees and an increase in wage is likely.[55] While the prices for machinery may not vary across space, the costs to operate and maintain that equipment are likely to do so. This variation is imperative to financial feasibility for bioenergy production. While not fully explored in this study, an area of potential future work lies in the labor costs associated with bioenergy production in the Upper Midwest, including the Dakotas, Minnesota, and Nebraska. This is especially pertinent because some studies suggest that much of the perennial grass supply could come from this region.[1] The rapid increase in the presence of the petroleum industry in the Dakotas has drastically increased the opportunity cost of labor in the region and may create an outsized impact on the costs associated production in other industries.[56]

In addition to land and resource pricing issues, there are wide discrepancies among researchers as to the conversion efficiencies of cellulosic feedstocks to ethanol. This disagreement can lead to wide differences in estimated biomass needed to meet the RFS2 goals. For example, the Environmental Protection Agency (EPA) assumes that as low as 301 L of ethanol can be derived from one Mg of switchgrass biomass, whereas Schmer et al. 2008 assumes 379 L Mg^{-1} may be achieved.[8,20,57] These numbers become very important when assessing the impact that individual cost components for switchgrass may have on ethanol production. Fig. 2.7 addresses the costs associated with the generation of biofuels from switchgrass feedstocks. We look at the range of costs to produce switchgrass on the landscape in the study area and potential conversion efficiencies for biofuels in terms of liters produced. For the biofuel scenarios we use conversion efficiencies of 200 L Mg^{-1} through 500 L Mg^{-1}. We find that as conversion efficiencies increase, the cost per unit of energy substantially decreases. This may suggest that while the increase of yield and lowering of production costs are beneficial to the overall system, significantly increasing the efficiencies of conversion technologies may have a greater impact on the financial success of the bioenergy industry.

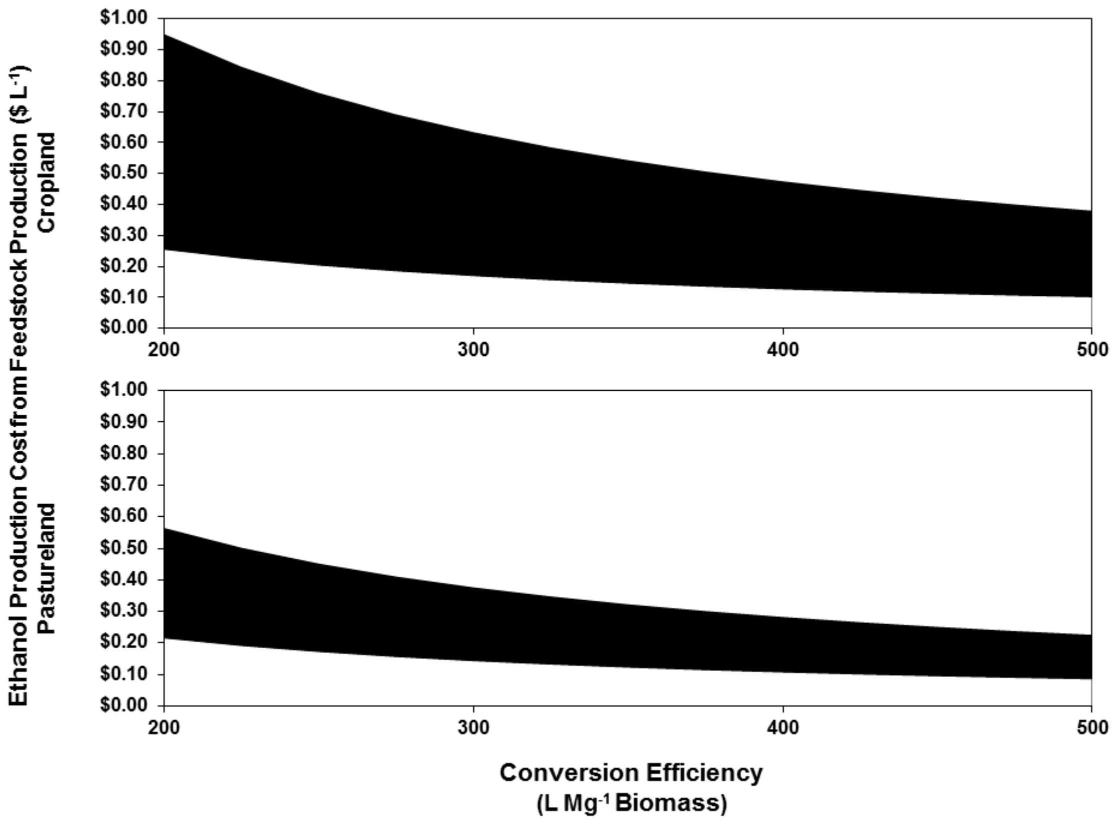


Figure 2.6 Cost curves for the production of ethanol from biomass on both cropland and pastureland. The area represents the high and low ranges of the per liter cost of ethanol production attributed to the production of switchgrass. The efficiency curves address the potential for converting biomass feedstock into energy. Equation: $C_b = C_{Mg}/E_{bf}$, where C_b is the cost of biomass (L^{-1}) of biofuel created, C_{Mg} is the cost of biomass feedstock (Mg^{-1}), and E_{bf} is the conversion rate of biofuel produced (L Mg^{-1}).

2.3.5 Profitability

Costs are not the only portion of the economic scenario that will drive biomass for bioenergy crops onto the landscape. Returns, and ultimately, profits will be necessary to ensure a prosperous and sustainable cropping system. To assess the profitability of switchgrass grown throughout the study are we conducted a financial analysis of switchgrass production using the costs and yields from this study and a range of projected commoditized biomass prices ($0, $25, $50, $75, $100, $125, and $150 Mg^{-1}).[3,4,17,57,58] In doing so we were able to calculate a range of projected profitability for each state on both lands priced as crop and pasture, as shown in Fig. 2.7 (ha^{-1}) and Fig. 2.8 (Mg^{-1}). In most cropland grown cases, switchgrass failed to become profitable. The converse is true for pastureland grown switchgrass. However, the profitability of switchgrass relies on substantially high enough biomass prices to overcome production costs. Under certain pricing scenarios, some states were able to show that switchgrass farming may be able to become a profitable operation. There were no states with profitable operations with biomass prices at or below $25 Mg^{-1} on either land type. Furthermore, no states saw profitable operations with biomass prices of $50 Mg^{-1} or less when switchgrass was grown on cropland. However, profitability was seen at the $50 Mg^{-1} biomass level in Arkansas, Mississippi, and Tennessee on pastureland grown switchgrass.

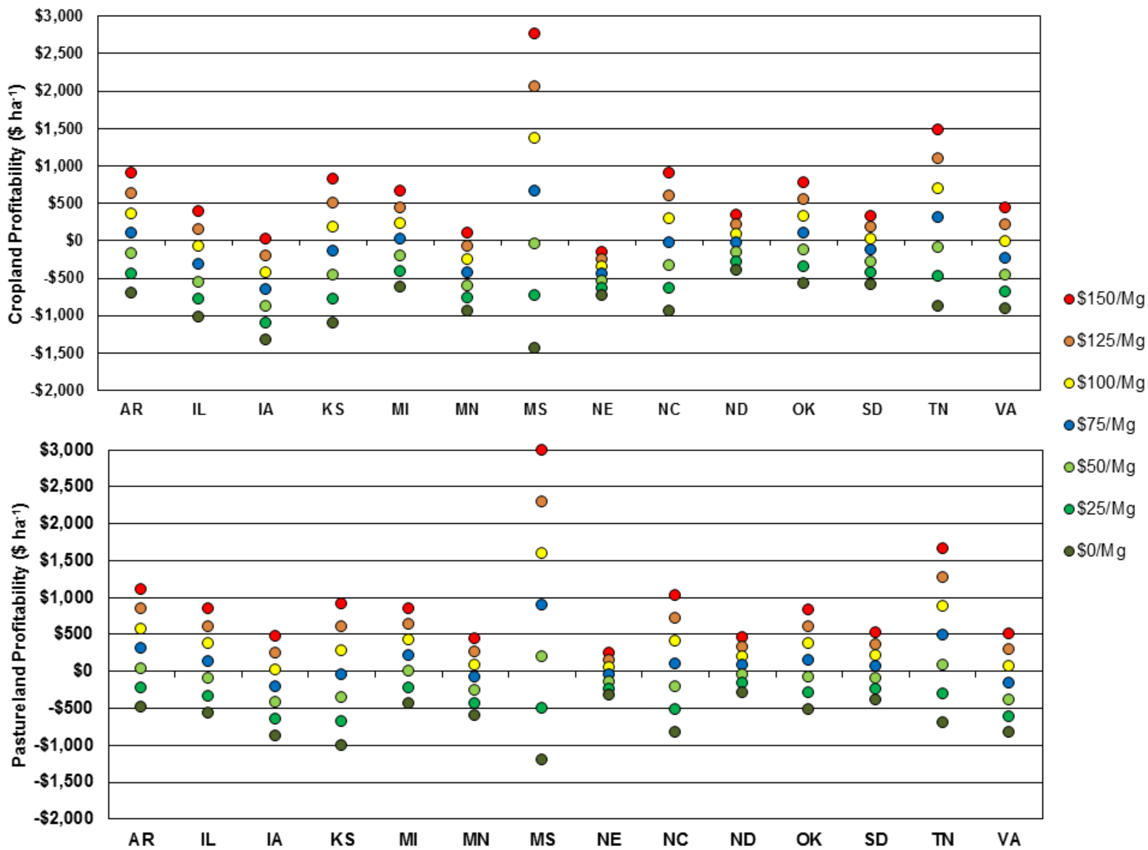


Figure 2.7 Profitability of switchgrass grown in the United States (ha^{-1}) on both land with both crop and pasture land rents at biomass prices of \$0, \$25, \$50, \$75, \$100, \$125, and \$150 Mg^{-1}.

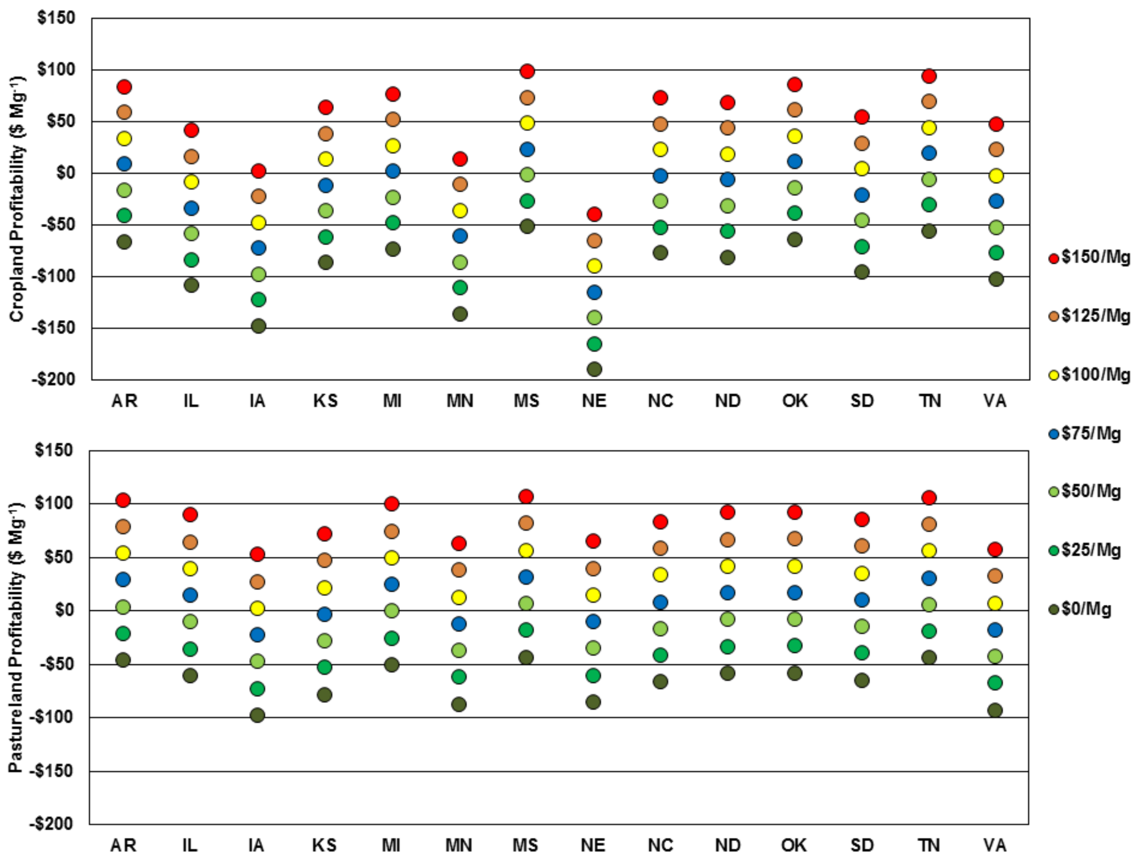


Figure 2.8 Profitability of switchgrass grown in the United States (Mg^{-1}) on both land with both crop and pasture land rents at biomass prices of $0, $25, $50, $75, $100, $125, and $150 Mg^{-1}.

These profitability valuations are simple breakeven calculations that only report a net positive result when costs are subtracted from returns. However, it is unlikely that producers would be willing to assume the risk that is associated with a breakeven profitability operating model. Therefore, it is likely that producers will want to see a return on their costs of a certain level above and beyond breakeven. Some experts have suggested that the minimum acceptable level of return for producers to accept would be breakeven plus the interest rate on operating bank loans.[59] For example, if a producer takes out an operating loan with an interest rate of 5%, then the producer should expect a minimum return of 5% over breakeven. In that respect, four of fourteen states (Arkansas, Mississippi, Oklahoma, and Tennessee) saw profits at or above at least 5% over breakeven at cropland grown biomass with biomass prices of at least \$75 Mg^{-1}. Comparatively, three states (Arkansas, Mississippi, and Tennessee) saw profitability returns of at least 5% on pastureland grown biomass at biomass prices of at least \$50 Mg^{-1}. An additional four states (Michigan, North Dakota, Oklahoma, and South Dakota) saw 5% profitability returns over breakeven with biomass prices of at least \$75 Mg^{-1} on pastureland grown switchgrass. With less than 30% of the cropland switchgrass states and 50% of the pastureland switchgrass states achieving a 5% premium over breakeven at biomass prices of \$75 Mg^{-1}, it is likely that either lower production costs or higher commodity biomass prices will be needed to entice producers to grown switchgrass for biomass throughout the country.

As previously mentioned, other studies have shown that costs and yields between switchgrass grown on productive lands and on marginal lands does not significantly differ. However, we have analyzed the potential changes in profitability on pastureland grown switchgrass resulting from a 25% increase in production costs, a 25% decrease in annual yield, and a combination of a 25% increase in production costs and a 25% decrease in annual yield. We used a 100\$ Mg^{-1} price for biomass because our work showed that all states were profitable when producing switchgrass on pastureland at this biomass price (Fig. 2.7). This was done to show the potential trends and magnitude that could be experienced between the production of switchgrass on high quality lands and more physically marginal lands. We found that, across the study area, a 25% increase in costs results in a 44.9% reduction in baseline profitability, a 25% decrease in annual yield represents a 45.4% decrease in baseline profitability, and a combination of the two results in a 149.5% decrease in baseline profitability.

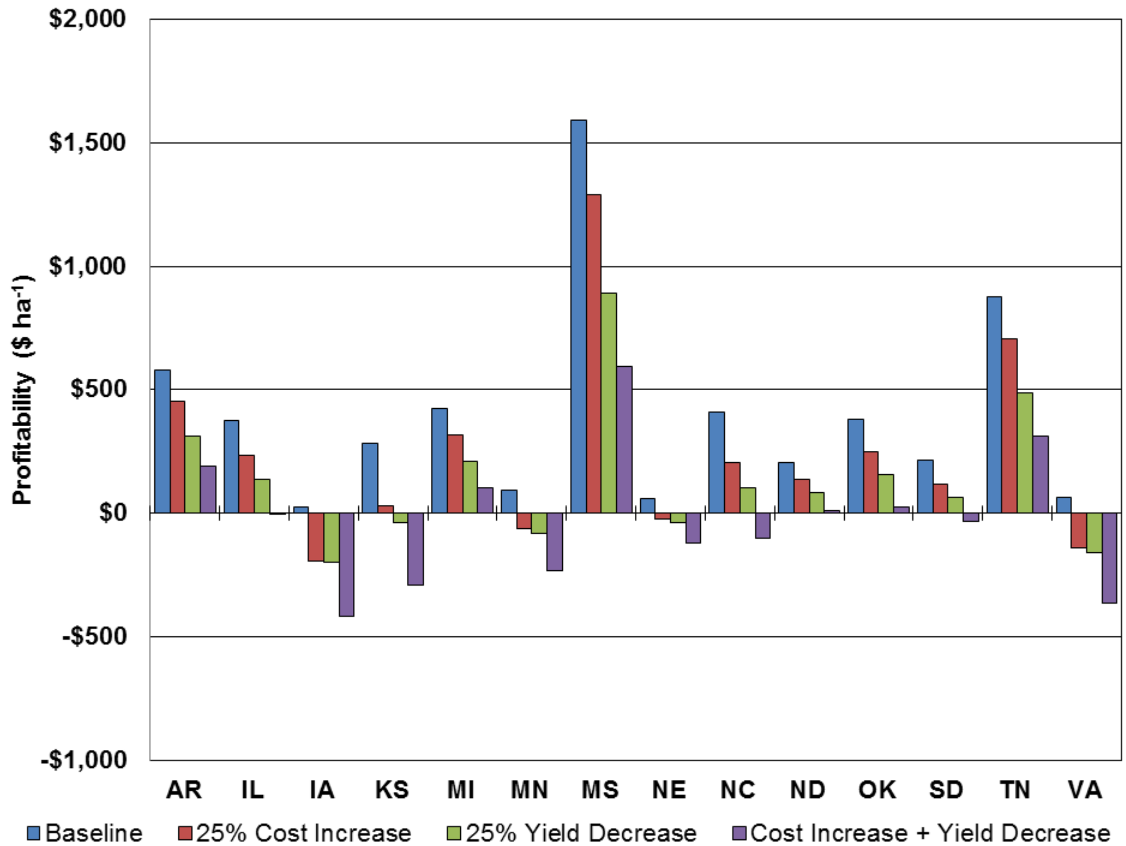


Figure 2.9 Profitability ($ ha^{-1}) of pastureland grown switchgrass comparing the baseline profitability at 100$ Mg^{-1} with a 25% increase in production costs, a 25% decrease in yield, and a combination of 25% production cost increase and 25% yield decrease.

There will need to be a paradigm shift in the agricultural production system to generate the extent of energy crops required to meet policy goals. Lands that are currently in cash crop production are likely to remain so. Lands that are in pastureland may be able to be converted to energy crop in certain situations. However, as commodity crop prices have risen over the past half-decade, it seems as though it may be more difficult for energy crops to successfully enter the landscape. To meet the cellulosic ethanol and advanced fuel requirements of Energy Independence and Security Act of 2007 and RFS2, energy crops will likely need to be grown on both cropland and pastureland. Some studies suggest that it will be possible to meet a majority of cellulosic ethanol requirements through the production of switchgrass (and other energy crops) on land that is currently not considered cropland.[8,14,60,61] However, current land use practices also suggest that use of agricultural lands is optimized in a manner that best suits the producers needs and ideals.[14]

Jensen (2007) suggests that farmers are wary of biomass for biofuel crops for many reasons, including a lack of market and a lack of technical assistance with regard to optimal switchgrass production practices. This survey found that less than 30% of respondents would be willing to grow switchgrass, even if it were profitable, because of the learning involved and lack of a stable market for the crop.[19] Kelsey (2009) profiled farmers in Oklahoma and asked where they obtained biofuels information and whether or not they would be willing to grow biomass for biofuels. The study suggests that, in addition to the lack of a market, other concerns include the added costs of switching lands and a need to learn new methods to manage unfamiliar crops.[18] The results from these studies propose that farmers are currently unwilling to begin growing biomass for biofuels.

Beyond the supply-side difficulties of producing switchgrass, the demand side of switchgrass production has its own issues. Currently, there is no commercial market for energy biomass and thus no established price for biomass. Estimates of the potential biomass price indicate that it will be on the low end of the prices modeled in this study.[3,4] Furthermore, simply covering costs or hitting the ‘breakeven’ price is not enough to establish an economically sustainable system. The producers may be likely to expect a profit over the breakeven price to make their operation successful. Because there are costs associated with production and the market has yet to set a price for biomass energy feedstocks, there is a gap that exists between what a producer is willing to accept as payment for their goods and what a user is willing to pay for those goods. This gap creates a substantial hurdle for the biomass energy industry. As long as it is more expensive to produce the bioenergy feedstocks than what they can be sold for, the producers are unlikely to begin growing the feedstocks.

This is a likely place for ecosystem service valuation to provide additional financial support for producers of perennial bioenergy feedstocks. As noted, switchgrass and other perennial grasses are touted as environmentally beneficial options for energy feedstocks. By monetizing the environmental benefits provided by perennial feedstocks like switchgrass, it may be possible to reduce the financial disparity between the costs and returns of perennial grass production and the costs and returns of other crops on the landscape.[13] Other intervention methods may be employed, in addition to ecosystem service valuation, in order to increase the competitiveness of switchgrass in the agricultural marketplace. For example, an expansion of the Biomass Crop Assistance Program (BCAP) to cover a larger portion of production costs for bioenergy feedstocks could incent more producers to begin implementing biomass feedstocks into their operations. Currently, BCAP provides cost-sharing for establishment year production costs and annual payments to producers who have enrolled land into the program. However, the restrictions on BCAP payments limit the amount of funding available to producers, thereby inhibiting the expansion of biomass feedstocks. The restrictions surround the application of the biomass and, in effect, penalize the producer if cellulosic biofuels are not the most valuable application for biomass feedstocks. In fact, a quarter of funding may be removed annually if the produced biomass is used for alternate products such as bio-plastics.[62] The expansion of financial incentives for biomass producers are likely necessary to promote the production of biomass feedstocks on the landscape. Until then, the willingness-to-pay and willingness-to-accept differences may be too large for bioenergy feedstocks to see a substantial role in United States agriculture.

2.4 Conclusions

The United States is falling short of its goal to produce billions of gallons of cellulosic ethanol for transportation fuel by the year 2022. This is due, in-part, to the risks associated with the production of economically viable perennial biomass crops on the landscape. Low costs, high yields, and high prices received are imperative to the success of perennial biomass crops entering the landscape.

This analysis finds that it is more economically beneficial to produce switchgrass on pastureland than cropland, assuming equal costs and yields on both lands. This would suggest that it is likely that for switchgrass to become integrated into the landscape, it will first be done on the lower priced land. Additionally, as nitrogenous fertilizer is a major component of productivity and is a major cost driver, the near-term future realized fertilizer prices may result in being a help or a hindrance to switchgrass production.

In the current high commodity price age, there is added pressure on incoming energy crops to be able to provide producers with a crop that is environmentally superior to fossil fuel provides a substantial economic benefit. Not only will switchgrass need to be able to compete against the option of leaving land unfarmed or in conservation programs, but to successfully reach the renewable energy goals set forth by the United States Congress, switchgrass must also be able to compete on lands that may be of a higher value.

Chapter 3

How commodity crop economics have changed in recent history and how crop insurance policy has impacted the profitability of farming operations in the United States

Abstract

Rising food prices and major changes in agricultural and energy policy have greatly affected the economic conditions under which commodity crops are produced. In this paper, we describe the financial profile of the two most prevalent commodity crops grown in the United States, corn and soybeans. We assess the costs, returns, and resulting profitability for the production of these crops in two periods, 2005-2008 and 2009-2011. We find that both corn and soybeans experience an increase in production costs across the entire study period. However, these increases are outpaced by commodity prices, ultimately increasing operating profit margins by 13% for both crops between 2005-2008 and 2009-2011. We also assess federal crop insurance policy to determine the financial impact that it has on production revenues and any potential inefficiencies that may be present in the system. We look at two policy inefficiencies in the crop insurance program: (1) counties experiencing a net loss before indemnities are paid but realizing a profit after insurance is paid and (2) counties that experience strong operating profit margins (greater than 25%) yet realize an additional 5% increase or greater in operating profits after indemnities. In total, we discover that approximately 49% of soybean producing and 40% of corn producing counties experience an inefficiency of either type over the 2005-2011 time period. These findings suggest that the agriculture industry has increasing financial stability recent years and that the crop insurance program has been operating with noticeable inefficiency over the same period.

3.1. Introduction

Commodity crop agriculture has a formidable presence in the United States, with corn and soybean making up a considerable portion of production. In 2013, approximately 132 million hectares of commodity crops were planted in the United States. Of those planted acres, corn and soybean represent nearly 54 percent (39.4 million and 31.4 million ha, respectively).[63] Commodity crops also play a large role in the national economy. In 2010 the agriculture industry contributed 5% to the country's nominal GDP and was responsible for employing more than 2.6 million people.[64] Crop prices began to rise in the middle of the last decade and continue to remain above the long-term moving average.

From 2005 to 2011, the price of corn nearly tripled and the price of soybeans more than doubled.[44] These increased prices have caused definitive changes in the way the farming industry operates, most notably through expansion of planted acres.[44] What is less certain is the degree to which these price increases have led to noticeable economic gains for producers, absent any subsidy they might receive. If costs to producers have increased at a rate equal to or greater than prices, the overall rate of profitability for operations would remain constant or decrease. If the costs of production increase too much, the risk of producers experiencing loss in their operations becomes a real threat. Understanding the drivers of price and cost, as well as the relationship between them, will lead to greater comprehension of the agriculture industry and how it changes in differing economic climates.

One of the proposed reasons behind the increase in commodity crop price is the wide-spread adoption of corn grain ethanol as a fuel source.[50,51,65–67] Federal policy, through the Renewable Fuel Standard (RFS2), has mandated that the United States produce 57 billion liters of corn-grain (henceforth referred to as conventional) ethanol.[57] The increased demand for corn has also indirectly affected the price of many other commodities. As farmers have planted more hectares in corn, other commodity crops have become scarcer. For instance, soybean prices have increased due to lower supply from increasingly larger portions of land being dedicated to corn.[14]

While ethanol production consumes approximately 40% of the corn the United States produces, the majority of the demand for corn, and subsequently a major driver of price, comes from the livestock industry. More than 50% of the corn produced in the United States is used as animal feed.[68] Additionally, about a third of soybeans produced are used as feed.[69] The use of corn and soybean meal as the primary source of nutrition for livestock and ethanol, coupled with a growing global demand for fuel and meat products, may result in supply pressures that lead to an increase in price and the possible expansion of cropland.[70]

In addition to increases in corn and soybean prices, petroleum prices have also steadily increased over the last decade. Between 2005 and 2011 the price of a barrel of West Texas Intermediate crude oil rose from \$9.01m^3 to \$15.08m^3, and reached an all-time annual high of \$21.29m^3 in 2008.[71] This increase in crude oil price has a two-fold effect on agricultural operations. As commodity crop-based fuels gain a greater presence in the fuel markets, the demand for producing energy-generating commodity crops will likely rise.

Beyond straightforward cost and price calculations, a potentially major propellant of revenue and profit for corn and soybean farmers is the crop insurance program in the United States. Crop insurance is a tool that is employed by farmers to limit their risk exposure in production. The USDA's Risk Management Agency (RMA) is the governing entity of the crop insurance program. It is responsible for determining the cost of insurance for all eligible crops throughout the country.[72] The crop insurance program provides a number of benefits to the agriculture industry: it subsidizes farmer insurance premiums, pays the administrative and operating costs of the insurance companies, and provides coverage for operations that would be of exceptionally high risk for private insurance under typical actuarial calculations.[73] There is a wide array of insurance packages available to farmers, including the ability to guarantee up to 85% of historically-based annual production before a seed is even planted. Doing so allows for producers to realize a revenue floor for their operations, even with total crop failure.

Still, the reasoning behind crop insurance is sound: to provide returns to farmers in the case of failure, which limits pricing volatility that would ultimately be passed onto consumers. All farmers in the United States growing a crop covered under the system, regardless of land type or geographic location within the country, must be granted coverage.[15] To ensure that insurance companies will provide coverage to all, the government provides reimbursements to these companies. These reimbursements consist of payments that are intended to help offset the costs of administering and insuring high-risk policies. Additionally, the USDA provides direct premium subsidies to the farmers who purchase crop insurance.[74] The government provides subsidies totaling approximately 60% of the premium cost charged to the farmer.[75] Through these policies, farmers are able to reduce the financial risk associated with crop production. Theoretically, this program also protects the American public through price stabilization and reducing the risk of volatility in the commodity marketplace.

While previous studies have looked at the impacts of policy and demand on commodity prices and the role natural resources play in economic scenarios, a gap exists in the literature surrounding the recent trends in commodity crop costs, returns, profits, and the intersystem efficiency of national crop insurance policy. Commodity crop prices have undoubtedly increased in the past decade.[44] Understanding how these increases have occurred in conjunction with production costs and insurance revenues, and how these variables ultimately impact profitability, is the goal of this study.

Swinton et al.,2011 report that in light of higher commodity crop prices, farmers are not significantly expanding their operations onto previously unfarmed or marginal lands.[14] This could indicate that while prices have increased, so have costs. Additionally, both Platinga et al., 2002 and Nickerson et al., 2012 suggest that land rents vary depending on the value of what is being produced on those lands.[49,53] Therefore, as commodity prices increase it would be expected that land values would also increase and raise the cost of production, all else held equal, due to the opportunity cost of producing those crops. An increase in land rent (among other costs) causing an increase in total production costs would potentially offset gains seen in commodity prices.

The purpose of this study is to analyze the enterprise budgets for the two most prevalent commodity crops (corn and soybean) grown in the United States from 2005 to 2011. We first assess the evolution of direct costs and returns seen by producers throughout the United States, analyzing both county-level and per-hectare production costs, as well as county-level profitability seen across the country. We hypothesize that an increase in profitability will be realized; however the increase will be less than the growth of prices over the same time frame.

We then examine the difference between corn and soybean profitability with and without insurance indemnity payments included. More specifically, we assess the counties that see inefficiencies in crop insurance indemnity payments in the form of experiencing losses before indemnity payments and realizing profits after indemnities or being a financially solvent county and experiencing additional profits after indemnities are paid. This allows us to explore the impact the crop insurance program has on both county-level economics as well as the financial stability of corn and soybean systems as a whole. Here we hypothesize that the majority of counties will not experience inefficiencies over the study time period.

The production years are split into two time-periods, the four year span directly following the implementation of the RFS (2005-2008) and the three year period of time (2009-2011), in which major financial crises struck the United States. In each case it was possible to determine an annual mean, median, and spread for the profitability associated with each commodity crop. The latter time period was assessed both with and without crop insurance indemnity payments to evaluate the influence that these payments had on production economics.

3.2 Methods

3.2.1 Data

Commodity crop data for this study were obtained from the USDA National Agricultural Statistical Service (NASS) and the USDA Economic Research Service (ERS).[42,44,76] The USDA gather, organize, and report data regarding agricultural production. The data from each of the research services were downloaded from their respective data portals. The NASS data were selected from the QuickStats portal and sorted by county, year, and crop. The ERS data were gathered from the Data Products portal and were sorted by geographic region, year, and crop.

The NASS portion was comprised of production and pricing data. These components include, on a per-county per year basis: hectares planted, hectares harvested, yield, and commodity prices. The ERS data were comprised of all the production cost data, at the regional level. These data include costs for: seed, fertilizer, pesticide, machinery, custom operating, fuel, repairs, irrigation, labor (direct and opportunity cost), financials/interest/taxes, and overhead. The opportunity cost of land was also included in this dataset; however, it was decided that the NASS state level cropland rent price would be used in place of the regional ERS land opportunity cost because those data were of higher resolution and were more straightforward in definition.

NASS data were joined together so that all crops and years were comparable. The ERS data were first consolidated so that all crops and years, for all regions, could be assessed. In parallel, a file that links counties to their respective ERS regions was constructed so that each county was assigned an ERS region. This file was then joined to the ERS region production cost data, resulting in each county having their respective production costs assigned for each crop grown over the database timespan. The resulting datasets were: all county-level NASS production results for the two commodity crops for the years under examination and all counties with assigned ERS production costs for both crops during the study timespan. The result was a database of production costs and returns for each region, county, crop, and year.

In addition to the production costs and outputs associated with corn and soybean production, county-level crop insurance policies were gathered from the RMA. These data provide the counties where policies were taken out, whether the plans were collected upon, the premiums paid by farmers, the premiums subsidies offered by the government, and the level of indemnity paid to farmers for crops. These data were consolidated to the county level by crop and year, and coupled with the existing database to determine the additional revenue generated by counties that grow corn and soybeans and received insurance indemnity payments. If a county did not receive an indemnity payment, then the insurance revenue for that county was zero.

It should be noted that all county-level costs in this study include the costs for insurance premiums. These costs were not excluded in the non-insurance profitability calculations because they are embedded in the costs for taxes, insurance, and other financial obligations. This aggregated cost component accounted for less than five percent of the total production cost, of which insurance premiums only made up a portion. Therefore it was decided that the premium costs did not meaningfully contribute to the overall production costs and were not of concern when left in the cost equation.

3.2.2 Analysis

There are a variety of economic inputs that make up the production costs for this database. The cost variables include: seed, fertilizer, pesticide, fuel, repair, irrigation, labor, machinery, land, and certain financial factors. Because the commodity crops being assessed are annuals, their respective costs are associated with one growing season. The costs for production are on a per-hectare basis. To determine total cost per county, the per-hectare costs are multiplied by the number of hectares planted per county. In contrast, returns to the producers are more straightforward than costs. The return per-hectare is the product of commodity price and per-hectare yield. This provides the per-hectare revenue that the producer will receive for the crop. To determine total region or county return, the per-hectare revenue is multiplied by the hectares harvested for the crop in the specific geographic area. By using hectares planted for cost calculations and hectares harvested for revenue calculations it is possible to capture any physical losses associated with production during the growing season. Profitability for each crop was calculated at the county level by subtracting costs associated with production of a crop from returns generated from the sale of the crop.

Once the data were compiled and the costs, revenues, and profitability were calculated, the data were aggregated by yearly values to provide temporal county-level averages. These averages were calculated for 2005-2008 and 2009-2011 to assess how the economics trended over these time periods. Summary statistics for corn and soy profitability were also calculated, with and without crop insurance. This was done at the national level to show policy influence. Additionally, the data were imported into ESRI ArcMap to provide a spatial analysis of insurance policy inefficiencies that occur in the United States. These examinations of policy are considered inefficiencies because they are instances in the policy where there is potential for an efficiency failing in the policy. We examine two types of policy inefficiency. The first inefficiency includes all scenarios where crop insurance indemnity payments help to turn counties that have experienced a loss into counties that realize a profit. The second inefficiency entails counties which are considered financially solvent pre-indemnity receiving additional revenue from insurance.

To calculate whether a county experienced a loss-to-gain transition, the post-indemnity profitability was divided by the pre-indemnity value. If the resulting ratio was negative, then those counties experienced a loss-to-gain change. To determine financially solvent counties receiving additional revenue, we looked for counties that see an increase in operating profit of greater than 5% after indemnity payments for counties that have an operating profit margin of 25% or greater. According to Michigan State University Extension, outfits with operating profit margins equal to or greater than 25% can be considered "strong" and are unlikely to be significantly hindered by changes in commodity prices or input costs in the short term.[77] The profitability change layers from the 2005-2011 production years were overlaid in ArcMap to determine which counties experienced inefficiency. The number of counties that experienced these changes were then documented and calculated against the total number of counties producing each crop in those years.

3.2.3 Sensitivity Analysis

Sensitivity analyses were performed to assess which cost components have the largest effect on the overall production costs for the commodity crops under examination. By looking at which inputs drive the variation in the total production cost help us understand which inputs will have produce the largest changes in overall production cost. In unison with this analysis, we analyze the impact on the total production cost when the most impactful cost components see changes of 10% (+/-). In each of these cases, only the input cost in question was varied and all other costs in the production cost equation were held equal. By doing so we are able to look at the specific changes caused by each cost component. In this analysis the production costs for the two commodity crops were averaged over 2005-2008 and 2009-2011 in an effort to reduce year-to-year volatility in agricultural production caused by changes in demand and supply or uncontrollable forces such as weather. Each production cost component for the two commodity crops were assigned a distribution fit by Crystal Ball, a third party statistical analysis software developed by Oracle and used as an add-in to Excel. Crystal Ball is a predictive modeling software application that allows for the analysis of scenarios and sensitivity through Monte Carlo methods. The distribution selection technique used was chi-square; chosen because it is considered the best approach for fitting distributions with discrete data.[78]

After the distributions were fit, the production cost formula was input into Crystal Ball and calculated. The formula is the sum of all the previously described annual cost components. Each commodity used the same formula for production costs, with different data inputs. Once the formula and assumptions were entered, the simulation was run 10,000 times in a Monte Carlo routine to determine which individual cost components are most impactful. The 10% sensitivity analysis that was performed on each cost component was run concurrently in Crystal Ball during this time.

3.2.4 Switchgrass and Commodity Crop Profitability

The final portion of analysis was to look at the profitability differences between switchgrass grown in the United States (Chapter 2) and corn and soybean commodity production. This was done to compare the national averages of production for both cropland and pastureland grown switchgrass against the production of corn and soybean. We also looked at the individual results for states producing switchgrass (Chapter 2) against the state level profitability for both corn and soybean. All these analyses use the 2001 amortized costs for cropland and pastureland switchgrass production and the 2011 costs and returns for corn and soybean.

We first assess the national averages (ha^{-1}) for switchgrass production on pastureland and cropland and determine the profitability at \$25 Mg^{-1} increments between \$0 and \$150. Then we find the difference between these values and the national (ha^{-1}) averages for corn and soybean produced in 2011.

Next, we examine the (ha^{-1}) profitability of switchgrass produced in each state, on each land type at multiples of what the DOE, EPA, and USDA assume to be the necessary price of biomass to meet the goals of RFS2 (\$41, \$82, \$122, \$163, \$204 Mg^{-1}). We then compare these results to the average (ha^{-1}) profitability for corn and soybean grown in the corresponding states in 2011. We determine the profitability gap by finding the difference between switchgrass grown on each land type at the various biomass price points and the profitability for each commodity crop grown in the matching state.

3.3 Results and Discussion

Together, the costs and returns to producers allow for the examination of financial trends and the solvency of commodity crop production over time. These analyses can be compared and contrasted with other agricultural production data (e.g. energy crops) to help understand how the agricultural sector may move forward and what levels of competition may be fostered between crops as the demand for agricultural land continues to rise.

3.3.1 Comparing production costs between time periods

There has been a substantial increase in the real prices of commodities over the last two decades. Over that time, the commodity crops in this study had experienced fairly steady prices through 2005. However, after 2005, prices for these commodities began to rise sharply. When looking at the price received between the two time periods and crops, it is seen that the average for corn and soybeans in 2005-2008 were 131$ Mg^{-1} and 317$ Mg^{-1}, respectively. For the 2009-2011 time period for the same crops were 196$ Mg^{-1} and 438$ Mg^{-1}. These changes represent a 50% and 38% increase in price for the respective commodities between the two time periods. It is suggested that these changes in price are driven by the increased demand for corn for biofuels and the pressure that the added corn demand placed on soybean supply. The soybean supply decrease was likely caused by a transition of soybean land to corn and from a corn/soy rotation to a corn-on-corn farming operation.[14,47]

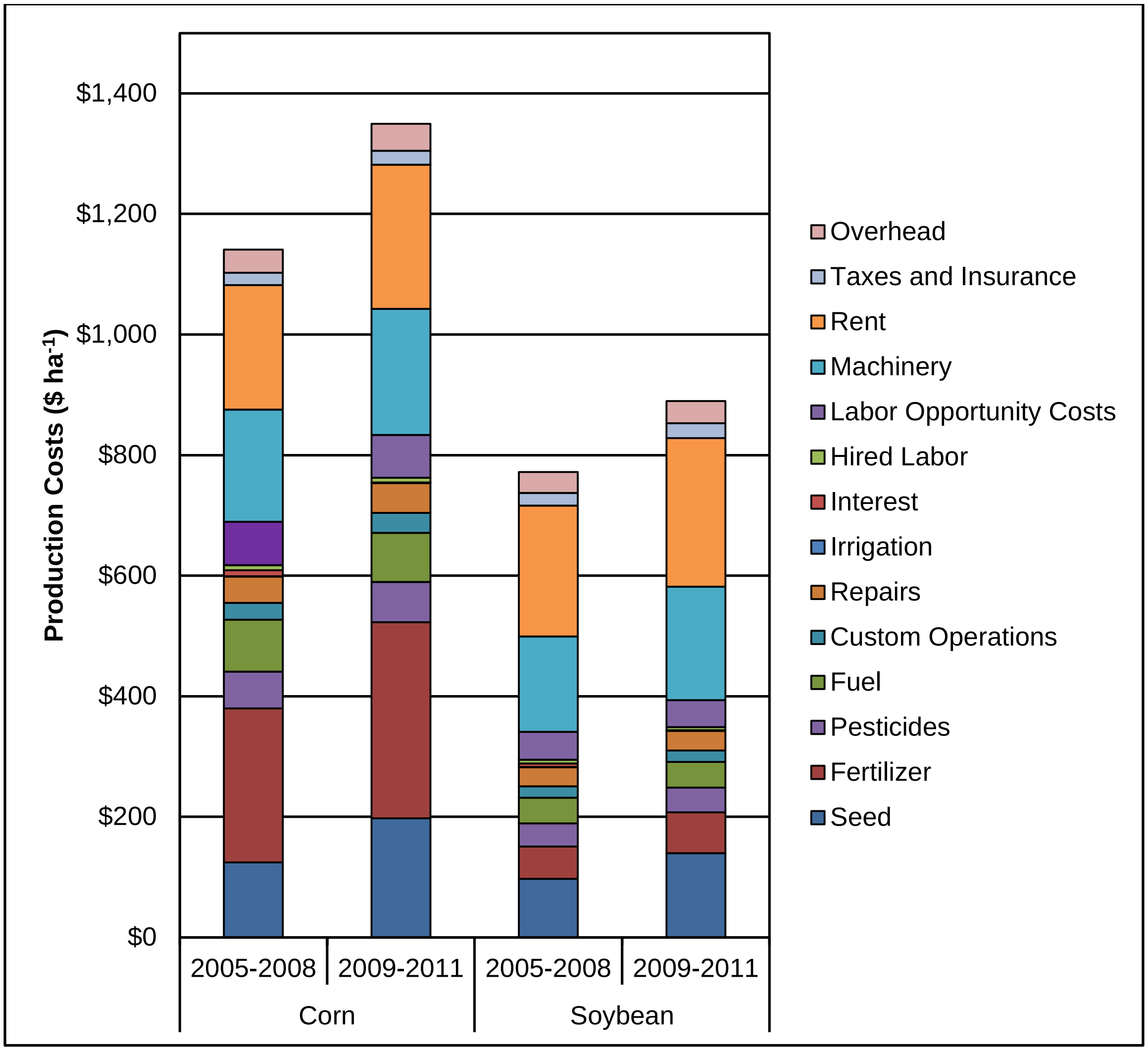


Figure 3.1 Breakdown of nationwide average individual cost components of commodity crop production costs for both corn and soybean from 2005-2008 and 2009-2011.

As shown by the individual input costs and total production costs in Table 3.1 and Fig. 3.2, both crops saw an increase in costs among the 2005-2008 and 2009-2011 span. Corn producers saw an 18% increase in mean production cost and a 19% increase in median production cost. Soybeans saw slightly lower growth with a 15% mean production cost rise and a 14% median production cost increase.

Table 3.1. County-level production cost statistics (ha^{-1}) for corn and soybean crops in the United States from 2005-2008 and 2009-2011 in real 2011$.

	Corn		Soybean	
Year	2005-2008	2009-2011	2005-2008	2009-2011
Mean	$1,143	$1,349	$772	$890
Median	$1,121	$1,337	$769	$877
Std Dev	$131	$132	$94	$98
Max	$1,475	$1,666	$1,001	$1,109
Min	$805	$1,002	$554	$685

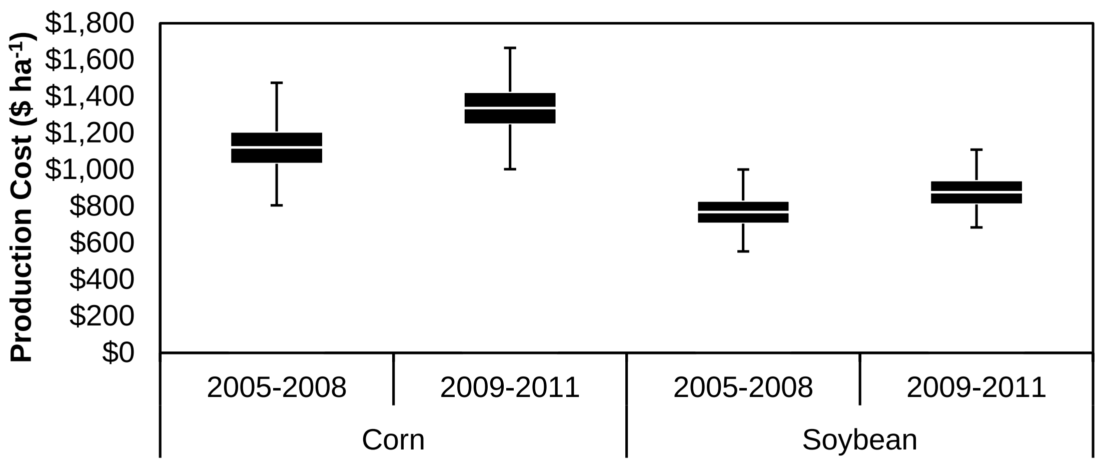


Figure 3.2 County level production costs ($ ha^{-1}) for corn and soybean in both time periods. These costs are borne annually by producers and are averaged among the time periods reflected in this study. Black boxes represent the 25-75 percentiles and the white line represents the median, and whiskers represent the minimum and maximum production costs.

Seeing that there is a greater difference in the growth of prices than costs, it would suggest that producers likely experienced an increase in the profitability of their operations between the 2005-2008 and 2009-2011 time periods.

3.3.2 Evaluating commodity crop profitability and the impacts of crop insurance indemnities

To determine whether there was a profitability increase among the crops between time periods, we assessed the counties that produced corn and soy from 2005-2011 while excluding crop insurance indemnity payments from the respective budgets. From 2005-2008, the increase in commodity price was less pronounced than the following three years. Because of this, we see a lower mean profit than is present from 2009-2011. However, while both time periods exhibit a positive mean profitability, the 2005-2008 time period also shows a negative median profitability (Table 3.2). This suggests that while some counties in that time period saw profit in their operations, the majority of the counties actually experienced losses when producing corn or soy. This differs from 2009-2011, which saw dramatic increases in both the mean and median county-level profitability across the study area, as compared to the previous period. Both the mean and median profitability were positive, suggesting a majority of the corn and soy producing counties saw profits in their operations.

Table 3.2 County-level profitability statistics for (a) corn and (b) soybeans in the United States from 2005-2008 and 2009-2011 *with* and *without* the inclusion of crop insurance indemnity payments (in thousands).

(a)	**Corn**			
Year	2005-2008		2009-2011	
Indemnities	*Without*	*With*	*Without*	*With*
Mean	$1,675	$2,503	$9,344	$10,591
Median	($434)	($300)	$1,128	$1,839
Std Dev	$12,804	$12,996	$19,828	$20,293
Max	$135,714	$135,736	$153,126	$154,877
Min	($48,671)	($42,710)	($31,998)	($25,732)

(b)	**Soybean**			
Years	2005-2008		2009-2011	
Indemnities	*Without*	*With*	*Without*	*With*
Mean	$1,517	$2,211	$5,216	$5,877
Median	($22)	$97	$2,157	$2,691
Std Dev	$6,444	$6,865	$8,405	$8,436
Max	$57,444	$57,475	$77,375	$77,508
Min	($30,736)	($28,157)	($30,093)	($20,193)

After assessing the profitability of corn and soy production at the county level without the impact of crop insurance indemnity payments, those payments were reintroduced to the profitability equation to determine how they affect the overall profitability of the system. For this study component we looked at both the 2005-2008 and 2009-2011 time periods. We contrasted the non-indemnity profitability with the post-indemnity profitability. This allowed us to see what kind of profitability increases, if any, were enacted across the study space.

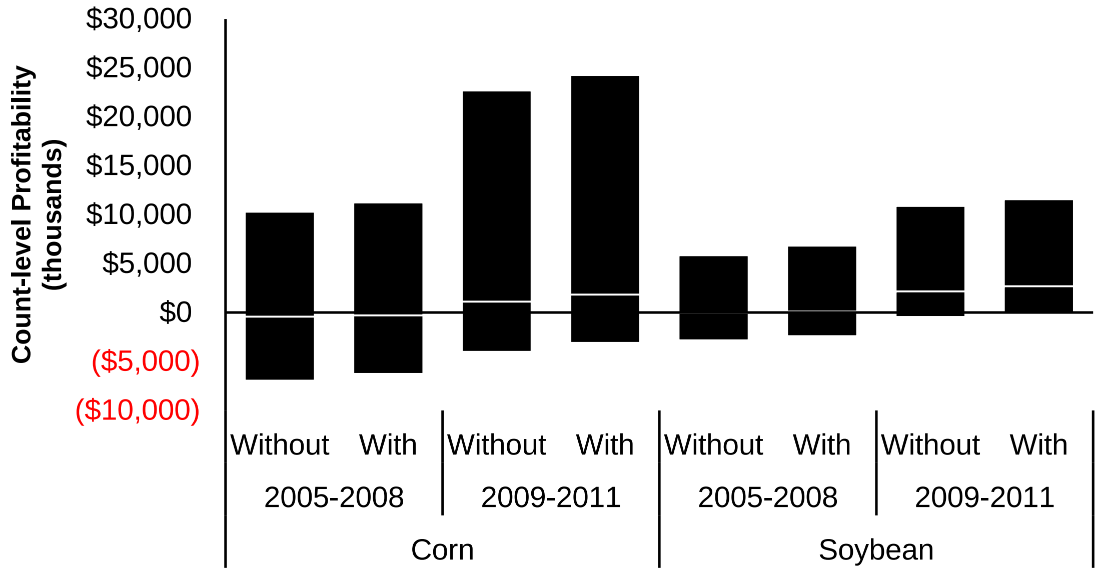


Figure 3.3 The assessment of the 25-75 percentiles for county-level profitability values for both crop types in each time period. These values represent the profitability without crop insurance indemnities included and the profitability of corn and soybean production at the county-level with crop insurance indemnities included for the both the 2005-2008 and 2009-2011 time periods. The black boxes represent the 25-75 percentiles, and the white line represents the median.

At a broad scale, we found that overall county level median profitability was increased 63% and 25% for corn and soybeans, respectively (Fig. 3.3). We also found that the mean profitability rose 13% for both corn and soybeans. With these findings we are able to suggest that crop insurance provides large monetary increases to farmers above and beyond the non-indemnity scenarios. While the magnitude of increased profitability was unclear before analysis, we did fully expect an increase in profitability as there were no increased costs to the producers, only an increase in revenues.

In addition to wide-scale insurance impacts, we looked at the inclusion of crop insurance indemnity payments on the individual county level to assess the study area for inefficiencies that may arise through crop insurance. In this study we define a crop insurance inefficiency as any scenario in which a county that had experienced a loss pre-indemnity realized a profit post-indemnity or a county with a strong financial standing experiencing an additional 5% gain in profitability post-indemnity. Through our analysis we determined that at least 6.2% of all counties experienced inefficiencies annually.

The two types of inefficiencies described in this paper differ with respect to what they may mean for the agriculture industry. The first inefficiency, counties experiencing a loss before becoming profitable with indemnities, may artificially support the production of crops in areas where a purely market-based system may not survive (Figure 3.4). We discovered that, on average, 4.0% of corn producing counties and 5.4% of soybean producing counties annually experience the loss-to-profit inefficiency.

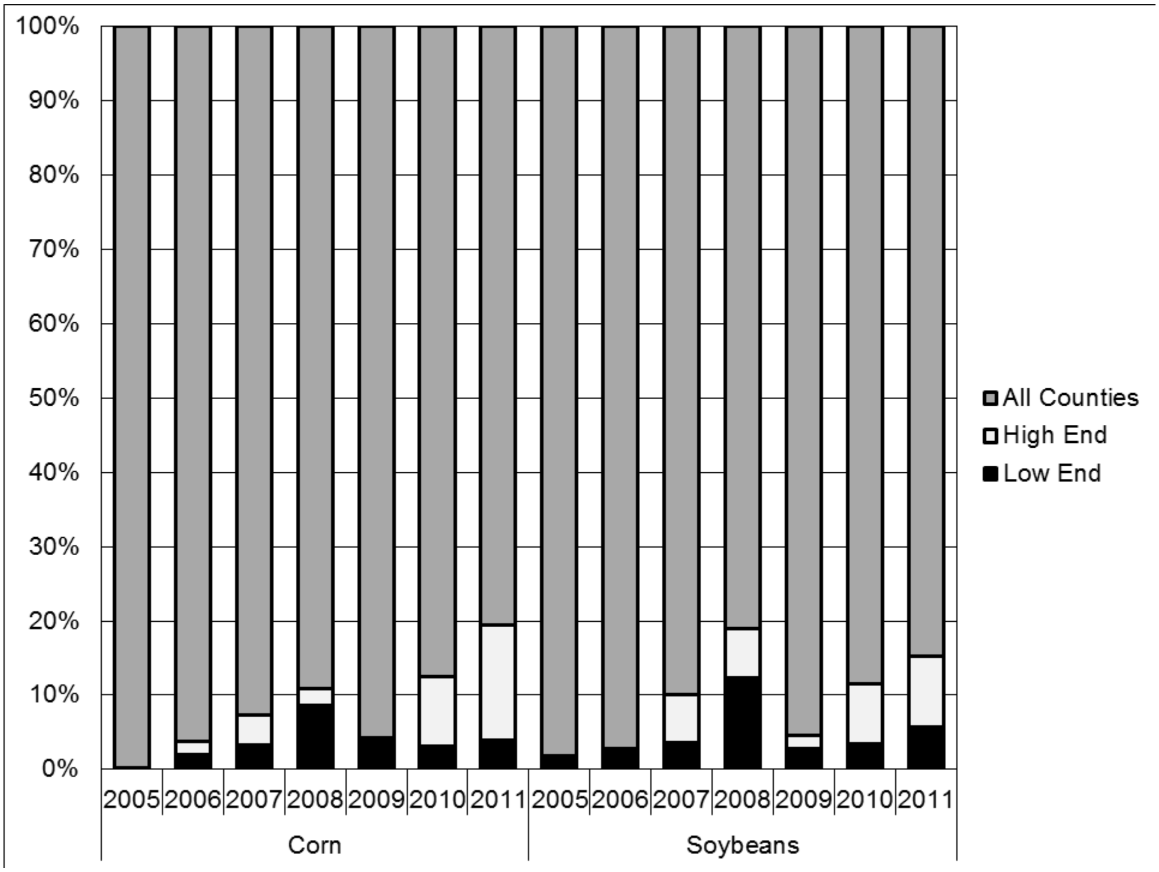
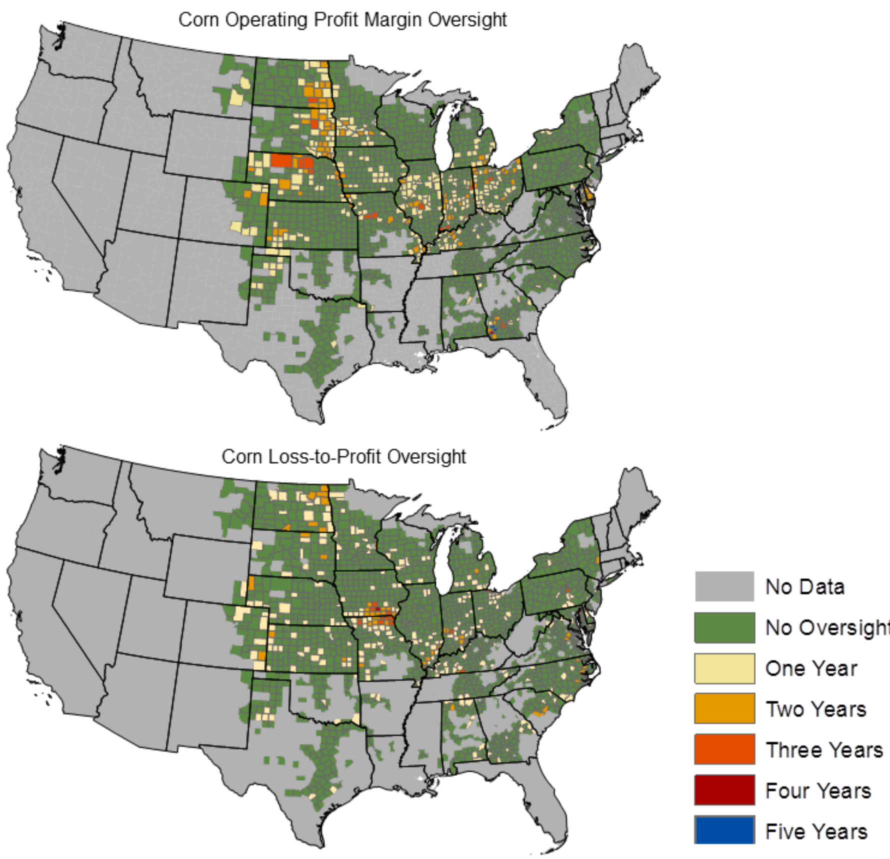
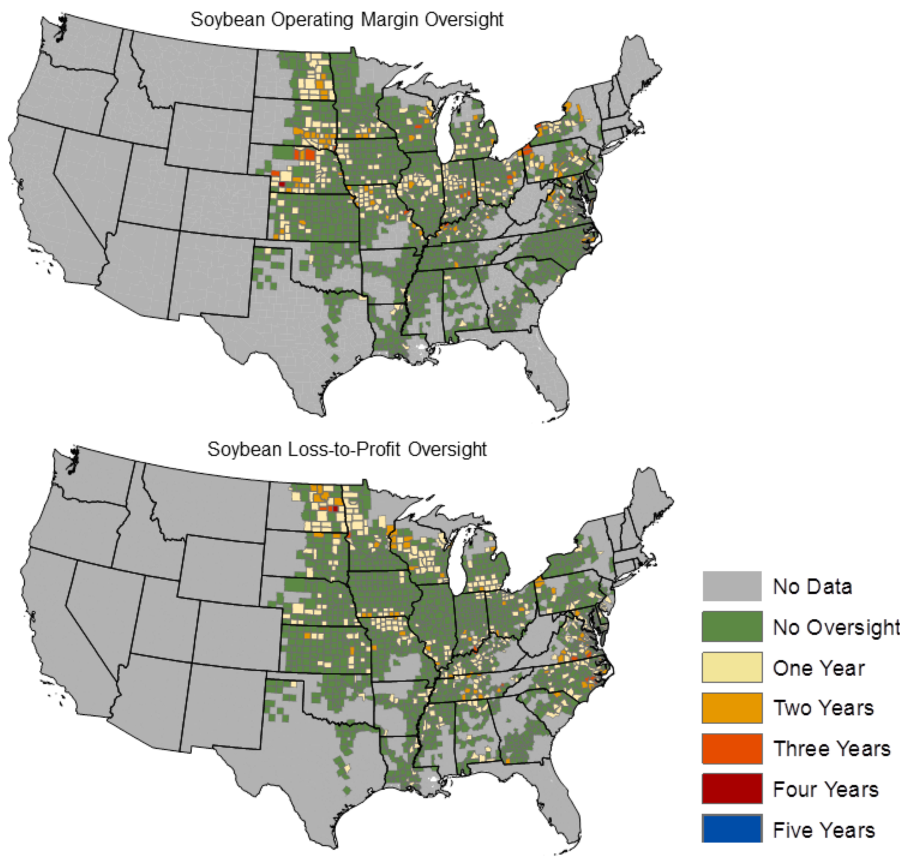


Figure 3.4 Percentages of counties that experienced crop insurance policy inefficiencies. Low end inefficiency refers to the counties that experience losses before indemnities and become profitable after indemnities. High end inefficiency refers to counties that experience at least a 25% operating profit margin before indemnities and realize an addition 5% increase in operating profit margin after indemnities are paid.

The other inefficiency addressed in this paper is the increased profit seen in financially solvent operations (i.e., 5% or greater profitability gain in counties seeing 25% operating profit). In this study it is assumed that extrapolating the "strong" operating profit margin value to the county-level is appropriate to address financial stability for farming operations. Additionally, this increase is also reflected in the number and percentages of counties seeing additional gains from indemnity payments even in the face of having solid operating profits. We found that corn saw an average of 5.6% of counties experience this inefficiency in any given year with a maximum of 19.2% of counties experiencing this inefficiency in 2011. Soybean producing counties saw an annual average of 5.4% inefficiency, with a maximum of 11.4% of counties experiencing this inefficiency, also in 2011. This would suggest a less than optimal use of crop insurance funds on counties that do not necessarily need additional financial support to maintain solvency.



(a)



(b)

Figure 3.5 Spatial representation of crop insurance inefficiencies seen from 2009-2011 for all counties that grow (a) corn and (b) soybean in the United States. The counties that experience inefficiency were analyzed to determine how many years between 2009-2011 they experienced either a change from loss-to-profitability after the inclusion of insurance indemnity payments or whether they saw an increase of 5% in operating profit margin on top of the already present, pre-indemnity, 25% operating profit margin.

We also analyze the spatial distribution of the counties which experience inefficiencies over the 2005-2011 timeframe. Fig. 3.5 displays the spatial location of counties that produced (a) corn and (b) soybeans from 2005-2011. In this figure we highlight the counties that grew crops but did not experience inefficiency, counties that experienced inefficiency in one to five years out of the seven in the time period. Of the counties that planted soybeans (n = 1666), 48.6% (n = 809) of counties experienced inefficiency in at least one year. Of the counties that grew corn, 39.7% (n = 715) of counties experienced inefficiency in at least one year. No soybean or corn producing counties saw inefficiency in more than four years or five years of production, respectively. Also, due to the definitions of the inefficiencies, it is not possible for a county to experience both inefficiencies in the same year. It is, however, possible for a county to experience both inefficiencies in differing years.

When assessing the soybean loss-to-profit inefficiency, we found that 24.5% (n = 408) 20.0% (n = 333) of counties had one year, 3.8% (n = 64) of counties had two years, 0.6% (n = 10) had three years, and 0.1% (n = 1) had four years of loss-to-profit inefficiency. When assessing corn producing counties we found that 13.8% (n = 248) of counties experienced only one year, 2.9% (n = 52) of counties experienced two years, 0.8% (n = 14) of counties experienced three years, and 0.1% (n = 1) experienced four years of loss-to-profit inefficiency. Where there are counties that are seeing a consistent annual switch from loss-to-profit through crop insurance may suggest that these counties are less effective at growing certain crops and may not be able to support crop production without intervention.

Counties also saw substantial influence from crop insurance on the other end of the economic spectrum. Many counties that are already financially solvent are reaping additional benefits from the inclusion of crop insurance revenues on their balance sheets. When assessing soybean counties for operating profit margin inefficiency we found that: 24.1% (n = 401) of counties experienced operating margin inefficiency in at least one year. 18.6% (n = 310) had one year, 4.6% (n = 76) had two year, 0.8% (n = 14) had three years, and 0.1% (n = 1) had four years of operating profit margin inefficiency. When assessing corn producing counties for operating profit margin inefficiency we found that: 16.4% (n = 295) experienced only one year, 4.9% (n = 88) experienced two years, 0.8% (n = 14) experienced three years, 0.1% (n = 1) experienced four years, and 0.1% (n = 2) experienced five years of operating profit margin inefficiency.

The ability for farmers to readily access subsidized crop insurance indirectly promotes the expansion of commodity croplands onto lower quality and environmentally sensitive lands.[72] This occurs due to the guaranteed revenue floor for the farmer. By purchasing crop insurance, the farmer has set the lower limit of revenue that they will receive. These guarantees can be based on historic yield, price received, or revenue. In doing this, the farmer has the ability to collect income in the event of sub-par production or all-out catastrophe.

The expansion of commodity crops will likely occur on land ideally suited for bioenergy production or conservation, hindering national goals in both spaces. Farmers are already utilizing their best, most fertile lands for commodity crops and have been using less productive lands for conservation purposes.[79] High demand for corn helped prices more than triple between 2005 and 2012.[44] Through the increase in commodity prices and risk mitigation with crop insurance, there is an incentive for converting marginal lands that carry higher environmental risks to cropland. These lands, with crop insurance guarantees, are now potentially too valuable to sit idle and are becoming viable sources of income. This trend has increased the amount of revenue that farmers are able to capture; however, it has also removed more than 1,300,000 of grassland that is vital to wildlife and ecosystem prosperity.[80]

Commodity crop expansion may also be exacerbated with the elimination of direct payments from newly passed 2014 Farm Bill. The reasoning behind the removal of these payments includes rising prices for crops and the need to cut government spending. However, some proponents of the direct payments see their removal as damaging to conservation practices.[15] Under the previous system, farmers were provided payments based on the past crop history, regardless of whether a crop was being grown on the land. These proponents suggest that the removal of direct payments will incent farmers to make up lost income by expanding the previously unfarmed land into more crop acres. The money that is saved from the elimination of direct payments, approximately $5 billion annually, has been budgeted to other aspects of crop protection, crop insurance.[81] By cutting the direct payments and allocating a portion of those funds to crop insurance the government is incentivizing the move toward commodity crops over conservation through the monetary guarantee for the producer. Conversely, no such mechanism has been made available for energy crops or conservation lands.[15]

3.3.3 Sensitivity and Uncertainty

Assessing individual inputs of enterprise budgets is integral to determining how the budgets may change over time in the face of economic pressures. In this study we both determine the most important inputs in the system and the effect that each input has on the outcome under differing economic situations. Fig. 3.6 shows the inputs that contribute greater than 95% of the variation in the model and how each of those variables would affect the per-hectare production cost.

Rent, fertilizer, machinery, and the opportunity cost of labor are all major drivers of production costs for both crops over all time periods. Other costs that play a larger role in production costs include fuel and seed. The remaining costs in the production budget equation: pesticides, irrigation, custom operations, labor, repairs, operational interest, general overhead, and taxes and insurance were excluded from Fig. 3.6 because collectively they account for less than 5% of the total production cost variation.

Over both time periods, many of the most impactful costs remained in their relative rank order for each crop type. The three most impactful costs for corn, in order of impact, are: fertilizer, rent, and machinery costs. For the 2005-2008 time period, a 10% change in the price of each variable result in 2.3%, 1.8%, and 1.6% changes in total production cost, respectively. During the 2009-2011 time period, a 10% change in variable cost resulted in 2.4%, 1.8%, and 1.6% changes in total production cost. These analyses were done to estimate the elasticity of production costs given changes in input variables.

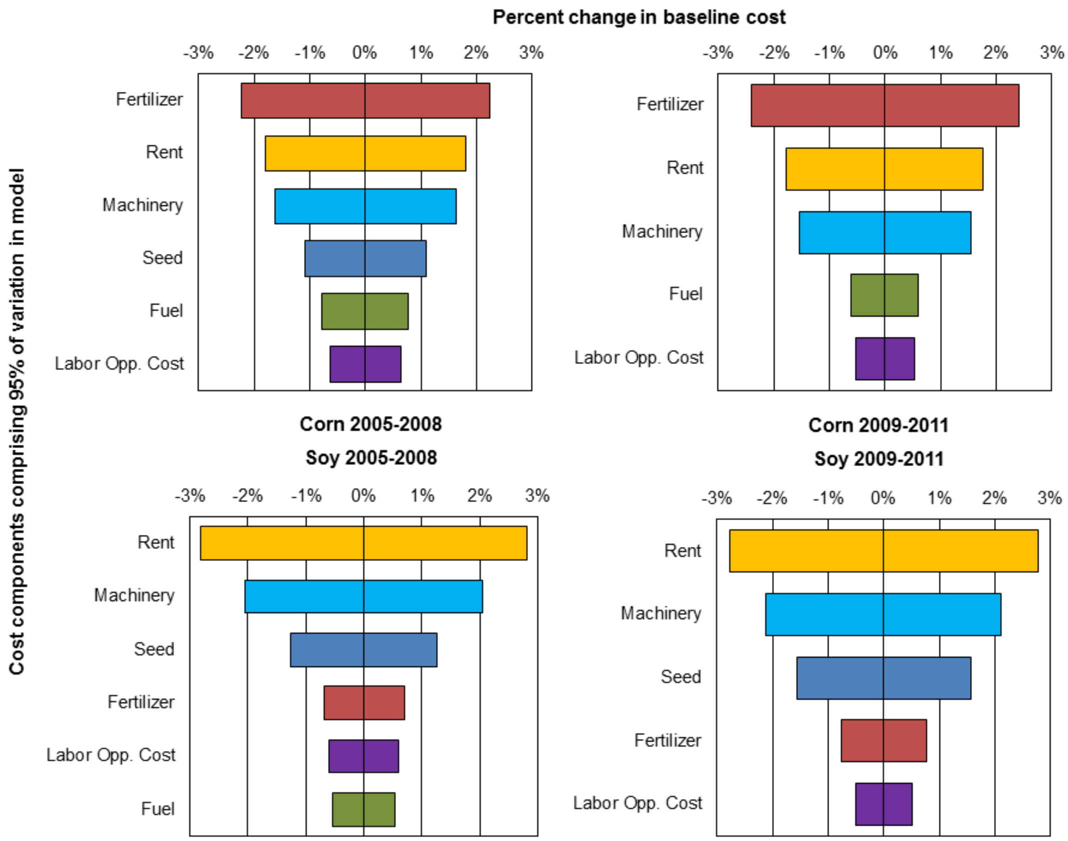


Figure 3.6 Sensitivity analyses for corn and soybean crop cost inputs that make up greater than 95% of the total variation in cost. Each bar represents the percent change on the total production cost stemming from a ±10% change in each individual cost component.

Conversely, there are four cost variables that remain in the same position over both time periods for soy production. They are, in order of impact: rent, machinery, seed, and fertilizer. A 10% change in input cost for these variables during the 2005-2008 time period resulted in 2.8%, 2.0%, 1.3%, and 0.7% changes in total production cost. The same change in input cost resulted in 2.8%, 2.1%, 1.6%, 0.8% changes in cost during the 2009-2011 time period.

These differences in production cost may seem minimal on an individual basis. However, a 10% change in cost is not an unprecedented alteration. In all four cases, rent and fertilizer are some of the more impactful costs on production costs. Within the study period, 2005-2011, nitrogen (44-46% urea) fertilizer and cropland rent prices have increased 58% and 35%.[42,44] It should be noted that during this same time period, inflation increased only 13%.[41] From the historical data, we can postulate that there is likely to be a dramatic change in production cost over the coming decade. By knowing which input cost factors have the greatest effect on the overall production cost, it becomes easier for producers to be able to assess their future economic burden in the face of rising or sinking cost components.

3.3.4 Switchgrass and Commodity Crop Profitability

In assessing the profitability differences between the production of switchgrass stands beginning in 2011 and the production of major American commodity crops corn and soybean, we aim to uncover the level of economic discrepancy between perennial bioenergy crops and annual commodity crops and the potential for bioenergy crops to gain some of the share of the landscape.

We first look at the profitability of switchgrass (ha^{-1}) grown on land priced as cropland and pastureland at a variety of biomass feedstock price points ($0-150 at $25 Mg^{-1} increments) and compare them to the national averages (ha^{-1}) of corn and soybean profitability. We find that switchgrass grown on pastureland becomes more profitable than soybean at a biomass price of approximately $75 Mg^{-1}. However, cropland grown switchgrass does not become more profitable than corn until biomass prices reach a level above $100 Mg^{-1} (Fig. 3.7). We also find that the production of switchgrass on both cropland and pastureland is less profitable than corn or soybean at the biomass price suggested by the DOE, EPA, and USDA for being large enough to produce biomass in quantities sufficient for meeting RFS2 goals.[3]

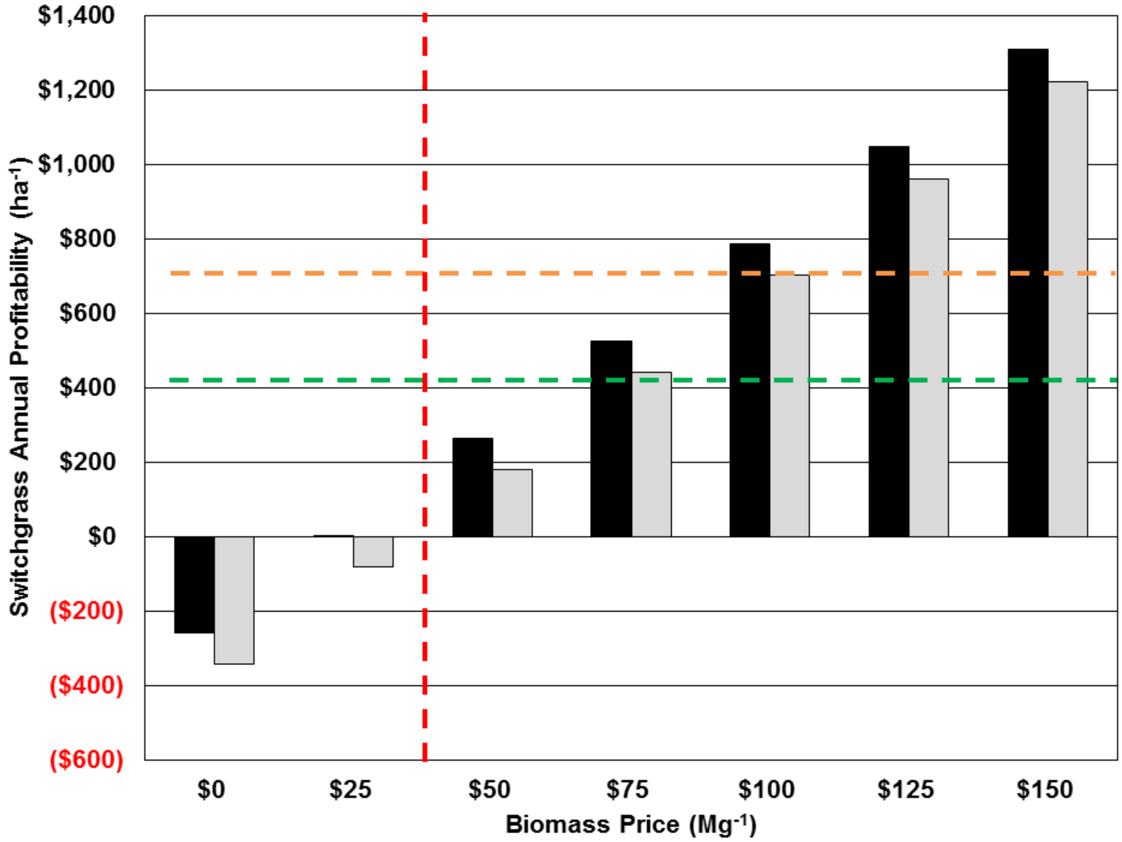


Figure 3.7 National average (ha^{-1}) profitability for cropland and pastureland switchgrass as compared to corn (top), soybean (bottom), and the estimated biomass price predicted by DOE, USDA, and EPA as being sufficient to meet RFS2 goals (vertical).

Next, we assess the stale-level profitability of cropland and pastureland grown switchgrass against the profitability of both corn and soybean grown in each state that is featured in Chapter 2. Here we calculate the profitability (ha^{-1}) of switchgrass at biomass prices from 1-5 times the value suggested by the DOE, USDA, and EPA ($41, $82, $122, $163, and $204 Mg^{-1}.[3]

We find that, with switchgrass grown on cropland, that no states producing switchgrass realize a profit at $41 Mg^{-1} biomass. Additionally, only Mississippi experiences a greater loss with commodity crop production (corn) as compared to switchgrass. All other states see larger losses from the production of switchgrass at $41 Mg^{-1} biomass. However, at two times the recommended price we see that Mississippi, Oklahoma, and Tennessee make more money from switchgrass than soybean, while only Mississippi and Oklahoma see that phenomenon with corn. States such as Iowa and Nebraska see no instances of higher switchgrass profitability for either commodity crop even at five times the suggested value and Minnesota experiences no switchgrass profitability when compared to the production of corn (Fig. 3.8).

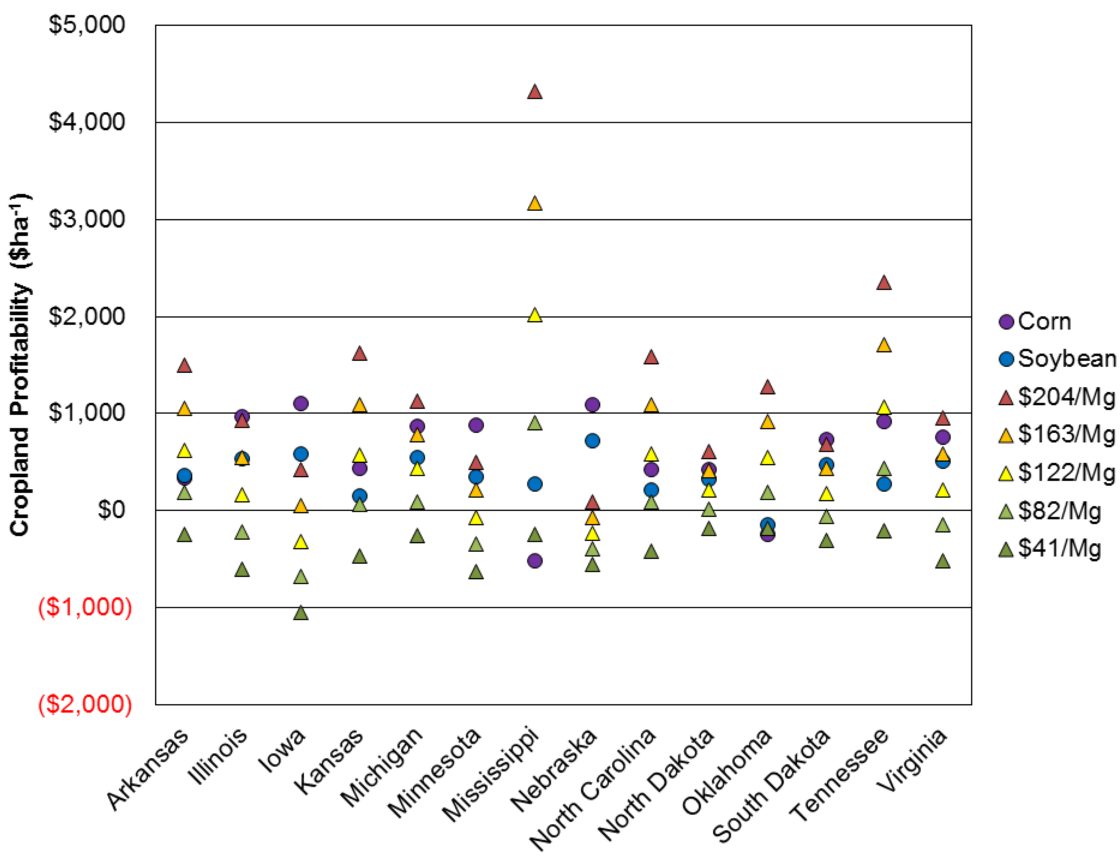


Figure 3.8 Profitability comparisons (ha^{-1}) between amortized switchgrass grown on crop priced land and corn and soybean produced in 2011.

When assessing pastureland grown switchgrass against corn and soybean production we find that there are still no states that are profitable at \$41 Mg^{-1} biomass, but that the difference between corn and soybean profitability has diminished. This decrease is due to the fact that non-land production costs and yields between the switchgrass production studies remain constant while the land price decreases. This is compared to the commodity crop profits, which are the same for both sets of analysis. At the upper end of biomass prices (\$204 Mg^{-1}), we see that Nebraska still remains more profitable for corn and soybean production while Iowa and Minnesota are only more profitable for corn production. Mississippi and Oklahoma remain the states with the lowest cost of entry for switchgrass due to the fact that switchgrass produces a higher return for corn in both states.

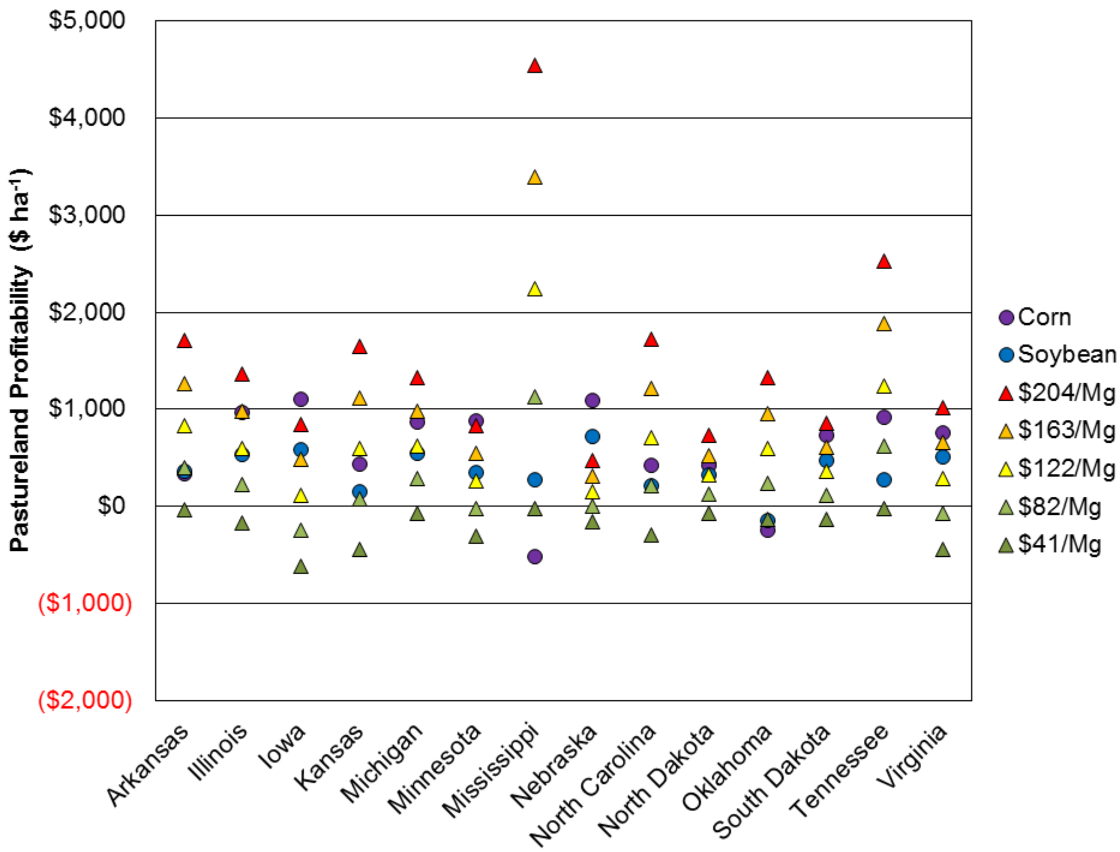


Figure 3.9 Profitability comparisons (ha^{-1}) between amortized switchgrass grown on pasture priced land and corn and soybean produced in 2011.

3.4 Conclusions

Commodity crop production is a major piece of the American agriculture industry and corn and soybean are two of the largest crops grown in the United States. In recent years, the market price and input costs for these crops have increased. The crop prices reached historic highs in 2008 and have settled above the long-term average. Costs to produce these crops have also increased, with substantial gains seen in fertilizer and land prices. However, the pace at which the price of the commodity has risen has outpaced the costs associated with growing the crops; therefore farmers have seen their profits for these particular commodities increase.

From 2005-2008 the mean result from corn and soybean production was profitable. However, the median result from the production of these commodities resulted in a loss, suggesting that while some producers did very well, most actually lost money on the production of commodities over this time without the aid of insurance. Conversely, in the 2009-2011 time period both the mean and median profit were positive over the study space, suggesting that the majority of farmers turned a profit on their operations. We feel that the findings from the analysis of the 2005-2011 time period concerning the implementation of crop insurance indemnity payments are of exceptional value. Post-insurance profitability showed that there are certain inefficiencies present in the system. Many counties experienced a change from loss to profit and even more counties, which were already financially solvent, experienced an increased revenue stream through the inclusion of insurance indemnity payments. Additionally, our findings surrounding the comparison of switchgrass and commodity crop profitability highlight the wide gap between current commodity crop economics and where biomass feedstock economics will need to be trending toward in the very near future if biomass crops are to become a prominent part of the agricultural landscape. It is our hope that this study will shed light on the recent financial history for two of the most dominant commodity crops on the American landscape and the areas of the federal crop insurance system where there may be room to improve fiscal efficiency.

Chapter 4

Economic assessment of solar and conventional biomass gasification technologies: financial and policy implications under feedstock and product gas price uncertainty.

Abstract

Four configurations of a novel solar-heated biomass gasification facility and one configuration of conventional biomass gasification are analyzed through financial and policy scenarios. The purpose of this study is to determine the potential financial position for varying configurations of a novel technology, as compared to the current state-of-the-art gasification technology. Through the use of project finance and policy scenario development, we assess the baseline breakeven syngas price (normalized against natural gas prices and based upon annual feedstock consumption), the sensitivity of major cost components for the novel facilities, and the implications of policy levers on the economic feasibility of the solar facilities. Findings show that certain solar configurations may compete with conventional facilities on a straightforward economic basis. However, with renewable energy policy levers in place the solar technologies become increasingly attractive options.

4.1 Introduction

4.1.1 Overview

There is an ever growing push away from fossil fuels as an energy source. Cleaner, energy sources are being discussed, researched, developed, and employed on a global scale. These technologies range from more nascent renewable technologies, including concentrating solar thermal systems such as the solar gasification process discussed here, to improvements in the efficiency and emissions of conventional power generation methods. The developments underway are aimed at creating new energy systems that do not contribute to environmental degradation and climate change. By instituting new, clean, renewable technologies, the impact from human activity on the environment can be greatly reduced.

This paper reports results from an economic analysis of conventional and renewable technologies that create gaseous fuel from solid biomass through the process of gasification. Energy generation through gasification of sustainably grown and harvested biomass is one approach to displace fossil fuels. Specifically, we calculate economic scenarios of a conventional, internally-heated, biomass gasification system and variations of a biomass gasification system that is heated from an external source, solar radiation. The results provide information on the economic promise of a solar gasification technology with respect to how it compares to state-of-the-art gasification methods under current economic conditions. In addition, this study examines which variables have the most impact on the profitability of the technologies and possible policy levers and incentives that could be employed to promote development. By elucidating these limiting factors, it is possible to address how to move forward in developing alternative energy technologies which are more economically viable and competitive in a global energy economy.

Conventional biomass gasification is the incomplete combustion of biomass materials in a high-temperature, oxygen-limited environment. This incomplete combustion allows for a higher yield of energy [via gas] from the biomass than conventional combustion of biomass for steam production.[82] Gasification adds value to low- or negative-value feedstock by converting it into potentially marketable fuels and products.

The product created and collected during the gasification process is commonly referred to as synthesis gas (syngas). Syngas can be used in a variety of applications including: direct combustion for heat, synthesis of fuels and chemicals, and direct combustion for electricity generation, among others.[83] Currently, a majority of biomass gasification systems are used to generate heat and electricity for their internal operations.[84] The high level of flexibility which syngas displays is a major reason why it is a desirable energy option. However, creating power and fuel generation facilities require large amounts of capital investment. These technologies must be financially solvent enough to generate revenues above and beyond the breakeven level to ensure stable and sustainable operation over the life-span of the facility. Facilities must be built substantially enough to be able to produce energy for the generation of excess revenue beyond covering construction and operating costs.

4.1.2 Technology Overview

Five simulated biomass gasification facilities are developed for economic assessment: a conventional fluidized bed gasifier and four variations of a solar-heated gasification system. The conventional approach to biomass gasification involves carrying out the chemical reactions under conditions that consume biomass feedstock in combustion as a heat source. Supplying sufficient energy to achieve conventional gasification requires that 20 to 30% of the feedstock be combusted within the gasifier to generate the heat necessary to drive the gasification reactions. This partial combustion limits the product yield, dilutes the gas with combustion byproducts, and often requires a dedicated oxygen facility.[85]

Allothermal biomass gasification processes utilize different conditions, where heat is supplied by carrying out combustion of a portion of the feedstock or product gas in an external reactor. This approach avoids dilution of the product stream and the need for an oxygen facility. However, the gas yield per unit feedstock is still limited due to consumption of a portion of the feedstock or product gas to drive the biomass gasification reactions.[86] An alternative to consuming the feedstock or product gas is the use of concentrated solar energy as the source of process heat. The advantage of this method is that it uses heat from outside the gasifier and does not result in the consumption of feedstock or product gas. Not only are the byproducts of combustion eliminated and the costs associated with an oxygen plant avoided, but the available feedstock is conserved for upgrading into syngas.

The conventional fluidized bed system is commonly used in biomass gasification and its characteristics and economics have been thoroughly studied.[82,87] The new technologies assessed are variations of an externally-heated solar gasification reactor technology which uses molten salts as the gasification medium.[88,89]

4.1.3 Solar Technology

4.1.3.1 Concentrated Solar Power

The solar-heated gasification facility generates its source heat through a concentrated solar power system. The solar radiation is concentrated by solar reflectors (heliostats). The solar concentrating facility includes a field of heliostats which reflect sunlight to a focal point at the top of the tower. The solar receiver/reactor is located either on the tower or optical mirrors are used to reflect the concentrated radiation downward to a reactor located at ground level. The new technology scenarios are variants of a solar-heated gasification system which differ by the amount of solar radiation collected and heat storage capacity as determined by the relative size of the molten salt containing portion of the reactor.[90,91] For each facility, the solar receiver/reactor collects the radiation, which in turn is absorbed by the cavity wall and transferred to the molten salt. The molten salt is maintained at temperatures near 1200K, which is conducive to gasifying biomass.[92]

4.1.3.2 Molten Salt Gasification

The solar energy maintains the salt mixture in the reactors at the desired operating temperature and supplies the energy required to drive the endothermic biomass gasification reactions. The salt of choice is a eutectic blend of carbonate salts ($Li_2CO_3/Na_2CO_3/K_2CO_3$). The melt temperature of the eutectic mixture is 673K. This carbonate salt mixture is also favored because it has corrosion resistant properties that can aid in prolonging the life of the facility, and has been shown to catalyze the gasification reactions.[89] After the injection of biomass into the molten salt, the product is collected for future use while the biomass remnants (ash, sulfur) remains in solution until the salt cleaning mechanisms remove it from the slurry.[91] For the scenarios discussed in this study, the reactor design was varied in two ways. The diameter of the aperture is varied depending on the nominal solar power configuration of the facility; a larger aperture being used for a higher nominal solar power. The relative outer diameter of an annular region used for salt storage is varied to achieve either a high or low heat storage capacity configuration.

4.1.3.3 Solar-Heated Gasification Configurations

In the present work, two solar concentration configurations are investigated. The nominal amount of solar radiation collected is primarily a result of differing solar array configurations: ‘High Solar’ (HS) and ‘Low Solar’ (LS), 250,000m^2 and 125,000m^2, respectively. For the same amount of annual biomass consumption, the HS case experiences no product gas hybridization, defined by the consumption of product gas for assisted heating, while the LS case will inherently require some degree of hybridization, due to a lower level of concentrated sunlight. The LS facility is smaller and a less costly capital investment; however the decrease in solar input requires more hybridization to supply the energy required to gasify the biomass material.

The other set of configurations address the volume of molten salt a facility contains. In one scenario, the facility contains a large enough volume of molten salt to maintain the required temperature necessary for continuous gasification, even in the absence of sunlight. In the other scenario, the facility contains only enough molten salt to act as a catalyst and heat-transfer medium for the gasification process, and during periods of insufficient sunlight to maintain operation, uses a portion of the produced syngas to maintain reactor temperatures and allow a minimum nominal rate of biomass gasification to take place. These two scenarios are named ‘High Capacity’ (HC) and ‘Low Capacity’ (LC), respectively.

While the LC consumes more of the product gas, the HC option has significantly greater capital costs due to larger salt volumes and necessary storage. Additionally, the HC system exhibits less process output variation due to the high thermal stability, while the LC system with less thermal mass would require the rate of feed consumption to vary along with the solar input. This difference is not reflected in total annual output, and as such is not further discussed in this study, but is an important consideration depending on the sensitivity of the downstream process.[88]

The combination of these configurations creates four different solar-heated gasification scenarios: High Solar, High Capacity (HSHC); High Solar, Low Capacity (HSLC), Low Solar, High Capacity (LSHC); and Low Solar, Low Capacity (LSLC). Table 4.1 summarizes the various features of the scenarios under consideration. While the economics of the current gasification reactor technology are well documented and understood, the solar technologies are in the development stage and only have tangential real-world examples against which to estimate values.[82,87,93] These scenarios allow for an analysis of current and prospective gasification technologies.

4.1.4 Conventional Technology

The circulating fluidized bed is a common conventional gasification system where the gases are passed through the inert particles and feedstock at a high velocity, pushing them to the top of the reactor. At the top, the particles are caught in a cyclone, where the product gas is extracted, and then particles are sent back into the reactor.[87] Table 4.1 includes the biomass consumption and synthesis gas production associated with the conventional gasification scenario.

Table 4.1 Biomass gasification facility configurations for the five scenarios under consideration.

	High Solar, High Capacity	High Solar, Low Capacity	Low Solar, High Capacity	Low Solar, Low Capacity	Conventional
Heliostat Field Area	250,000 m^2	250,000 m^2	125,000 m^2	125,000 m^2	-
Salt Mass	57,300 Mg	1,000 Mg	20,400 Mg	360 Mg	-
Annual Biomass Consumption	250,000 Mg				
Annual Syngas Production (Thousands)[1]	5,487,264 MJ	5,581,872 MJ	4,730,400 MJ	4,761,936 MJ	4,170,320 MJ

It should be noted that fluidized bed systems are typically the system of choice in modern biomass gasification. Fluidized bed gasification has advantages over older methods in certain situations. For example, they are much better for performing rapid reactions, yet yield medium-level tar amounts, and provides a uniform product gas.[87] However, like many other technologies, there are drawbacks to the circulating fluidized bed technology. An uneven temperature gradient may occur in the reactor; the velocity of the fuel particles is decided by their size, with smaller particles moving more quickly and possibly increasing the rate at which the reactor erodes; and the heat recuperation from the product gas is less efficient.[87]

4.1.5 Feedstock Pre-treatment

The natural condition of biomass feedstock is generally not applicable for gasification process and pretreatment is required. Before biomass can be used in a gasification reactor, it must be properly prepared. Usually this entails shredding or

[1] Calculated using LHV of 0.02195MJ Mg^{-1} for syngas

resizing the material into a more manageable size and lowering the moisture content through drying. The technologies needed to pretreat biomass feedstocks for gasification are not without significant cost. However, these costs can be somewhat mitigated by using gasification methods that can incorporate varying levels of feedstock quality.[87] In this study, switchgrass biomass (LHV: 0.02195 MJ Mg^{-1}) is assumed to be the feedstock used in gasification.[92]. However, in theory, all facilities are assumed to have the ability to process a variety of feedstock types, including wood, corn stover, and municipal solid waste.

4.1.6 Syngas Cleaning

Depending on the properties of the feedstock and the gasification technology, gasification may or may not produce a low-tar syngas. In the event that the syngas is no- or low-tar, it can be used directly in turbine and synthesis applications. However, if the product contains tar, it must be cleaned before use. Gas cleaning technologies help remove materials like: trace metals, particulate matter, heavy hydrocarbons, and mercury.[94]

Syngas cleaning usually occurs in two forms, scrubbing and catalytically cracking. Scrubbing is the more common method for syngas cleaning. However, scrubbing comes with large process inefficiency. During the scrubbing process, the gas is cooled and a hydrocarbon waste stream is generated. These actions lead to a lower quantity and lower quality of syngas than a cracked alternative. Catalytically cracking the hydrocarbons in the syngas does not generate a waste stream, as the heavy hydrocarbons are broken into light hydrocarbons, or syngas. Additionally, cracking the heavy hydrocarbons does not result in heat loss, unlike scrubbing. Heat loss from syngas scrubbing is a negative effect because the excess heat cannot be recovered and used, usually to create steam for a separate process.[87]

The gas generated from the conventional system in this study is assumed to need cleaning before it is acceptable for sale. To combat the particulates, sulfur, and tar that are generated during gasification, the conventional system is fitted with a ceramic candle filter and a wet scrubber. The solar gasification systems produce a cleaner product gas and therefore do not require a wet scrubber to remove tars and sulfur.[91] However, there are fine particulates that may be released, so a ceramic candle filter is required to mitigate those pollutants.

4.2 Materials and Methods

4.2.1 Economic Modeling

As a part of the economic analysis, a model for the scenario facilities previously listed in Table 1 was created to estimate costs of materials and construction. Table 4.2 presents assumptions used in the construction of scenario facilities and financial analyses.

Table 4.2 Data constraints and assumptions for the economic analysis of solar-heated and conventional fluidized-bed gasification facilities. All dollar values are expressed in real 2012 terms.

Variable Costs		Fixed Costs	
Tax rate	40%[2]	Li_2CO_3	$7800/Mg[3]
After-tax Cost of Capital	4.1%[4]	K_2CO_3	$1175/Mg[5]
Inflation Rate	3%[6]	Na_2CO_3	$230/Mg[7]
Depreciation Life	5 years[8]	Inconel 600	$2425/Mg[9]
Depreciation Schedule	MACRS GDS[10]	General Fees	10%[11]
Bond Length	30 years[12]	Engineering	15%
Bond Yield	6.9%[13]	Contingencies	15%
O&M	3.5%[14]	Installation	15%
		Piping	45%
		Instrumentation	10%
		Building and Structure	10%
		Auxiliary	25%
		Outside Line	10%
		Down Payment	0%[15]
		Biomass	$40.82/Mg[16]

Masses of the materials needed for the novel technology reactors were determined from personal communications with the developers of the technology and available literature.[90,92] Costs for the solar collection devices were obtained from industry reports.[95] The material costs for the novel technologies were gathered from various industrial purchase sources.[96–99] Because the solar technology is still in its infancy, the size of the components and volumes of materials needed are based on calculations and not realized

[2] Deloitte, 2012
[3] Nanjing Stable Trading Co., 2013
[4] $C_{AT} = Y_{\mathbf{B}} \times (1-R_T)$ where C_{AT} is the after-tax cost, Y_B is the bond yield, and R_T is the tax rate.
[5] Luancheng Terife Agricultural Materials, 2013
[6] Based on the historical average US inflation rate, rounded to the nearest integer.
[7] Oceanking Group Inc., 2013
[8] Internal Revenue Servive, 2013
[9] Shanghai Yikai Metal Products Ltd., 2013
[10] Internal Revenue Servive, 2013
[11] $C_{auxn} = C_D \times R_{auxn}$ where C_{auxn} is the cost of auxiliary 'n', C_D is the cost of direct materials, and R_{auxn} is the percent of direct material cost to be multiplied by direct material cost.
[12] Based on corporate length for large-scale investments
[13] 2012 yield for Bank of America/Merrill Lynch Corporate 'B' rated bond
[14] Mitchell, 2006
[15] No upfront payments, all costs are spread across life of bond.
[16] Keeler et al., 2013

results. The solar receiver/reactor systems considered here are geometrically similar to that presented in a previously published study on reactor scale-up, though at a smaller scale nominal solar power.[91] Similar calculations are used to determine component sizes for this study. The solar costs were compared to similar, albeit different, solar heated gasification facilities and the systems were comparable in most aspects.[100,101] The conventional system materials and costs were acquired from government agency reports and then adjusted to 2012 dollar values.[82,87] In addition to direct costs for materials, there are also direct and indirect costs for development, construction, and auxiliary components. These values were calculated from construction and development cost factors.[82] These amounts were based on a percentage of total material costs for the facilities. The calculated costs for all components used in this analysis are displayed in Table 4.3. Additionally, all costs and prices for materials, feedstocks, fuels, and any other items are expressed in real 2012 U.S. dollars. This method is used because it allows for a uniform comparison of values. The conversions are calculated using the Individual Year Conversion Factors from Oregon State University.[41]

Table 4.3 Estimated component costs for the different technologies assessed in the study. All values in real 2012 US dollars (thousands).

		High Solar, High Capacity	High Solar, Low Capacity	Low Solar, High Capacity	Low Solar, Low Capacity	Conventional
Optics	*Heliostats*[17]	$29,070	$29,070	$14,535	$14,535	-
	Tower[18]	$1,327	$1,327	$1,327	$1,327	-
Gasification	*Gasifier*[19]	$6,487	$4,705	$3,153	$2,374	$23,130
	Molten Salt Li_2CO_3 Na_2CO_3 K_2CO_3	$170,875	$3,013	$60,856	$1,077	-
	Salt Cleaning and Storage[20]	$60,000	-	$60,000	-	-
	Air Separation[21]	-	-	-	-	$3,470
Post Processing[22]	*Ceramic Filter*	$4,745	$4,745	$4,745	$4,745	$4,745
	Wet Scrubber					154
Direct Capital Expenditures		$101,628	$39,846	$83,759	$22,981	$31,499
Indirect Capital Expenditures[23]		$157,524	$61,761	$129,827	$35,620	$48,823
Total Capital Expenditures		$259,152	$101,607	$213,586	$58,601	$80,322
Total Capital Expenditures w/ Salt		$430,027	$104,620	$274,442	$59,678	$80,322
Land Costs[24][25]		$4,300	$4,300	$4,300	$4,300	$65
Total Plant Capital Costs		$434,327	$108,920	$278,742	$63,978	$216,824
Operations and Maintenance	*O & M*[26][27]	$9,070	$3,556	$7,475	$2,051	$2,996
Annual Biomass Cost[28]		$11,250	$11,250	$11,250	$11,250	$11,250

[17] Blackmon, 2013
[18] Sandia National Laboratories, 2011
[19] Conventional technology is high pressure gasifier, aero derivative gas turbine (50.3MWe) from Craig and Mann, 1996
[20] Biello, 2009
[21] National Energy Technology Laboratory, 2014a
[22] National Energy Technology Laboratory, 2014b
[23] Craig and Mann, 1996
[24] Land and Farm, 2013a
[25] Land and Farm, 2013b
[26] 3.5% of installed costs
[27] Mitchell, 2006
[28] Keeler et al., 2013

The technologies in this study are subject to the same economic assumptions. The constants that are used are: a 30-year bond length, 6.9% bond yield, 3% annual inflation rate, marginal corporate-tax rate of 40%, 4.1% after-tax cost of capital, and zero upfront payments for the sake of assessing the full cost of construction and capital. These constants are applied to all technologies and scenarios. The bond yield and term variables were used to determine the financing expenses for which the facility will be subject. The bond yield and term were determined from the 2012 Bank of America/Merrill Lynch 'B' rated corporate bond.[102] A 'B' rating represents the highest non-investment grade for an operation, meaning it is more risky than investment grade firms but default is not near-term. The annual inflation rate accounts for the time-value of money and the idea that current dollars are worth more than future dollars. Additionally, all systems are subject to the same tax and depreciation constraints.

The United States corporate income tax rate is currently 40%.[103] This rate is used as the baseline tax burden on revenues. The after-tax cost of capital, or the interest rate charged to a facility for after-tax debt, is 4.1%. This value is derived from the yield for the bond and the corporate tax rate using the equation $C_{at} = Y_b * (1-R_t)$ where C_{at} is the after-tax cost of capital, Y_b is the bond yield, and R_t is the corporate tax rate. The facilities are subject to a 5-year modified accelerated cost recovery system (MACRS) depreciation scale. The MACRS is the current method of calculating depreciation by the Internal Revenue Service. The 5-year MACRS timeframe was chosen because these facilities fall into the solar-thermal and combined heat and power classifications [104]. Syngas prices were calculated on a per gigajoule (GJ) basis, comparable to current and recent historic natural gas prices. A per GJ price was used to normalize value between high energy-by-volume natural gas and a much lower energy-by-volume syngas product.

Once the constraints and assumptions were determined, the gasification technology scenarios were analyzed and were solved for the breakeven price of syngas. We used a GJ normalized natural gas price as a proxy, as syngas is not a widely traded commodity. We chose this method for determining natural gas price because the success of these facilities hinge on the profitability of the operations. We felt that knowing what the required natural gas prices would need to be to allow these facilities to breakeven allows for a greater understanding of what economic climate is necessary for these projects to move forward.

Natural gas pricing was used as a proxy for syngas production in this analysis because the final use of the product syngas is undetermined. Syngas has many potential uses, not limited to electricity generation, conversion to liquid fuel, heating, and fertilizer creation.[105] Natural gas can also be used in all of these applications. Through the normalization of syngas and natural gas on an energy equivalent basis we are able to determine under what natural gas pricing climates these technologies may be able to exist.

This was done using standard project finance methods for calculating cash flow, tax burden, loan payments, depreciation, and financial feasibility. Financial feasibility was the metric used to determine the breakeven price because it takes into account all costs and revenues that a facility is subject to over its lifespan. Determining the breakeven price of syngas illustrates the price of natural gas, under each technology scenario, where the project yields a net zero profit/loss value over the life of the facility. Any gas price below this value, all else constant, would result in a facility that loses money over its life. Conversely, an average natural gas price higher than the breakeven price would result in a facility that is profitable over time.

After evaluating the changes to the baseline scenarios, we examine how the solar gasification baseline scenarios are affected by subsidies and incentives. The conventional system was excluded from the incentive analysis because these facilities are already in existence and the goal of this study is to assess the economic potential for the novel technologies. For the solar facilities, we assess three possible subsidy/incentive options. These three options are a subsidized federal bond, modeled after the Clean Renewable Energy Bond program through the Department of Energy, which provides a lower yield than the traditional 'B' rated corporate bond, a syngas production subsidy that simulated a 5% or 0.236$ GJ^{-1} natural gas equivalent increase the 2012 annual average wellhead price, modified from the Renewable Electricity Production Tax Credit through the Internal Revenue Service, and a 30% corporate tax credit under the Energy Improvement and Extension Act of 2008.[106–108]

In the case of the lower yield bond, the yield required is reduced from 6.9% over 30 years to 4.5% paid over 21 years, as occurs under the bond program. This incentive helps to lower fixed costs over the lifespan of the facility. The 0.236$ GJ^{-1} subsidy was enacted to simulate other production-based policies that have existed for other renewable energies.[109] This production credit is intended to provide a financial bonus to producers of renewable fuels. Finally, the 30% corporate tax reduction allows the facility to pay a

28% tax on earnings, as opposed to the federally mandated 40%. This credit allows the facility to keep more of its earnings. However, as an unintended side-effect, it raises the after-tax cost of capital from 4.1% to 5.0%.

4.3 Results and Discussion

4.3.1 Economic Overview

The results from the economic analysis for the four solar gasification systems and the conventional system all show promise under different economic climates. The breakeven values for these facilities are all within the range of observed natural gas prices over the past decade and some could possibly compete with historically low, recent natural gas prices with the inclusion of subsidies or incentives. The systems, as configured, would breakeven at the following natural gas prices: HSHC, 10.33\$ GJ^{-1}; HSLC, 4.55\$ GJ^{-1}; LSHC, 8.45\$ GJ^{-1}; LSLC, 3.83\$ GJ^{-1}; and Conventional, 7.36\$ GJ^{-1}. The average wellhead natural gas price for 2012 in the United States was 2.24\$ GJ^{-1} [107]. On one hand, the HSLC and LSLC systems are relatively close to the 2012 U.S. natural gas price and a combination of market-driven increases in natural gas prices and the use of policy incentives could make these facilities more attractive to investors. On the other hand, the two facilities that require high capacity salt storage (HSHC, LSHC) are currently prohibitively expensive and it is unlikely that policy incentives and slight increases in natural gas prices would do much to alter this.

While this study is United States focused, it is important to address the potential for these technologies outside the country. Providing a global perspective, 2012 average natural gas prices in Japan were 18.08\$ GJ^{-1}, 10.45\$ GJ^{-1} in Germany, and 8.97\$ GJ^{-1} in the United Kingdom.[110] These countries do not produce significant amounts of their own natural gas and are required to reply on imports to meet most, if not all, of their demand. Based on these international prices, and assuming comparable capital and operating costs in other regions, all solar technology configurations may be competitive without incentives in both Japan and Germany. All technology variants besides the HSHC configuration would be feasible in the UK. Further analysis is needed to determine the impact of policy initiatives on economic feasibility, if the assumption of equal costs is valid, and the solar threshold for operation is met; however at first glance the realization of this technology being adopted outside of the United States is promising.

Conventional systems, which are currently in operation, have two distinct differences in their operations from how these solar facilities are modeled. First, many of them were built before the significant decrease in natural gas prices, making the only alternatives in the new era of low-priced natural gas either closing the plant or operating on decreased or negative margins. Second, many conventional systems have dual purposes. In addition to providing energy, they are typically located next to a partner industrial/commercial facility and provide process heat to those facilities as well. The heat supply is an added benefit to the partner facility that is likely to be less valuable in areas of sufficient solar radiation, such as Arizona.

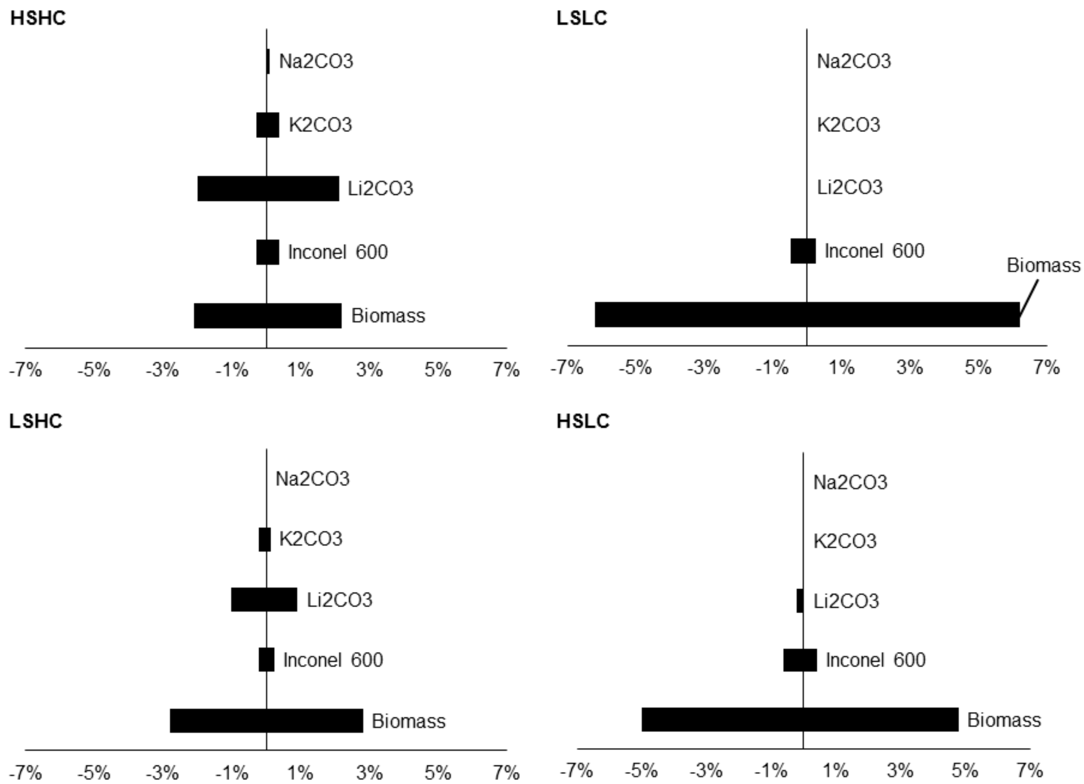
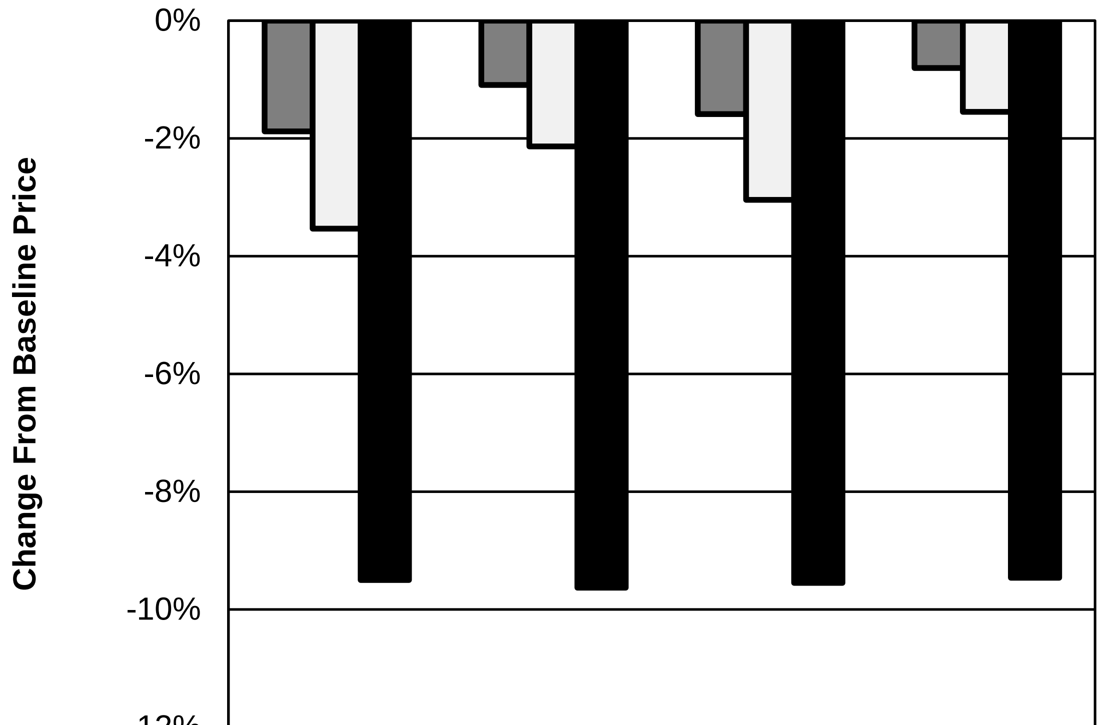


Figure 4.1 The change in baseline breakeven price of syngas from the baseline from a positive or negative 10% change in individual cost variables, with all other variables held constant. Clockwise from upper left: (a) HSHC, (b) HSLC, (c) LSHC, (d) LSLC

In addition to estimating a breakeven gas price, we also assess the sensitivity of the independent cost variables for the four solar technologies. The conventional system was removed from this analysis because the individual material costs for the facility was not known, as they were embedded in available costs reports.[82] Fig. 4.1 highlights the results of the sensitivity analysis. In all cases, the price of biomass had the biggest effect on the resulting price of natural gas necessary to break even. The salt Li_2CO_3 also had an effect on the overall price in scenarios that required salt storage. Beyond those two variables, no change in cost resulted in more than a 1% change to the baseline gas price.

4.3.2 Policy Scenarios

We apply three policy levers to the solar technologies to our assessment to simulate the potential impact of government incentives on the economic performance of solar biomass gasification. These come in the form of tax credits, bond yield reduction, and a price subsidy that help ease the total cost burden or provide additional revenue. The examples used in this study are not exhaustive and other methods of subsidies and incentives used in renewable energy projects may include: capital subsidies, investment tax credits, and biofuel volume mandates. Our results, however, provide a glimpse into the effects of reasonable policy mechanisms aimed at stimulating alternative energy generation.



	HSHC	HSLC	LSHC	LSLC
Tax Credit	-1.9%	-1.1%	-1.6%	-0.8%
CREB	-3.5%	-2.1%	-3.0%	-1.5%
NG Subsidy	-9.5%	-9.6%	-9.5%	-9.5%

Figure 4.2 The tax credit, bond yield, and product subsidy policy levers employed and their effective change on the baseline level of natural gas price necessary to reach a net zero financial feasibility. Example: applying the tax credit to the HSHC facility results in a 1.89% decrease in the price of natural gas necessary to break even over the life of the facility.

Fig. 4.2 shows the impact from policy stimulants on the breakeven cost of natural gas. As expected, all facilities perform better than the baseline scenarios when incentives and subsidies are included. However, the non-product incentives (lowered bond yield and corporate tax credit) did not produce nearly the same effect as an increase in gas price. The 30% tax credit, which lowers the tax burden from 40% to 28%, has the smallest effect on the system. Across all technologies, its inclusion alters the breakeven natural gas price by less than 2%. The CREB produced only a marginally larger effect on the breakeven price. By decreasing the bond yield from 6.9% to 4.5%, this policy incentive reduces the breakeven gas price by 1.5% to 3.5% across technology scenarios. Both of these policies fall significantly short of the production subsidy. A 0.236$ GJ^{-1} equivalent increase in the sale price resulted in an approximately 9.5% decrease in the necessary gas price in all four scenarios. This policy is akin to the current Renewable Energy Production Tax Credit, in which the federal government pays producers $0.023 for each kWh generated through certain renewable sources.[111] Having an understanding of how potential policies can affect the economic perception of a technology is vital to determining whether the technology has viability in the marketplace.

4.3.3 Implications

The basis for this study is to assess the direct economic scenarios surrounding novel solar biomass gasification systems and how they compare to current state-of-the-art non-solar systems. We determined that, depending on the configuration, the novel technologies straddle the economic breakeven point of conventional gasification facilities. Additionally, all solar facilities exhibit a breakeven point less than that of the highest natural gas prices seen in the past decade. Falling within the historical band of pricing is of importance because it highlights the fact that these technologies may have the ability to compete with natural gas. The Energy Information Administration suggests a steady increase in natural gas spot pricing over the coming two and a half decades. While the projections may not reach the all-time historic levels seen in the late 1990s, a more than three-time multiple of natural gas price by 2040 is within the projection bound.[112] At these levels, both LC systems necessary breakeven price would be less than the realized natural gas price, allowing them to be financially competitive without policy intervention. Moreover, it should be reiterated that these projections are just that and that a wide-variety of factors could inhibit these projections from becoming a reality. These factors may include, but are not limited to, increased demand, tighter exploration regulation, and fossil fuel use restrictions.

Furthermore, existing policies (or realistic variants thereof) were modeled to assess how government support could bolster technological advancement. The use of these drivers helped bring the breakeven price closer to the current price of natural gas and through the potential combination of incentives and a slight change in the economics of natural gas production these facilities may become competitive in the near-term. However, direct costs are not the only factor that may play into the eventual inclusion of these technologies into the energy production sector.

Another unforeseen boon to alternative energy technologies may be the inclusion of environmental benefit and remediation pricing. Through the monetization of environmental externalities and the economic benefit of more efficient waste streams, it may be advantageous to investors to pursue these technologies. However, these economic levers are currently unused in the United States. Because of this, the indirect costs savings from environmental benefits of each technology are not factored into this model. The indirect economic benefits of energy produced from waste are a burgeoning topic and could help bolster the argument for low-input, high-value energy production, even in the face of steep economic constraints.

Finally, funding large capital projects is a substantial financial undertaking and characteristically involves many stakeholders and partners. Typically, large-scale alternative energy projects carry higher levels of risk. Risk can be a major driver of investment, with the potential of greater returns offsetting the threat of loss. However, limiting the uncertainty surrounding large capital projects may help spur investment in alternative energy. Future work examining the risk profiles associated with the volatility of feedstock and material costs or product prices could help shed light on potential barriers to financing for large-scale biomass gasification facilities.

4.4 Conclusion

On a purely economic level, the solar technologies modeled are a viable option in certain situations. We find that the necessary breakeven prices for the solar technologies range from 10.33\$ GJ^{-1} to 3.83\$ GJ^{-1}. These prices are above the 2012 natural gas price in the United States, but fall within the range of other countries' natural gas prices. Therefore, they currently do not compete in a market-based system on price alone in the United States. Nevertheless, based on the necessary breakeven price and the realized natural gas prices in other nations, they may be feasible in other locations without subsidization.

To become competitive in the United States, it is likely that pro-renewable policies and changes in natural gas economics will be necessary to bring these facilities to fruition. In assessing three potential policy levers: a tax rate reduction, a bond yield and duration reduction, and a production credit, we find that all policies help reduce the costs associated with the technologies but the production credit results in the largest reduction in total cost. The tax rate reduction, which is based on the operating costs and revenue, resulted in an overall reduction of 0.8% to 1.9% of the breakeven price across all technologies. The bond yield and duration reduction, which is based on the fixed capital costs, resulted in a reduction of 1.5% to 3.5% of the breakeven price across all technologies. Finally, the production credit, which is based on the amount of gas produced, resulted in a reduction of 9.5 to 9.6% of the breakeven price across all technologies. Based on these findings, it is recommended that a production credit policy be used to incent the development of these technologies. If possible, it would be best to couple the production credit policy with other policy methods to maximize the cost savings and further reduce the necessary breakeven price for the technologies.

There are many components throughout a biomass gasification system and each carries a different monetary burden. The physical structures require capital to design and build, and annual funds to operate and maintain. Refining the system, making them more economically efficient, and instituting policy incentives would provide a solid base for the economic viability of these technologies.

Chapter 5

Conclusion

5.1 Overview

This dissertation aims to analyze the economic scenarios surrounding different aspects of bioenergy and agricultural production, as well as potential use methods for bioenergy feedstocks. By further advancing the conversations around biomass feedstock economic potential, the recent history of commodity crops and the impact crop insurance can have on production economics, and the potential for new processing technologies, these studies aim to contribute meaningful analysis and knowledge to the bioenergy and agricultural literature.

5.2 Switchgrass Economics

In Chapter 2 it was found that switchgrass production costs vary widely across the study space. Production costs range from \$1717 ha^{-1} for cropland grown switchgrass in Illinois to \$285 Mg^{-1} for pastureland grown switchgrass in North Dakota. It was also discovered that yields differ across space. In more northern regions it was found that yields are lower whereas yields in the southern states see increased biomass ($Mg\ ha^{-1}$). It is important to assess all factors of production when analyzing financial feasibility. On one hand, locations with the lowest costs are not necessarily the most optimal place to produce biomass. On the other hand, states with higher costs are not necessarily unfavorable. Combining cost, yield, and price together paints more realistic picture of where switchgrass may have potential on the landscape. Doing so calculates the profit or loss that a producer may see which ultimately drives production more than costs or prices alone.

This study also addresses the technological improvements that could assist biomass feedstocks in becoming a more substantial part of the transportation fuel system. Current conversion efficiencies of feedstock to ethanol are approximately 300 to 375 L Mg^{-1}. Through this analysis we show that it is likely that as conversion efficiencies increase, the proportion of ethanol production costs associated with feedstock production costs will diminish. This would suggest that as conversion efficiency increases, the spatial location of switchgrass production would matter less and could create more clustered areas.

Finally, this study finds that switchgrass has the potential to become profitable when the commoditized biomass price is sufficiently high enough. In the case of cropland grown switchgrass, no states are profitable with biomass prices below \$75 Mg^{-1} and for pastureland grown switchgrass the price must be above \$50 Mg^{-1}. However, it should be noted that these prices do not ensure profitability in all cases. For instance, even when biomass prices are at \$150 Mg^{-1}, switchgrass grown on cropland in Nebraska fails to become profitable. Additionally, it was discovered that some areas with higher costs, particularly those states located in the southern region, tended to be more profitable. Alternatively, states in the northern region that experienced lower costs were typically less profitable. This is likely due to the vast difference in yield that is seen across the regions. This analysis also addresses the potential economic trends of increased costs or decreased yields on physically marginal lands. The study finds that, across the nation, both a 25% increase in costs and a 25% decrease in yield result in a 45% reduction in profitability. Additionally, when a 25% increase in costs and a 25% decrease in yield are experienced together, a 150% reduction in profitability is seen. This assessment was done with a \$100 Mg^{-1} biomass price because all states were profitable at this price in a baseline analysis. However, when assessing the combination of increased costs and decreased yields the net profit is negative.

5.3 Commodity Crop Economics

Chapter 3 addresses the recent economic history of corn and soy production, the impact of crop insurance on profitability, the spatial locations and intensities of potential crop insurance indemnity payment inefficiencies, and the comparison of commodity crop and switchgrass profitability. The aim of this chapter is to analyze the economic role of commodity crop production in the United States and how the current commodity crop structure may or may not hinder the widespread production of biomass crops on the landscape.

It was found that between the 2005-2008 and 2009-2011 time periods that both production costs and returns increased. However, returns to producers outpaced cost increases between the two time periods. This increase resulted in 13% increases in profit margin for both corn and soybean. These increases would indicate that commodity crop financials became stronger over this time period and it would increase the difficulty of displacing these crops.

When crop insurance indemnities were overlaid on the commodity crop financial data, it was shown that profitability increased. Nevertheless, further research is needed to determine whether or not the increase in profitability resulted in a statistically significant change or not. Potential inefficiencies in the system were also analyzed at the county level; both the change from loss-to-profit after indemnity payments or additional profit seen in financially solvent counties. In this work it was found that 49% of soybean producing counties experience and inefficiency in at least one year and 41% of corn producing counties experience inefficiency in at least one year. Additionally, it was concluded that the majority of inefficiencies experienced between the time periods saw a change. From 2005-2008 the majority of inefficiencies experienced were of the loss-to-profit variety. Conversely, from 2009-2011 the majority of inefficiencies seen were additional profits to financially solvent counties. More research is needed to determine why this is the case.

Lastly, the profitability of corn and soy in 2011 were compared to the switchgrass profitability results from Chapter 2. This was done to assess how switchgrass may compare to the two most dominant crops in American agriculture. First, national averages of corn and soybean were compared to the national average switchgrass profitability at a variety of biomass price points. It was found that switchgrass does not begin to displace soybean until biomass prices are above \$75 Mg^{-1} and switchgrass does not begin to displace corn until biomass prices are above \$100 Mg^{-1}. These values far exceed the federal agency suggested necessary biomass price of \$41 Mg^{-1} to ensure sufficient volumes to reach RFS2 goals. After national assessments were complete, state level analysis was done to assess which states see commodity crops as the better economic choice and which states may see switchgrass (at the necessary biomass price) as the better economic choice. The biomass prices assessed in this portion of the study are one- to five-time multiples of the federal agency estimated price (\$41 Mg^{-1}). It was found that at some multiple of the necessary biomass price, most states became more profitable for switchgrass than commodity crops on both land types. However, Nebraska remained more profitable for commodity crops in all cases, Iowa was more profitable for corn production in all cases and more profitable for soybean production on cropland, and Minnesota was more profitable for corn on cropland in all cases. Conversely, Mississippi switchgrass was more profitable than corn on both land types and Oklahoma was more profitable, as compared to corn, for pastureland grown switchgrass.

5.4 Solar Gasification

Chapter 4 assesses the financial feasibility of four variants of a nascent solar-heated biomass gasification technology. These variants are compared against a state-of-the-art conventional biomass gasification system and the feasibility is tested against an energy equivalent natural gas price to determine at what natural gas price would these facilities break even and cover their costs.

It was found that there is a wide range of necessary breakeven natural gas prices, from 10.33\$ GJ^{-1} to 3.83\$ GJ^{-1}. As a reference point, the 2012 natural gas price was 2.24\$ GJ^{-1}. A reduction in the necessary breakeven price was realized when the application of policy levers were employed. However, the greatest reduction seen in breakeven price was approximately 10%, which would still result in a breakeven price above the 2012 natural gas price. These facilities have promise, and through the combination of policy incentives and rising natural gas prices, it may be feasible for these technologies to come online in the future.

5.5 Conclusions

This study aims to encapsulate the potential for meeting federal bioenergy goals through the economic analysis of a biomass feedstock crop, the hindrances that bioenergy crops may face when competing with current commodity crops, inefficiencies on the upper and lower ends of the crop insurance indemnity program, and the financial feasibility of nascent biomass gasification facilities. All of these study components work together to help expand the conversation surrounding biomass feedstock production and the utilization of that feedstock.

By addressing the economics of feedstock production it is possible to see the circumstances in which biomass crops become a profitable undertaking for producers on differing land types. Looking at the recent economic history of commodity crops sheds light on the current state of agricultural production and the hurdles that new crops may need to overcome when trying to gain space on the landscape. Analyzing the crop insurance program and assessing areas where producers may be continually seeing additional or favorable subsidized payments delves further into the assessment of hurdles that biomass crops, which are not privy to such insurance programs, need to overcome. And finally, by investigating the financial feasibility of biomass utilization technologies, the use of the produced crops can be examined and the ability to evaluate more of the biofuel generation life-cycle is possible. All together, these analyses provide near-term assessment for the possibility of biomass for bioenergy.

Bibliography

(1) Wullschleger, S. D.; Davis, E. B.; Borsuk, M. E.; Gunderson, C. a.; Lynd, L. R. Biomass Production in Switchgrass across the United States: Database Description and Determinants of Yield. *Agron. J.* **2010**, *102*, 1158.

(2) Sanderson, M. A.; Adler, P. R.; Boateng, A. A.; Casler, M. D.; Sarath, G. Switchgrass as a biofuels feedstock in the USA. *Can. J. Plant Sci.* **2006**, *86*, 1315–1325.

(3) Keeler, B. L.; Krohn, B. J.; Nickerson, T. A.; Hill, J. D. U.S. Federal Agency Models Offer Different Visions for Achieving Renewable Fuel Standard (RFS2) Biofuel Volumes. *Environ. Sci. Technol.* **2013**, *47*, 10095–10101.

(4) U.S. Department of Energy. *US Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry*; Oak Ridge, TN, 2011; pp. 1–229.

(5) Tilman, D.; Hill, J.; Lehman, C. Carbon-negative biofuels from low-input high-diversity grassland biomass. *Science* **2006**, *314*, 1598–1600.

(6) Fike, J. H.; Parrish, D. J.; Wolf, D. D.; Balasko, J. a.; Green, J. T.; Rasnake, M.; Reynolds, J. H. Switchgrass production for the upper southeastern USA: Influence of cultivar and cutting frequency on biomass yields. *Biomass and Bioenergy* **2006**, *30*, 207–213.

(7) Walsh, M. U.S . Bioenergy Crop Economic Analyses: Status and Needs. *Biomass and Bioenergy* **1998**, *14*, 341–350.

(8) Schmer, M. R.; Vogel, K. P.; Mitchell, R. B.; Perrin, R. K. Net energy of cellulosic ethanol from switchgrass. *Proc. Natl. Acad. Sci. U. S. A.* **2008**, *105*, 464–469.

(9) Schmer, M. R.; Vogel, K. P.; Mitchell, R. B.; Moser, L. E.; Eskridge, K. M.; Perrin, R. K. Establishment Stand Thresholds for Switchgrass Grown as a Bioenergy Crop. *Crop Sci.* **2005**, *46*, 157.

(10) McLaughlin, S. B.; Adams Kszos, L. Development of switchgrass (Panicum virgatum) as a bioenergy feedstock in the United States. *Biomass Bioenergy* **2005**, *28*, 515–535.

(11) McLaughlin, S. B.; Kiniry, J. R.; Taliaferro, C. M.; De La Torre Ugarte, D. Projecting Yield and Utilization Potential of Switchgrass as an Energy Crop. *Adv. Agron.* **2006**, *90*, 267–295.

(12) Khanna, M.; Dhungana, B.; Clifton-Brown, J. Costs of producing Miscanthus and switchgrass for bioenergy in Illinois. *Biomass and Bioenergy* **2008**, *32*, 482–493.

(13) James, L. K.; Swinton, S. M.; Thelen, K. D. Profitability Analysis of Cellulosic Energy Crops Compared with Corn. *Agron. J.* **2010**, *102*, 675.

(14) Swinton, S. M.; Babcock, B. A.; James, L. K.; Bandaru, V. Higher US crop prices trigger little area expansion so marginal land for biofuel crops is limited. *Energy Policy* **2011**, *39*, 5254–5258.

(15) Claassen, R. *The Future of Environmental Compliance Incentives in U.S. Agriculture: The Role of Commodity, Conservation, and Crop Insurance Programs*; 2012; pp. 1–18.

(16) Jordan, N.; Warner, K. Enhancing the multifunctionality of US agriculture. *Bioscience* **2010**, *60*, 60–66.

(17) National Research Council. *Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy*; National Academies Press: Washington, D.C., 2011; p. 394.

(18) Kelsey, K. D.; Franke, T. C. The Producers’ Stake in the Bioeconomy : A Survey of Oklahoma Producers ' Knowledge and Willingness to Grow Dedicated Biofuel Crops. *J. Ext.* **2009**, *47*, 1–6.

(19) Jensen, K.; Clark, C.; Ellis, P.; English, B.; Menard, J.; Walsh, M.; de la Torre Ugarte, D. Farmer willingness to grow switchgrass for energy production. *Biomass and Bioenergy* **2007**, *31*, 773–781.

(20) Haque, M.; Epplin, F. M. Switchgrass to Ethanol: A Field to Fuel Approach. In *Agricultural & Applied Economics Association Annual Meeting*; AAEA: Denver, CO, 2010; p. 24.

(21) Parish, E. S.; Hilliard, M. R.; Baskaran, L. M.; Dale, V. H.; Griffi, N. A.; Mulholland, P. J.; Sorokine, A.; Thomas, N. A.; Downing, M. E.; Middleton, R. S. Multimetric spatial optimization of switchgrass plantings across a watershed. *Biofuels, Bioprod. Biorefining* **2012**, *6*, 58–72.

(22) Heaton, E. A quantitative review comparing the yields of two candidate C4 perennial biomass crops in relation to nitrogen, temperature and water. *Biomass and Bioenergy* **2004**, *27*, 21–30.

(23) Lee, D. K.; Boe, a. Biomass Production of Switchgrass in Central South Dakota. *Crop Sci.* **2005**, *45*, 2583.

(24) Lemus, R.; Charles Brummer, E.; Lee Burras, C.; Moore, K. J.; Barker, M. F.; Molstad, N. E. Effects of nitrogen fertilization on biomass yield and quality in large fields of established switchgrass in southern Iowa, USA. *Biomass Bioenergy* **2008**, *32*, 1187–1194.

(25) Mooney, D. F.; Roberts, R. K.; English, B. C.; Tyler, D. D.; Larson, J. a. Yield and Breakeven Price of “Alamo” Switchgrass for Biofuels in Tennessee. *Agron. J.* **2009**, *101*, 1234.

(26) Perrin, R.; Vogel, K.; Schmer, M.; Mitchell, R. Farm-Scale Production Cost of Switchgrass for Biomass. *BioEnergy Res.* **2008**, *1*, 91–97.

(27) Popp, M. P. Assessment of Alternative Fuel Production from Switchgrass: An Example from Arkansas. *J. Agric. Appl. Econ.* **2007**, *39*, 373–380.

(28) Eberly, E. Switchgrass - Conventional Establishment http://pubs.ext.vt.edu/446/446-047/446-047.html.

(29) Green, J. T.; Benson, G. A. Switchgrass for Biomass, Establishment/Annual http://www.ag-econ.ncsu.edu/extension/forage_budgets.html.

(30) Extension, U. of T. *Guideline Switchgrass Establishment And Annual Production Budgets Over Three Year Planning Horizon*; Knoxville, TN, 2009; p. 15.

(31) Lazarus, W. F. *Minnesota Crop Cost & Return Guide for 2011*; St. Paul, MN, 2010; p. 13.

(32) Busby, D. P. The Cost of Producing Lignocellulosic Biomass for Ethanol, Mississippi State University, 2007, p. 115.

(33) Griffith, A. P.; Epplin, F. M.; Redfearn, D. D. *Cost of Producing Switchgrass for Biomass Feedstock*; Stillwater, OK, 2010; pp. 1–7.

(34) Holman, J.; Roberts, T.; Dumler, T.; Fick, W.; Gillen, R.; Harmoney, K.; Martin, K.; Maxwell, S.; Moyer, J. L.; Sloderbeck, P.; et al. *Kansas Switchgrass Production Handbook*; Manhattan, KS, 2011; p. 15.

(35) Duffy, M. *Estimated Costs for Production, Storage, and Transportation of Switchgrass*; Ames, IA, 2008; Vol. 1998, p. 8.

(36) Vadas, P. A.; Barnett, K. H.; Undersander, D. J. Economics and Energy of Ethanol Production from Alfalfa, Corn, and Switchgrass in the Upper Midwest, USA. *BioEnergy Res.* **2008**, *1*, 44–55.

(37) Sokhansanj, S.; Mani, S.; Turhollow, A.; Kumar, A.; Bransby, D.; Lynd, L.; Laser, M. Large-scale production, harvest and logistics of switchgrass (Panicum virgatum L .) – current technology and envisioning a mature technology. *Biofuels, Bioprod. Biorefining* **2009**, *3*, 124–141.

(38) Curtis, K. R.; Bishop, C. *Northwestern Nevada Switchgrass Establishment, Production Costs and Returns, 2008*; 2008.

(39) Painter, K.; Fransen, S. *2010 Cost & Returns for Irrigated Switchgrass Production under Center Pivot Irrigation Columbia Basin, Washington State*; 2010.

(40) Lazarus, W. F. Energy Crop Production Costs and Breakeven Prices Under Minnesota Conditions. *Staff Pap.* **2008**.

(41) Sahr, R. C. Consumer Price Index (CPI) Conversion Factors to Convert to 2011 Dollars Using the CPI-U-RS series, an experimental CPI measure http://oregonstate.edu/cla/polisci/sites/default/files/faculty-research/sahr/inflation-conversion/pdf/cv2010rs.pdf.

(42) USDA Economic Research Service. Fertilizer Use and Price http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx#26727 (accessed Apr 8, 2013).

(43) Iowa State University Extension. *Fertilizing Pasture*; Ames, IA, 1997.

(44) USDA National Agricultural Statistics Service. Quick Stats http://quickstats.nass.usda.gov/.

(45) Jiang, Y.; Swinton, S. Market interactions, farmers' choices, and the sustainability of growing advanced biofuels: a missing perspective? *Int. J. Sustain. Dev. World Ecol.* **2009**, *16*, 438–450.

(46) Langholtz, M.; Graham, R.; Eaton, L.; Perlack, R.; Hellwinkel, C.; De La Torre Ugarte, D. G. Price projections of feedstocks for biofuels and biopower in the U.S. *Energy Policy* **2012**, *41*, 484–493.

(47) Mehaffey, M.; Smith, E.; Van Remortel, R. Midwest U.S. landscape change to 2020 driven by biofuel mandates. *Ecol. Appl.* **2012**, *22*, 8–19.

(48) Fike, J. H.; Parrish, D. J.; Wolf, D. D.; Balasko, J. a.; Green, J. T.; Rasnake, M.; Reynolds, J. H. Long-term yield potential of switchgrass-for-biofuel systems. *Biomass and Bioenergy* **2006**, *30*, 198–206.

(49) Plantinga, A. J.; Lubowski, R. N.; Stavins, R. N. The effects of potential land development on agricultural land prices. *J. Urban Econ.* **2002**, *52*, 561–581.

(50) Hellerstein, D.; Malcolm, S. *The Influence of Rising Commodity Prices on the Conservation Reserve Program*; 2011; p. 44.

(51) Hausman, C.; Auffhammer, M.; Berck, P. Farm Acreage Shocks and Crop Prices: An SVAR Approach to Understanding the Impacts of Biofuels. *Environ. Resour. Econ.* **2012**, *53*, 117–136.

(52) Henderson, J.; Gloy, B. A. The impact of ethanol plants on cropland values in the great plains. *Agric. Financ. Rev.* **2009**, *69*, 36–48.

(53) Nickerson, C.; Morehart, M.; Kuethe, T.; Beckman, J.; Ifft, J.; Williams, R. *Trends in U.S. Farmland Values and Ownership*; 2012; p. 55.

(54) Chen, P.-Y.; Chang, C.-L.; Chen, C.-C.; McAleer, M. *Modelling the Effects of Oil Prices on Global Fertilizer Prices and Volatility*; Amsterdam, 2013; p. 38.

(55) Beaudry, P.; Green, D. A.; Sand, B. M. *How much is employment increased by cutting labor costs? Estimating the elasticity of job creation.*; 15790; Cambirdge, MA, 2010; p. 42.

(56) Brandt, C. M. Impact of the Bakken Oil Boom on Employment and Wages in North Dakota. *Undergrad. Econ. Rev.* **2014**, *10*, 14.

(57) U.S. Environmental Protection Agency. *Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis*; Washington, D.C., 2010; pp. 1–1107.

(58) USDA. *A USDA Regional Roadmap to Meeting the Biofuels Goals of the Renewable Fuels Standard by 2022*; Washington, D.C., 2010; pp. 1–21.

(59) Levey Larson, D. Switching to an energy crop: break even or make a profit? *Farm Industry News*. October 2012,.

(60) Perlack, R. D.; Wright, L. L.; Turhollow, A. F.; Graham, R.; Stokes, B. J.; Erbach, D. C. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*; Oak Ridge, TN, 2005; pp. 1–78.

(61) Timilsina, G. R.; Shrestha, A. How much hope should we have for biofuels? *Energy* **2011**, *36*, 2055–2069.

(62) USDA Farm Service Agency. BCAP Project Area Information http://www.fsa.usda.gov/FSA/webapp?area=home&subject=ener&topic=bcap-pjt (accessed Jun 25, 2013).

(63) USDA National Agricultural Statistics Service. *Acreages*; Washington, D.C., 2013.

(64) U.S. Environmental Protection Agency. Economic Overview http://www.epa.gov/oecaagct/ag101/printeconomics.html (accessed Jun 4, 2014).

(65) Zilberman, D.; Hochman, G.; Rajagopal, D.; Sexton, S.; Timilsina, G. The Impact of Biofuels on Commodity Food Prices: Assessment of Findings. *Am. J. Agric. Econ.* **2012**, *95*, 275–281.

(66) Mueller, S. a.; Anderson, J. E.; Wallington, T. J. Impact of biofuel production and other supply and demand factors on food price increases in 2008. *Biomass and Bioenergy* **2011**, *35*, 1623–1632.

(67) Runge, C. F.; Senauer, B. How Biofuels Could Starve the Poor. *Foreign Aff.* **2007**, *86*, 41–53.

(68) USDA Economic Research Service. *U.S. Domestic Corn Use*; 2013.

(69) U.S. Environmental Protection Agency. Major Crops Grown in the United States http://www.epa.gov/oecaagct/ag101/cropmajor.html (accessed Jan 9, 2014).

(70) Chakravorty, U.; Hubert, M.-H.; Nøstbakken, L. Fuel Versus Food. *Annu. Rev. Resour. Econ.* **2009**, *1*, 645–663.

(71) EIA. Spot Prices http://www.eia.gov/dnav/pet/pet_pri_spt_s1_a.htm (accessed Sep 28, 2012).

(72) Woodard, J. D.; Schnitkey, G. D.; Sherrick, B. J.; Lozano-Gracia, N.; Anselin, L. A Spatial Econometric Analysis of Loss Experience in the U.S. Crop Insurance Program. *J. Risk Insur.* **2012**, *79*, 261–286.

(73) USDA. About the Risk Management Agency, 2010, 2.

(74) Coble, K. H.; Barnett, B. J. Why do we subsidize crop insurance? *Am. J. Agric. Econ.* **2012**, *95*, 498–504.

(75) USDA. *2011 RMA Indemnities*; Washington, D.C., 2012; pp. 1–48.

(76) USDA Economic Research Service. Commodity Costs and Returns: Data http://www.ers.usda.gov/data/costsandreturns/testpick.htm.

(77) Michigan State University Extension. Determining the efficiency of the business http://msue.anr.msu.edu/news/financial_ratios_part_10_of_21_operating_profit_margin (accessed Apr 11, 2014).

(78) Morgan, M. G.; Henrion, M. Evaluating the Fit of a Distribution. In *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*; Cambridge University Press: New York, NY, 1990; p. 100.

(79) Jones, C. A.; Nickerson, C.; Heisey, P. New Uses of Old Tools: An Assessment of Current and Potential Agricultural Greenhouse Gas Mitigation with Sector-based Policies. In *Agricultural & Applied Economics Association Annual Meeting*; USDA - ERS: Seattle, WA, 2012; pp. 1–46.

(80) Wright, C. K.; Wimberly, M. C. Recent land use change in the Western Corn Belt threatens grasslands and wetlands. *Proc. Natl. Acad. Sci. U. S. A.* **2013**, *2013*, 1–6.

(81) Congressional Budget Office. *Estimated Budgetary Effects - Agricultural Act of 2014*; Washington, D.C., 2014.

(82) Craig, K.; Mann, M. *Cost and performance analysis of biomass-based integrated gasification combined-cycle (BIGCC) power systems*; Golden, CO, 1996; p. 59.

(83) Rajvanshi, A. K. Biomass Gasification. In *Alternative Energy in Agriculture*; Goswami, D. Y., Ed.; CRC Press, 1986; Vol. II, pp. 83–102.

(84) Bridgwater, A. V. Renewable fuels and chemicals by thermal processing of biomass. *Chem. Eng. J.* **2003**, *91*, 87–102.

(85) Klass, D. L. Biomass for Renewable Energy and Fuels. In *Encyclopedia of Energy*; Cleveland, C. J., Ed.; Elsevier, 2004; Vol. 1, pp. 193–196.

(86) Iliuta, I.; Leclerc, A.; Larachi, F. Allothermal steam gasification of biomass in cyclic multi-compartment bubbling fluidized-bed gasifier/combustor - new reactor concept. *Bioresour. Technol.* **2010**, *101*, 3194–3208.

(87) Ciferno, J. P.; Marano, J. J. *Benchmarking biomass gasification technologies for fuels, chemicals and hydrogen production*; 2002; p. 58.

(88) Hathaway, B. J.; Honda, M.; Kittelson, D. B.; Davidson, J. H. Steam gasification of plant biomass using molten carbonate salts. *Energy* **2013**, *49*, 211–217.

(89) Hathaway, B. J.; Davidson, J. H.; Kittelson, D. B. Solar gasification of biomass: kinetics of pyrolysis and steam gasification in molten salt. *J. Sol. Energy Eng.* **2011**, *133*.

(90) Hathaway, B. J.; Lipiński, W.; Davidson, J. H. Heat Transfer in a Solar Cavity Receiver: Design Considerations. *Numer. Heat Transf. Part A Appl. An Int. J. Comput. Methodol.* **2012**, *62*, 445–461.

(91) Hathaway, B. J.; Kittelson, D. B.; Davidson, J. H. Integration of Solar Gasification With Conventional Fuel Production: The Roles of Storage and Hybridization. *J. Sol. Energy Eng.* **2014**, *136*.

(92) Hathaway, B. J.; Honda, M.; Davidson, J. H. Improved switchgrass gasification using molten carbonate salts. In *Proceedings of the ASME 2011 5th International Conference on Energy Sustainability*; American Society of Mechanical Engineers: Washington, D.C., 2011; pp. 1–5.

(93) Roeb, M.; Neises, M.; Monnerie, N.; Sattler, C.; Pitz-Paal, R. Technologies and trends in solar power and fuels. *Energy Environ. Sci.* **2011**, *4*, 2503.

(94) Ratafia-Brown, J.; Manfredo, L.; Hoffman, J.; Ramezan, M. *Major Environmental Aspects of Gasification-Based Power Generation Technologies*; 2002; p. 270.

(95) Blackmon, J. B. Parametric determination of heliostat minimum cost per unit area. *Sol. Energy* **2013**, *97*, 342–349.

(96) Shanghai Yikai Metal Products Ltd. Inconel 600 Plate alibaba.com (accessed Jan 11, 2013).

(97) Nanjing Stable Trading Co. Li2CO3 - Industry Grade: CAS554-13-2 alibaba.com (accessed Jan 11, 2013).

(98) Oceanking Group Inc. Na2CO3 - Soda Ash: CAS487-19-8 alibaba.com (accessed Jan 11, 2013).

(99) Luancheng Terife Agricultural Materials. K2CO3: CAS584-08-7 alibaba.com (accessed Jan 11, 2013).

(100) EPRI. *Addressing Solar Photovoltaic Operations and Maintenance Challenges*; Palo Alto, CA, 2010; p. 22.

(101) Abbas, M.; Boumeddane, B.; Said, N.; Chikouche, A. Dish Stirling technology: A 100 MW solar power plant using hydrogen for Algeria. *Int. J. Hydrogen Energy* **2011**, *36*, 4305–4314.

(102) St. Louis Federal Reserve. Bank of America/Merrill Lynch US High Yield B Effective Yield http://research.stlouisfed.org/fred2/series/BAMLH0A2HYBEY?cid=32347 (accessed Jan 2, 2014).

(103) Deloitte. Corporate Tax Rates 2012 http://www.deloitte.com/assets/Dcom-Global/Local Assets/Documents/Tax/Taxation and Investment Guides/matrices/dttl_corporate_tax_rates_2012.pdf.

(104) Internal Revenue Servive. *Publication 946 - How To Depreciate Property*; Washington, D.C., 2013; p. 114.

(105) Belgiorno, V.; De Feo, G.; Della Rocca, C.; Napoli, R. M. a. Energy from gasification of solid wastes. *Waste Manag.* **2003**, *23*, 1–15.

(106) Internal Revenue Servive. *Qualified Tax Credit Bonds*; United States, 2008.

(107) U.S. Energy Information Administration. Natural Gas Prices http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm (accessed Oct 15, 2012).

(108) US Congress. *Energy Improvement and Extension Act of 2008*; United States, 2008.

(109) Thomas, V. M.; Choi, D. G.; Luo, D.; Okwo, a.; Wang, J. H. Relation of biofuel to bioelectricity and agriculture: Food security, fuel security, and reducing greenhouse emissions. *Chem. Eng. Res. Des.* **2009**, *87*, 1140–1146.

(110) BP. *BP Statistical Review of World Energy*; London, 2013; p. 48.

(111) DSIRE. Renewable Energy Production Tax Credit http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=US13F (accessed Jun 2, 2014).

(112) U.S. Energy Information Administration. *Annual Energy Outlook 2014 with projections to 2040*; Washington, D.C., 2014; p. 269.

(113) Mitchell, J. Production of Ethanol from Hardwood, University of Maine, 2006, p. 229.

(114) Sandia National Laboratories. Frequently Asked Questions http://energy.sandia.gov/?page_id=1278.

(115) Biello, D. How to Use Solar Energy at Night. *Scientific American*. February 2009,.

(116) National Energy Technology Laboratory. Acid Gas Removal http://netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/agr (accessed Apr 2, 2013).

(117) National Energy Technology Laboratory. Particulate Removal http://netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/particulate-removal (accessed Apr 2, 2013).

(118) Land and Farm. Solar Zoned Land - 268 Acres http://www.landandfarm.com (accessed Jan 11, 2013).

(119) Land and Farm. Land - 50 Acres www.landandfarm.com (accessed Jan 11, 2013).