

#

Alternative Crops and Biofuel Production#

Final Scientific/Technical Report#

Philip Kenkel

Rodney B. Holcomb

Oklahoma State University

1. Acknowledgment: "This material is based upon work supported by the Department of Energy under Award Number DE-EE0000392
2. Disclaimer: "This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

REPORT SECTIONS

Project Overview	3
Potential Biomass Yields in the South Central US	6
Feasibility Assessment of Biomass Harvesting Cooperative.....	57
Challenges in Financing the Biofuel Supply Chain.....	76
Development of Feasibility Templates for Biofuel Projects.....	81
A Comprehensive Supply Chain Model for the Production of Cellulosic Ethanol in Oklahoma	107
Economic Impact of Cellulosic Ethanol Production Under Different Ownership Structures	130
Overall Summary and Conclusions	153

PROJECT OVERVIEW

In order for the biofuel industry to meet the RFS benchmarks for biofuels, new feedstock sources and production systems will have to be identified and evaluated. The Southern Plains has the potential to produce over a billion gallons of biofuels from regionally produced alternative crops, agricultural residues, and animal fats. While information on biofuel conversion processes is available, it is difficult for entrepreneurs, community planners and other interested individuals to determine the feasibility of biofuel processes or to match production alternatives with feed stock availability and community infrastructure. This project facilitates the development of biofuel production from these regionally available feed stocks.

Project activities are concentrated in five major areas. The first component focused on demonstrating the supply of biofuel feedstocks. This involves modeling the yield and cost of production of dedicated energy crops at the county level. In 1991 the DOE selected switchgrass as a renewable source to produce transportation fuel after extensive evaluations of many plant species in multiple location (Caddel et al., 2010). However, data on the yield and cost of production of switchgrass are limited. This deficiency in demonstrating the supply of biofuel feedstocks was addressed by modeling the potential supply and geographic variability of switchgrass yields based on relationship of available switchgrass yields to the yields of other forage crops. This model made it possible to create a database of projected switchgrass yields for five different soil types at the county level. A major advantage of this methodology is that the supply projections can be easily updated as improved varieties of switchgrass are developed and additional yield data becomes available. The modeling techniques are illustrated using the geographic area of Oklahoma. A summary of the regional supply is then provided.

The second component of the project involved modeling the harvesting, transportation and storage of biofuel feedstocks. This information is vital for the design of a cost efficient biofuel supply chain. The first generation ethanol plants accessed grain feed stocks that could be easily purchased from the open market. Second generation biofuel industries will use dedicated energy crops like switchgrass for which a supply chain must be developed. Epplin et al. [2] suggest three alternatives for supply of biomass to ethanol facility. One alternative is to have producers grow, harvest and store biomass and provide it to the biorefinery on the basis of spot market prices or long term contracts. Another alternative is for the biorefinery to lease land from landholders and operate a large scale integrated production, harvest and storage operation. The third alternative is for the producers to form a biomass harvesting cooperative. While a spot market based system could be part of the supply chain for a mature biofuel industry it would likely be considered an unacceptable risk factor for the initial bio-refineries. For this reason, the modeling of the harvest, transportation and storage system focused on the integrated production and biomass harvesting cooperative models.

The third component of the project involved modeling alternative conversion processes. Because the goal of the project was to assist entrepreneurs, community planners and other interested individuals in assessing the feasibility of biofuel processes and developing commercial projects, this phase focused on the development of feasibility templates. In addition to creating a deliverable product for entrepreneurs and communities who are interesting in developing biofuel refineries, these decision aids provided information on biofuel feedstock transportation costs and conversion costs under various plant sizes and regional locations. This information, along with the data developed in the first phase was incorporated into a comprehensive supply chain model.

The fourth component of the project involves the development of a comprehensive biofuel supply chain model that incorporates feedstock production, feedstock logistics, biofuel production and distribution. The supply chain model identifies the optimal type, size and location of biofuel refineries. This involves balancing the tradeoffs in feedstock production and transportation costs, biorefinery capital cost and scale economies and distribution costs. The model provides information on the costs of delivering biomass to the bio-refineries, the breakeven price of biofuel, the optimal size and location of bio-refineries and the implications of increasing the number of bio-refineries on the breakeven price of biofuel.

The final phase of the project involved the development of a community economic impact model that demonstrates the impact of biofuel production and biofuel refinery operation on rural communities. This model incorporates information on the optimal type, size and location and cost structure of biofuel refineries that were developed in the previous steps. The model estimates the direct, indirect and induced impacts on employment and economic activity associated with the development of a biofuel refinery in a rural community. The model results will assist entrepreneurs and rural community leaders in identifying biofuel opportunities. It will also assist policy makers in justifying infrastructure improvements and plant location incentives that would facilitate biofuel refinery development.

POTENTIAL BIOMASS YIELDS IN THE SOUTH CENTRAL US

Background

The renewable fuel standard mandates in the Energy Independence and Security Act (EISA), 2007 target to achieve 20% reduction in petroleum consumption by 2015 and increase alternative fuel use by 10% each year. The mandates require 36 billion gallons of ethanol to be produced in 2022 of which 16 of the 36 billion gallons must be produced from cellulosic feedstocks. In order to meet the mandates, the Department of Energy (DOE) has launched the Biomass Program to conduct a geospatial analysis of current and potential bioenergy feedstock supply across the United States. As a part of the national DOE program, this study is undertaken to create a database of potential bioenergy feedstock supplies that may be available across the South Central U.S. The database for feedstock productivity in the region is required for land use planning, appraisal and identifying accurate locations for establishing future biofuel plants. The potential feedstocks are assumed to be converted into cellulosic ethanol and/or advanced biofuels to supplement and enhance the nations' dwindling oil supplies.

In 1991, the DOE selected switchgrass as a renewable feedstock source to produce transportation fuel after extensive evaluations of many plant species in multiple locations (Caddel et al., 2010). However, there is not enough data to truly understand the potential of switchgrass as a feedstock (Dicks et al., 2009). Considering this, the study attempts to create a database of county level switchgrass yields for top five most productive and predominant soils in the South Central US. The focus of the study is on modeling the geographic variability of switchgrass yields and assessing potential changes that may occur under various soil types. The methodology is illustrating using the geographic area of Oklahoma. Regional results are then provided in a subsequent section.

Several different types of mathematical models have been developed and used to predict crop yields. The most common being the regression-type models. Olson and Olson (1986) used multiple regression methods to estimate average corn yields using selected soils and climatic data from five experimental research plots in New York State. The resulting linear relationship between actual and estimated corn yields had an r^2 of 0.52. Garcia-Paredes, Olson and Lang (2000) used multiple regression to evaluate the relationship between 16 selected soil properties of 34 major soils in Illinois to update the corn and soybean yields. The approach they reported worked well and could be useful in surrounding states or countries. Landau et al (1999) used a parsimonious multiple regression model to estimate wheat yield in response to the environment in UK. De La Rosa, Cardona and Almorza (1980) used a procedure of computing algebraic equations following analyses by multiple regression to predict crop yield based on soil properties in Sevilla, Spain. Poldaru, Roots and Viira (2005) suggest artificial neural network as an alternative to multiple regression analysis for estimating the parameters of econometric models. Bellow (2003) compared Stansy-Goel, Griffith and standard ratio estimators using simulated NASS survey data for oats and barley in North Dakota. The result of their study favored Stansy-Goel method in almost all comparisons. The NASS ratio estimator reported by Bellow is computed as the ratio between the county estimates of production and harvested area for a given crop and can produce inconsistent yields due to fluctuations in harvested area from year to year.

Efforts have also been made to estimate crop yields using remote sensing data. Doraiswamy et al (2007) described the development of simplified process models and algorithms to supplement the NASS field data collection. In their study, a simple algorithm that uses a near-real time MODIS imagery and products was developed to predict crop yields at county and sub-county level. Prasad et al (2005) used NDVI, soil moisture, surface temperature and rainfall data

of Iowa for crop yield assessment and prediction using a piecewise linear regression with breakpoint. They report that the model reasonably minimizes inconsistency and errors in yield prediction giving high R^2 values with maximum accounting of variability in model.

Oak Ridge National Laboratory (ORNL) performed an extensive research on estimating county level switchgrass yields for all the states in the United States. Gunderson et al (2008) at ORNL used a modeling approach based on climatic factors and ecotype to predict potential dry matter yields for a given temperature and weather pattern based on 95th percentile response curves. The predictive equations were used to produce maps of potential yield across the US using PRISM in GIS. They reported that the mapped output using the model was relatively consistent with known switchgrass distribution. Dicks et al, 2009 used the switchgrass yield data from ORNL and estimated that roughly 24 million acres of cropland would be required in existing uses to shift into the production of switchgrass to meet the cellulosic ethanol production mandates.

Modeling Procedures Illustrated for the Geographic Area of Oklahoma

In Oklahoma, cropland has historically been worth more than pasture, but recently the differences between crop and pasture prices per acre have been shrinking (Guiling, 2010). Switchgrass is constantly being bred to improve the biomass production so it can be used to produce a cellulosic ethanol. This species is a warm-season perennial grass native to the Great Plains which means it has adapted to growing in a wide range of climatic conditions and has the ability to outperform a majority of the crops grown in the state. Over many years switchgrass has adapted to the environment, so it has resistance to pests, drought, and flooding. Even though moisture is typically the most limiting factor in switchgrass, soil depth and fertility are important factors to consider. Without frequent rainfall, biomass will be limited unless there is enough soil

depth (water holding capacity) to store an adequate amount of moisture during a drought (Caddel et al., 2010). Although switchgrass may outperform a majority of the crops in Oklahoma it will only be grown on marginal land which cannot sustain a crop that yields a higher profit.

Oklahoma is located in the South Central United States, which is right in the transition of humid to arid climate. Oklahoma's rainfall amount is the highest in the southeast corner and gradually decreases to the northwest corner which is the lowest in the state. As a general rule of thumb east of I-35 is moderately humid to humid and west of I-35 is semi arid to arid. The western half of Oklahoma is predominantly cropland whereas the eastern half is predominantly pasture and forest land (Guiling, 2010). The eastern half will likely grow more switchgrass than the western half since it is predominantly pasture and receives higher amounts of rainfall.

Materials and Methods

The study employs a simple method of ratio calculation and estimation to determine the yield of switchgrass for the top five soils in each Oklahoma County. The top five soils in each county comprise 35.6% of the total farmland land in Oklahoma. The ratio calculation and estimation method used in this study is different from the ratio estimator traditionally used by NASS to derive county yields. The NASS ratio estimator is computed as the ratio between the county estimates of production and harvested area for a given crop but the ratio estimation used in this study compares the yield of one crop in two different soil types to estimate the yield of another crop in a specific soil types. The estimates in this study are based on available data and improved estimates are made as new switchgrass or other crop yield data becomes available and new modeling approaches are applied.

Data Sources

The major sources of data collected for this study were the yields for crops from state research experiment stations test plot trials and the yield data available from the NRCS web resources. Relevant data were also collected from the published literatures (Taliaferro, 2002 and Thomason et al., 2004).

Experiment Stations

Several historic data from the state's research experiment stations that includes climate data, soils data, crops produced and yields, nutrients applied, irrigation used, harvest methods and other relevant data associated with actual field trials for all the eight states in the south central US were collected. About 2,000 records of county level switchgrass yield data was collected and catalogued for Oklahoma from research stations and literatures. The data was averaged to get an estimated yield based on soil type. We had switchgrass yield data from four different locations (3 counties) and for five different soil types. These switchgrass yield data for five different soil types were used as the basis for estimating switchgrass yield for all the top five soils in each county.

The table below shows the switchgrass yield information collected from the research stations at four different locations in Oklahoma and for five different soil types.

Table 1: Oklahoma switchgrass yield data obtained from research stations

Experiment Station Locations	County	Soil Type	Latitude	Longitude	Average Yield (ton/acre)
Stillwater	Payne	Easpur Loam	36.120	-97.095	6.08
Perkins	Payne	Teller Loam	35.998	-97.048	4.88
Chikasha	Grady	Reinach Silt Loam	35.032	-97.914	5.99
		Dale Silt Loam	35.032	-97.914	8.07
Haskell	Muskogee	Taloka Silt Loam	35.747	-95.640	6.27

NRCS Online Data

The information presented in this project is largely based off of NRCS Soil Data and the Land Capability Classes (LCC). The NRCS spent years collecting data from conservationists, extension agents, and farmers to make the database they have today. The NRCS data were used to aid in predicting crop yields that have the ability to serve as bioenergy feedstocks. Irrigated crop yield, non-irrigated crop yield, specific Land Capability Class (LCC), and county level soil types were used to categorize the NRCS yield data. The irrigated and non-irrigated crop yields were selected to provide two different yield possibilities. The LCC consists of eight classes to designate the different types of land in Oklahoma (Helms, 1992). Farmable land that can sustain crops was determined using the LCCs. The first four classes are arable land, suitable for cropland- with limitations on their use and the need for conservation measures and careful management as the class increases from I through IV (Helms, 1992). Soils classified as V-VIII were not included since they are not recommended for cropland. The LCC was simply our template to narrow the soils that were capable of crop production. Some of the soils we used may have slopes ranging from 5% to 20%. Some soils in this data collection include eroded soils which require intensive conservation practices. SQL codes were used to obtain county level yield data from the NRCS.

Top Five Soils

The top five soils were based on the criteria of productivity of the soil (Soil Classes I through IV and slopes 8% or less) and predominance in the area. Soil types that are most predominant in the county that fall within Soil Class 1 to 4 with slope less than or equal to 8%

were selected as the top five soils. These top five soils were assumed to support switchgrass growth in the region.

Ratio Calculation and Yield Estimation

After the top five soils for each of the counties in Oklahoma were identified, the yields for other forage crops obtained from the NRCS web resources for each top five soils were determined. Not all the top five soils had the yield data for all the other forage crops. There were several forage crops on specific soils with missing yield information. The switchgrass yield for all the top five soils for each county of Oklahoma were estimated using the available yield data of other crops from the NRCS web resources and the historic data from the research stations. Ratio calculation involves calculating the ratio of a particular crop for two different soil types. Then a similar approach is applied to calculate the ratio for another crop for the two soils types and several ratios are obtained. The ratios are then averaged. This average ratio is used to estimate the switchgrass yield of one soil type by using the switchgrass yield from another soil type.

$$\text{Ratio 1} = \frac{\text{Crop 1 Yield for Soil A}}{\text{Crop 1 Yield for Soil B}}$$

$$\text{Ratio 2} = \frac{\text{Crop 2 Yield for Soil A}}{\text{Crop 2 Yield for Soil B}}$$

$$\text{Ratio 3} = \frac{\text{Crop 3 Yield for Soil A}}{\text{Crop 3 Yield for Soil B}}$$

$$\text{Average Ratio} = \frac{\sum_{i=1}^n \text{Ratio}}{n}$$

$$\text{Crop 4 Yield for Soil B} = \frac{\text{Crop 4 Yield for Soil A}}{\text{Average Ratio}}$$

Table 2 below shows how this method is used to estimate the missing yield data of switchgrass.

Table 2: Estimating switchgrass yield using ratio estimation for Payne County, Oklahoma

Soil Classes	Bermuda grass	Ratio 1 (Yield 1/Yield 2)	Wheat	Ratio 2 (Yield 1/Yield 2)	Average Ratio# $\frac{\sum \text{Ratio}}{n}$	Switchgrass
--------------	------------------	------------------------------	-------	------------------------------	--	-------------

Easpur Loam	8.5	2.42	35	1.75	2.08	6.15
Stephenville Darnell Complex	3.5		20			2.95

The switchgrass yield data shown above for Easpur Loam was obtained from the research stations at Oklahoma. The switchgrass yield data for the Stephenville Darnell Complex soil has to be estimated. Yield data for Bermuda grass and Wheat for the Easpur Loam and Stephenville Darnell Complex soils was obtained from the NRCS web resources. The Bermuda grass yield for Easpur loam and Stephenville Darnell Complex was divided and the ratio of 2.42 was obtained. Similarly, the wheat yield for Easpur loam and the Stephenville Darnell Complex was divided and the ratio of 1.75 was obtained. These two ratios were averaged to get 2.08. Then the switchgrass yield for Easpur loam was divided by the average ratio to get the estimated switchgrass yield of 2.95 for the Stephenville Darnell Complex soil.

Similar approaches were used to determine the yield of switchgrass for other soil types. Once the switchgrass yield for all the top five soils for a county was determined, the top five soils for the neighboring counties were compared to determine matching soil types. Matching soil types were given the same switchgrass yield as those determined for the adjoining county. Then the newly assigned switchgrass yield and the yield of other forage crops are used to obtain the ratio and estimate the switchgrass yield for other top 4 soils. The same procedure is applied until the switchgrass yield for all the top five soils for all the counties are estimated.

Results

A projection of 49.59 million tons of total potential switchgrass supply was made for Oklahoma for the top five most abundant and productive soils. The total area for the top five soils in all the counties of Oklahoma was estimated to be 12.48 million acres. The top suppliers of switchgrass in Oklahoma are found to be North East, Central, Panhandle and North Central crop reporting districts. They could supply a total of over 6 million tons of switchgrass. These districts can be referred to as the suitable areas for establishing future biofuel processing plants.

County Analysis

The data obtained from the ratio estimator showed that Texas County in the panhandle district could supply the largest quantity of switchgrass. It could supply approximately 2.5 million tons of switchgrass from the top five soils. Texas County had a highest area of 675,232 acres of the top five soils with an average yield of 3.53 tons/acre. The lowest supply of switchgrass was estimated for Marshall County with a total potential supply estimated at 0.16 million tons. This was because the total area of the top five soils (72,921 acres) and the average yield (2.29 tons/acre) of switchgrass was comparatively low in this county. The average supply of switchgrass for a county was estimated to be about half a million tons from an average area of 162,397 acres (Top five soils).

District Analysis

The district level analysis showed that the North East district can supply the highest quantity of switchgrass. It could supply 7.4 million tons from an area of 1.88 million acres. The Southeast district was found to be the lowest supplier of switchgrass. It could supply 2.99 million tons from an area of 0.59 million acres. The average supply of switchgrass on a crop reporting

district basis was estimated to be 5.49 million tons from an average area of 1.38 million acres per crop reporting district.

Table 3: Oklahoma crop reporting districts-Total supply of Switchgrass

Oklahoma Districts	Total Supply (Tons)	Top Five Soils (Total Acres)	No. of Counties	Total Farm Land (Acres)	% of Farmland
North East	7,410,473	1,888,175	10	3,888,067	48.56%
Central	6,641,226	1,574,831	13	5,090,829	30.93%
Panhandle	6,292,770	1,862,584	5	4,714,382	39.51%
North Central	6,236,352	1,703,395	9	5,049,869	33.73%
South West	5,643,748	1,380,778	8	3,814,777	36.20%
South Central	5,561,676	1,435,346	12	4,513,767	31.80%
East Central	5,290,790	1,041,258	9	2,987,821	34.85%
West Central	3,517,203	999,656	6	3,573,477	27.97%
South East	2,999,421	597,872	5	1,454,280	41.11%
Total	49,593,659	12,483,895		35,087,269	35.58%

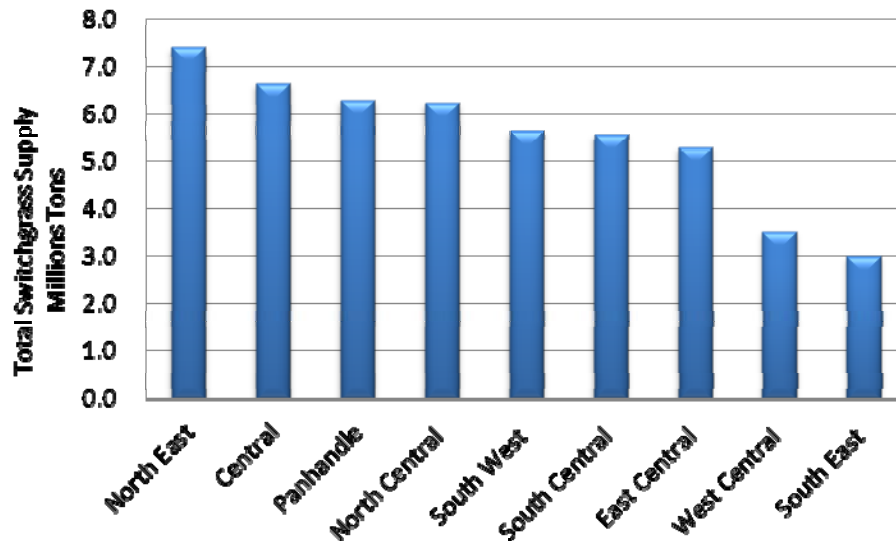


Figure 1: Switchgrass Supply in Oklahoma Crop Reporting Districts

Panhandle District

The Panhandle district could supply a total of 6.29 million tons of switchgrass. Texas County was found to supply the highest quantity of switchgrass. The lowest supply was provided

by Ellis and Harper counties. Harper County, although having a high yield compared to the other counties in the district, provides a low supply because of the low acreage of the top five soils.

Table 4: Panhandle District-County Level Switchgrass Supply

County	Total Supply (Tons)	Top Five Soils (Acres)	Switchgrass Yield (Tons/Acre)	Rainfall (Inches)	County Farmland (Acres)	% of Farm Land
Beaver	888,467	282,694	3.17	21.27	1,128,871	25.04%
Cimarron	1,827,103	554,405	3.29	18.6	1,044,528	53.08%
Ellis	536,296	187,634	2.85	25.44	718,058	26.13%
Harper	558,618	162,619	3.48	26.21	616,947	26.36%
Texas	2,482,285	675,232	3.53	18.32	1,205,978	55.99%
Total	6,292,770	1,862,584		110	4,714,382	39.51%

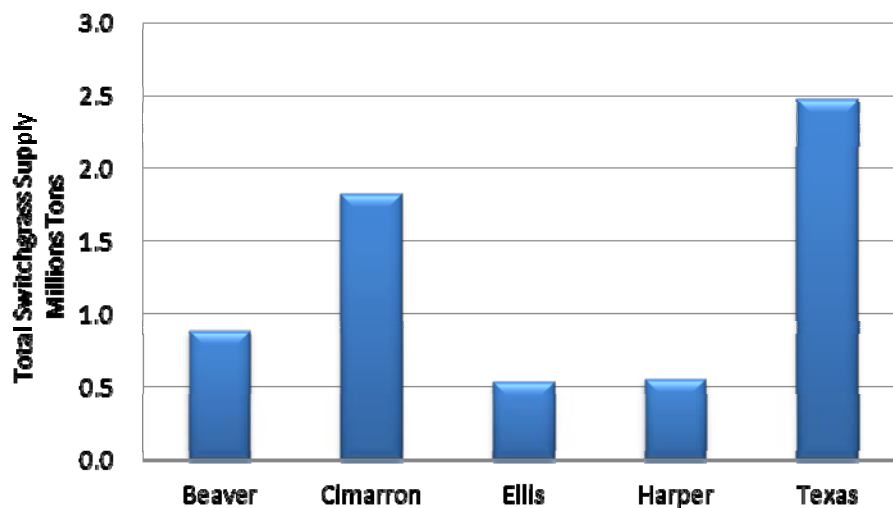


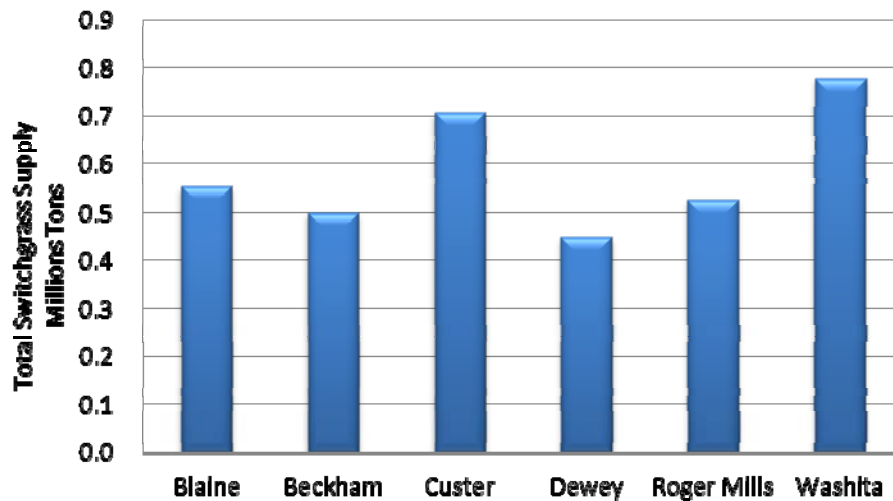
Figure 2: Switchgrass Supply in Panhandle Oklahoma by County

West Central District

The total supply of switchgrass in the West Central District was estimated to be 3.51 million tons of switchgrass from an area of 0.99 million acres. All the counties in this district had almost the same yield and total acreage.

Table 5: West Central District-County Level Switchgrass Supply

County	Total Supply (Tons)	Top Five (Acres)	Switchgrass Yield (Tons/Acre)	Rainfall (Inches)	County Farmland (Acres)	% of Farm Land
Blaine	554,606	110,476	4.98	29.48	585,908	18.86%
Beckham	499,715	164,250	3.06	26.11	519,503	31.62%
Custer	706,761	214,745	3.20	30.01	568,728	37.76%
Dewey	448,796	133,112	3.32	28.92	588,951	22.60%
Roger Mills	527,451	155,880	3.63	27.76	719,356	21.67%
Washita	779,873	221,193	3.32	29.77	591,031	37.42%
Total	3,517,203	999,656		172	3,573,477	27.97%

**Figure 3: Switchgrass Supply in West Central Oklahoma by County**

Southwest District

The South West district had an estimated total supply of 5.64 million tons of switchgrass from an area of 1.38 million acres. Kiowa county could supply the largest quantity of 1.13 million tons and Harmon County could supply the lowest quantity of 0.26 million tons of switchgrass.

Table 6: South West District -County Level Switchgrass Supply

County	Total Supply (Tons)	Top Five (Acres)	Switchgrass Yield (Tons/Acre)	Rainfall (Inches)	County Farmland (Acres)	% of Farm Land
Caddo	985,002	225,389	4.34	31.44	749,918	30.06%
Comanche	830,148	195,571	4.44	31.75	497,502	39.31%
Cotton	844,503	190,779	4.62	34.14	366,651	52.03%
Greer	300,454	87,745	4.09	28	375,447	23.37%
Harmon	261,157	83,672	3.23	25.97	322,222	25.97%
Jackson	675,195	165,359	3.98	29.09	474,502	34.85%
Kiowa	1,133,944	267,408	4.17	28.43	564,592	47.36%
Tillman	613,344	164,855	3.70	31.03	463,943	35.53%
Total	5,643,748	1,380,778		240	3,814,777	36.20 %

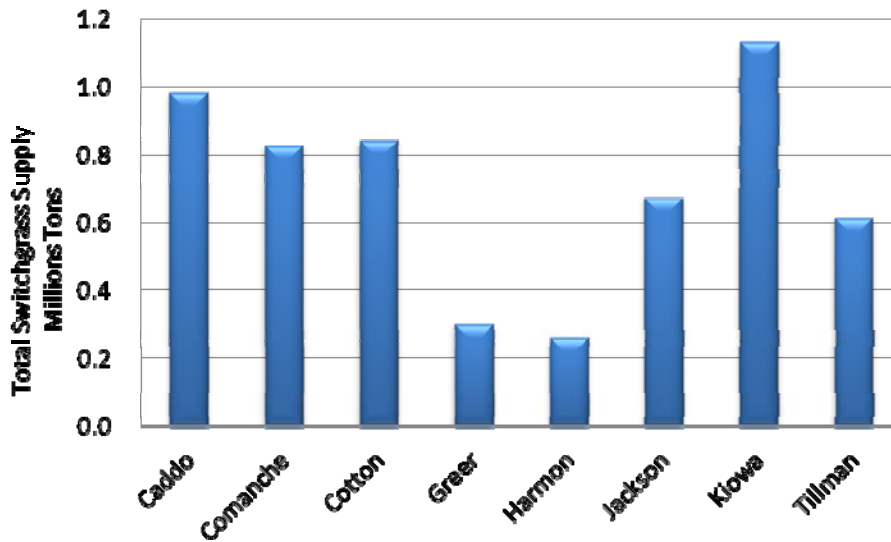


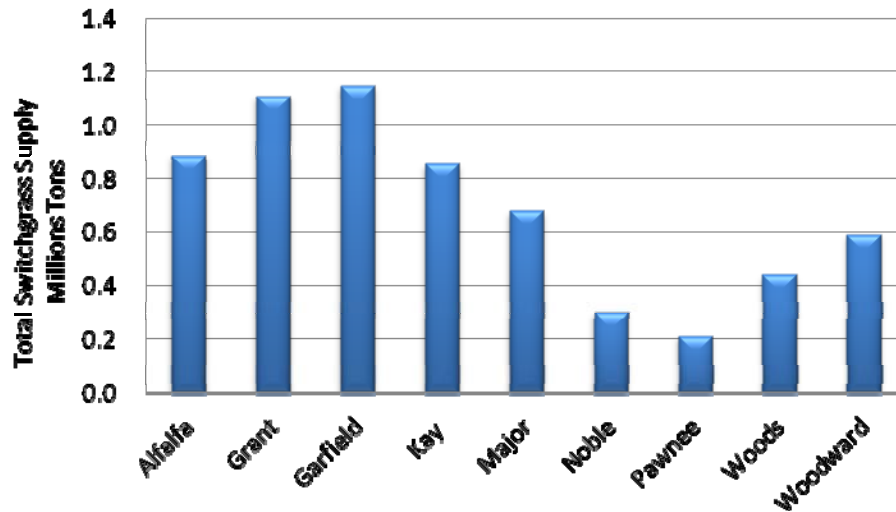
Figure 4: Switchgrass Supply in South West Oklahoma by County

North Central District

The North Central District could supply an estimated 6.23 million tons of switchgrass from a total acreage 1.70 million acres. Grant and Garfield counties could supply the most switchgrass in this district. The lowest supply of switchgrass was projected for Noble and Payne counties as they could supply only 0.2 to 0.3 million tons of switchgrass.

Table 7: North Central District-County Level Switchgrass Supply

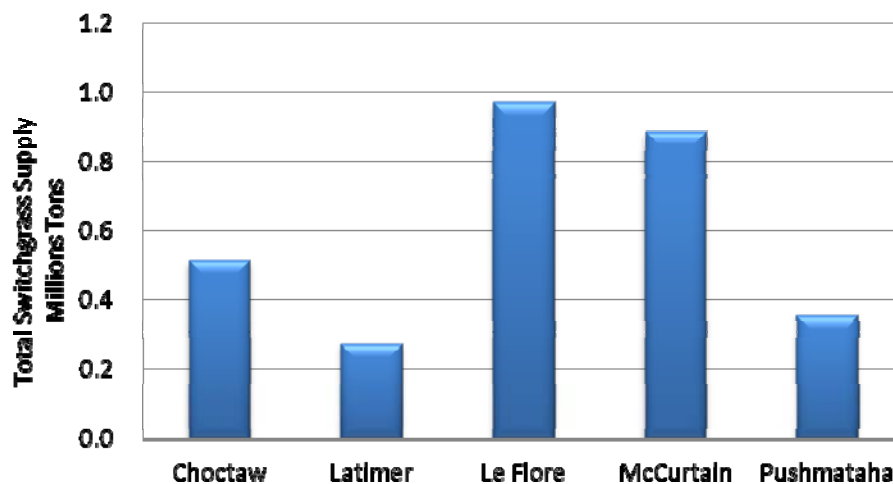
County	Total Supply (Tons)	Top Five (Acres)	Switchgrass Yield (Tons/Acre)	Rainfall (Inches)	County Farmland (Acres)	% of Farm Land
Alfalfa	888,154	194,689	4.37	31.64	542,813	35.87%
Grant	1,112,298	257,451	4.60	34.57	633,052	40.67%
Garfield	1,150,883	278,961	4.41	34.18	663,431	42.05%
Kay	857,063	254,434	3.17	38.85	492,178	51.70%
Major	678,830	186,022	3.94	34.67	336,852	55.22%
Noble	304,754	111,973	2.75	36.31	466,947	23.98%
Pawnee	212,792	97,054	2.21	38.77	297,621	32.61%
Woods	439,990	127,937	3.59	27.86	833,775	15.34%
Woodward	591,587	194,874	3.13	25.83	783,200	24.88%
Total	6,236,352	1,703,395		303	5,049,869	33.73%

**Figure 5: Switchgrass Supply in North Central Oklahoma by County****Southeast District**

The South East district was projected to be the lowest supplier of switchgrass in Oklahoma. The projected supply of switchgrass in this district was 2.99 million tons from an area of 0.59 million acres. Le Flore was projected to be the largest supplier of switchgrass and Latimer was projected to be the lowest supplier.

Table 8: South East District-County Level Switchgrass Supply

County	Total Supply (Tons)	Top Five (Acres)	Switchgrass Yield (Tons/Acre)	Rainfall (Inches)	County Farmland (Acres)	% of Farm Land
Choctaw	512,234	127,782	3.91	47.63	326,300	39.16%
Latimer	274,041	48,879	5.55	51.42	213,411	22.90%
Le Flore	971,244	185,259	4.94	46.55	466,406	39.72%
McCurtain	887,291	165,900	5.30	42.18	157,754	105.16%
Pushmataha	354,611	70,052	5.29	45.46	290,409	24.12%
Total	2,999,421	597,872		233	1,454,280	41.11%

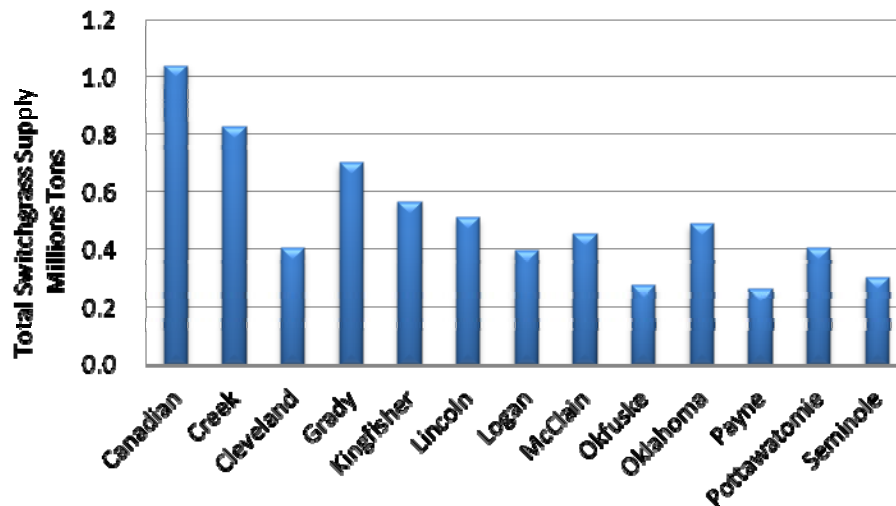
**Figure 6: Switchgrass Supply in South East Oklahoma by County**

Central District

There are thirteen counties in the Central district with an estimated total area of 1.57 million acres. This district is second in potential switchgrass supply after the Northwest district. The total supply is estimated to 6.64 million tons. Canadian, Creek and Grady counties are the top suppliers of switchgrass in this district.

Table 9: Central District-County Level Switchgrass Supply

County	Total Supply (Tons)	Top Five (Acres)	Switchgrass Yield (Tons/Acre)	Rainfall (Inches)	County Farmland (Acres)	% of Farm Land
Canadian	1,044,282	180,048	5.71	34.08	508,771	35.39%
Creek	829,319	167,279	5.56	40.39	377,437	44.32%
Cleveland	403,007	128,645	3.02	34.67	159,816	80.50%
Grady	701,871	145,269	4.75	35.28	608,373	23.88%
Kingfisher	565,506	177,137	2.98	32.95	566,212	31.28%
Lincoln	511,495	104,405	4.79	37.75	487,858	21.40%
Logan	397,923	95,495	4.03	35.93	403,810	23.65%
McClain	455,044	101,577	4.58	27.52	517,334	19.63%
Okfuske	274,784	64,707	4.35	42.28	298,814	21.65%
Oklahoma	488,205	143,713	3.25	35.97	159,823	89.92%
Payne	262,007	85,124	2.99	36.79	356,765	23.86%
Pottawatomie	403,659	104,713	3.71	40.05	395,065	26.51%
Seminole	304,114	76,719	3.97	40.95	250,751	30.60%
Total	6,641,216	1,574,831		475	5,090,829	30.93 %

**Figure 7: Switchgrass Supply in Central Oklahoma by County**

South Central District

There are twelve counties in the South Central District with a total estimated area of 1.43 million acres. The total supply of switchgrass for this district was estimated to be 5.56 million tons. Jefferson County was projected to be the top supplier of switchgrass at 1.30 million tons. Bryan, Pontotoc and Stephens was projected to supply around 0.5 million tons each and all other counties were projected to supply less than 0.5 million tons of switchgrass.

Table 10: South Central District -County Level Switchgrass Supply

County	Total Supply (Tons)	Top Five (Acres)	Switchgrass Yield (Tons/Acre)	Rainfall (Inches)	County Farmland (Acres)	% of Farm Land
Atoka	290,271	102,138	2.95	44.79	408,444	25.01%
Bryan	562,033	138,946	4.19	46.42	490,688	28.32%
Coal	329,756	76,998	4.26	41.54	269,401	28.58%
Carter	339,410	108,998	3.13	38.38	402,831	27.06%
Garvin	439,145	100,093	4.51	38.46	500,804	19.99%
Love	210,175	84,988	2.44	38.46	261,875	32.45%
Marshall	166,903	72,921	2.29	50.45	339,615	21.47%
Murray	216,116	45,730	4.81	41.14	197,022	23.21%
Jefferson	1,308,714	305,215	4.54	31.36	460,207	66.32%
Johnston	449,645	130,369	3.47	44.24	333,944	39.04%
Pontotoc	554,186	86,529	6.12	41.54	379,236	22.82%
Stephens	695,322	182,421	3.72	36.13	469,700	38.84%
Total	5,561,676	1,435,346		493	4,513,767	31.80%

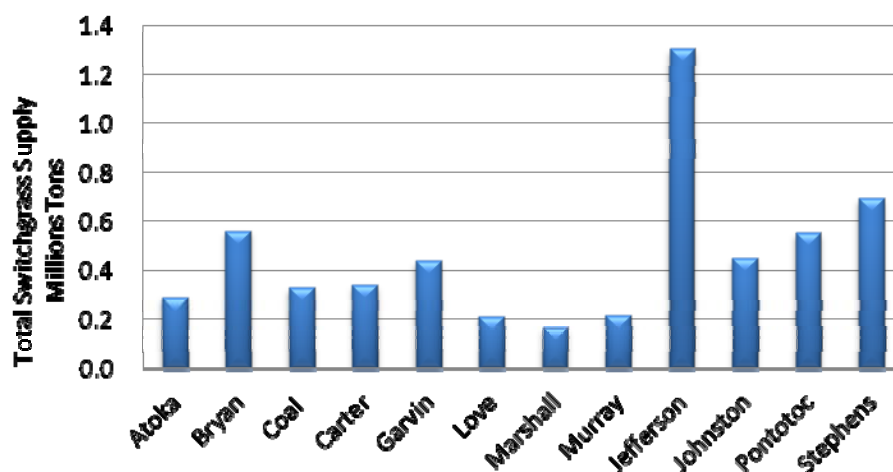


Figure 8: Switchgrass Supply in South Central Oklahoma by County

North East District

The Northeast district is projected to be the top supplier of switchgrass in Oklahoma. This district could supply 7.41 million tons of switchgrass from an area of 1.88 million acres. All the counties in this district are projected to supply more than 0.5 million tons of switchgrass. Craig County was projected to be the top supplier of switchgrass. All the counties in this district had a switchgrass yield of above 4 tons per acre except the Osage county which had a yield of 1.41 tons per acre. However, Osage county had the highest acreage of 0.54 million acres of the top five soils which made it able to supply 0.83 million acres of switchgrass.

Table 11: North East District-County Level Switchgrass Supply

County	Total Supply (Tons)	Top Five (Acres)	Switchgrass Yield (Tons/Acre)	Rainfall (Inches)	County Farmland (Acres)	% of Farm Land
Delaware	670,587	160,651	4.17	48.9	308,970	52.00%
Craig	1,131,492	200,559	5.52	45.8	457,292	43.86%
Wagoner	680,343	137,211	5.00	44.99	262,702	52.23%
Mayes	749,765	158,380	4.68	46.78	246,730	64.19%
Ottawa	725,693	146,464	4.77	44.51	237,986	61.54%
Nowata	730,923	151,496	5.02	41.83	354,636	42.72%
Rogers	770,691	158,080	4.91	44.04	371,349	42.57%
Tulsa	606,109	119,075	4.97	42.47	131,154	90.79%
Osage	839,119	546,586	1.41	43.98	1,290,680	42.35%
Washington	505,751	109,673	4.33	38.93	226,568	48.41%
Total	7,410,473	1,888,175		442	3,888,067	48.56%

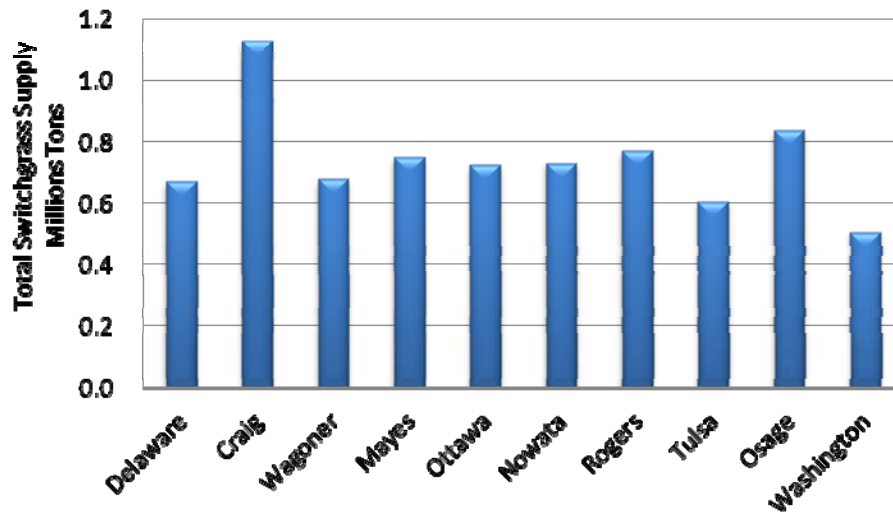


Figure 9: Switchgrass Supply in North East Oklahoma by County

East Central District

The projected total supply of switchgrass from the East Central District is 5.29 million tons from a total area of 1.04 million acres. The range of switchgrass supply for the counties in this district varied from 0.4 to 0.8 million tons. Muskogee and Okmulgee counties were projected to supply the most switchgrass in this district.

Table 12: East Central District-County Level Switchgrass Supply

County	Total Supply (Tons)	Top Five (Acres)	Switchgrass Yield (Tons/Acre)	Rainfall (Inches)	County Farmland (Acres)	% of Farm Land
Adair	458,519	122,425	3.92	49.87	249,280	49.11%
Cherokee	480,080	125,909	4.03	48.04	246,421	51.10%
Haskell	512,792	100,613	4.99	48.73	290,260	34.66%
Hughes	395,106	101,072	3.94	41.16	441,040	22.92%
Muskogee	888,498	156,384	5.66	46.93	374,372	41.77%
McIntosh	662,596	101,333	6.59	44.43	313,131	32.36%
Okmulgee	838,508	144,342	5.80	43.89	294,324	49.04%
Pittsburg	507,366	94,524	5.41	45.24	547,050	17.28%
Sequoyah	547,325	94,656	5.48	46.55	231,943	40.81%
Total	5,290,790	1,041,258		415	2,987,821	34.85%

Table 13: Oklahoma County Switchgrass Supply and Yields

County	Total Supply (Tons)	Acres (Top Five Soils)	Average Switchgrass Yield	County	Total Supply (Tons)	Acres (Top Five Soils)	Average Switchgrass Yield
Adair	458,519	122,425	3.92	McClain	455,044	101,577	4.58
Alfalfa	888,154	194,689	4.37	McCurtain	887,291	165,900	5.30
Atoka	290,271	102,138	2.95	McIntosh	662,596	101,333	6.59
Beaver	888,467	282,694	3.17	Major	678,830	186,022	3.94
Beckham	499,715	164,250	3.06	Marshall	166,903	72,921	2.29
Blaine	554,606	110,476	4.98	Mayes	749,765	158,380	4.68
Bryan	562,033	138,946	4.19	Murray	216,116	45,730	4.81

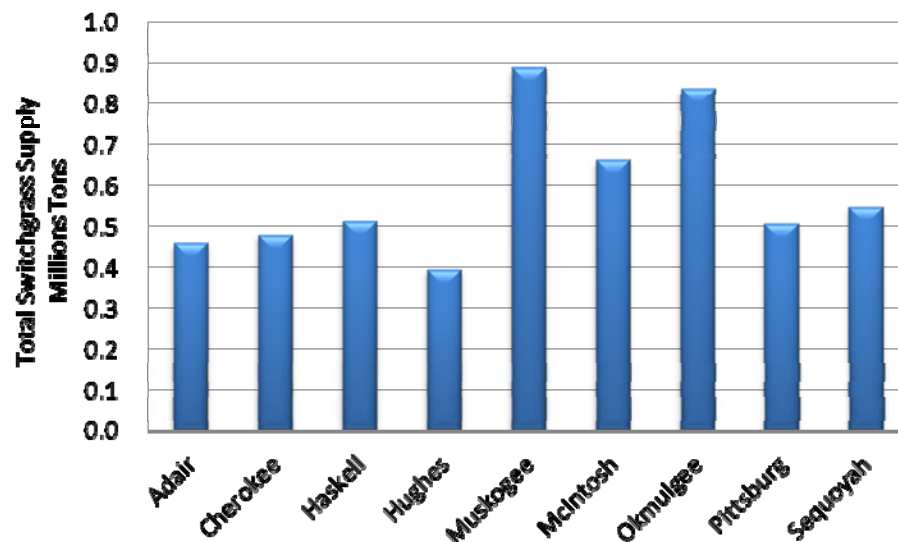


Figure 10: Switchgrass Supply in East Central Oklahoma by County

Summary: Potential Switchgrass Supply in Oklahoma

The estimation covered 43% of the total land area of Oklahoma. On an average we estimated yield for 51 different soil types in each county and in total, 3,909 soil types. In some counties, the soil types we used were as low as 19 (Nowata County) and in others it was as high as 117 (Harper County). The number of crops we used for comparison ranged from 3 to 8. The most frequently used crops for comparisons were alfalfa, grain sorghum, corn, improved bermuda grass, wheat grazeout, wheat, introduced bluestem, soybean, and tall wheat grass.

We have mapped the re-estimated average switchgrass yield using Arc GIS 9.2. The map is based on the estimated mean yield of switchgrass for each county in Oklahoma. The yield estimates correlates with the rainfall pattern in Oklahoma.

It seems reasonable that Oklahoma can support multiple ethanol plants. The best regions to start a biofuel processing plants would be in the north eastern and central Oklahoma based solely on the potential supply of switchgrass by region. Thus the actual distribution and total quantity of supply will depend on the profitability of switchgrass relative to other uses.

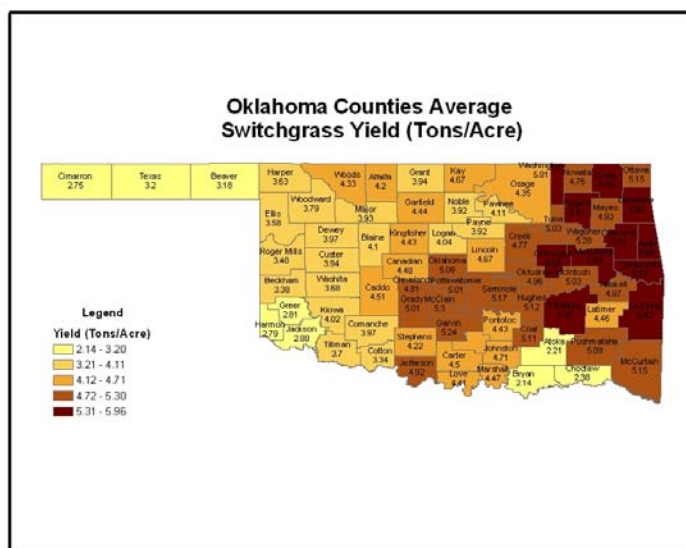


Figure 11: Oklahoma County Switchgrass Yields (tons/acre)

Estimated Switchgrass Yields in Kansas

Yield data collected from the NRCS web resources for primary and secondary biomass crops was used to estimate the switchgrass yield by soil types for all the 105 counties in Kansas. The estimation was performed for all the soil types that support crop production (Soil class 1 to soil class 4). All soil types in Soil class I-IV were taken under study assuming that the average of several soil types would better reflect the Switchgrass County yield.

The estimation was based on the average switchgrass yield data collected from the research stations. It was also based on switchgrass yields of northern Oklahoma counties. For example, if a soil type in the neighboring counties in Oklahoma and Kansas were same, then the yield for that soil type in Oklahoma was assigned to the soil type in Kansas assuming that the yield for these two similar soil types in neighboring counties should be same. Then the switchgrass yield from the experiment station and the neighboring counties in Oklahoma were compared with the yields of several other crops obtained from the NRCS for that particular soil type and switchgrass yields were estimated.

The estimation covered 81% of the total land area of Kansas. On average, we estimated yield for 42 different soil types in each county and in total, 4,379 soil types. In some counties, the soil types we used were as low as 5 (Linn County) and in others it was as high as 102 (Leavenworth and Reno County). The number of crops we used for comparison ranged from 2 to 6. The most frequently used crops for comparisons were grain sorghum and winter wheat. Other crops used as well are alfalfa, corn, soybean, smooth brome grass, tall wheat grass, improved bermuda grass and weeping love grass. The estimated yields were as low as 2.51 tons/acre (Cheyenne County) and as high as 7.35 tons/acre (Johnson County). The average switchgrass yield has been mapped using Arc GIS 9.2. The map is based on the estimated mean yield of switchgrass for several soil types in each county of Kansas.

Table 14: Estimates of Switchgrass Yield in Kansas Counties

SN	County	Yield (Ton/Acre)	Acres	SN	County	Yield (Ton/Acre)	Acres
1	Allen	6.00	287,219	31	Geary	4.80	146,621
2	Anderson	5.86	302,821	32	Gove	3.90	540,595
3	Atchison	4.27	275,073	33	Graham	4.30	408,099
4	Barber	4.40	356,138	34	Grant	3.75	375,425
5	Barton	4.93	524,498	35	Gray	3.89	536,185
6	Bourbon	6.06	299,014	36	Greeley	3.66	478,461
7	Brown	4.84	365,217	37	Greenwood	5.00	412,501
8	Butler	4.97	784,570	38	Hamilton	3.33	521,505
9	Chase	4.12	312,982	39	Harper	4.33	438,051
10	Chautauqua	4.86	175,308	40	Harvey	4.51	333,808
11	Cherokee	6.04	312,894	41	Haskell	3.67	360,809
12	Cheyenne	2.51	3,469	42	Hodgeman	4.49	486,508
13	Clark	4.12	349,844	43	Jackson	5.89	415,455
14	Clay	4.41	363,667	44	Jefferson	6.57	327,671
15	Cloud	4.89	389,013	45	Jewell	3.47	539,643
16	Coffey	4.88	371,726	46	Johnson	7.35	318,963
17	Comanche	4.85	320,977	47	Kearny	3.58	415,104
18	Cowley	4.01	224,714	48	Kingman	4.24	373,192
19	Crawford	6.23	332,789	49	Kiowa	4.92	284,739
20	Decatur	3.47	430,149	50	Labette	6.07	387,142
21	Dickinson	4.32	492,986	51	Lane	3.43	423,318
22	Doniphan	4.69	264,483	52	Leavenworth	6.19	246,532
23	Douglas	6.84	279,949	53	Lincoln	4.77	425,479
24	Edwards	4.80	329,281	54	Linn	6.82	63,488

25	Elk	5.32	105,680
26	Ellis	5.23	519,863
27	Ellsworth	4.89	378,785
28	Finney	3.23	691,613
29	Ford	4.39	701,803
30	Franklin	5.86	367,565

55	Logan	2.96	523,556
56	Lyon	4.86	470,476
57	McPherson	4.56	512,784
58	Marion	4.12	515,885
59	Marshall	3.78	480,299
60	Meade	3.80	427,025

SN	County	Yield (Ton/Acre)	Acres
61	Miami	6.38	272,846
62	Mitchell	4.60	534,895
63	Montgomery	5.37	255,369
64	Morris	4.60	384,968
65	Morton	3.70	437,940
66	Nemaha	4.28	567,856
67	Neosho	5.90	297,625
68	Ness	4.95	650,765
69	Norton	3.54	491,667
70	Osage	5.00	363,991
71	Osborne	4.87	571,072
72	Ottawa	4.78	354,514
73	Pawnee	4.94	440,282
74	Philips	4.14	425,329
75	Pottawatomie	5.79	329,451
76	Pratt	4.56	306,447
77	Rawlins	3.25	457,558
78	Reno	4.88	911,044

SN	County	Yield (Ton/Acre)	Acres
91	Sherman	2.84	533,697
92	Smith	4.13	560,602
93	Stafford	4.6	426,070
94	Stanton	3.57	426,939
95	Stevens	3.86	413,715
96	Sumner	4.39	714,056
97	Thomas	3.76	599,562
98	Trego	4.69	429,729
99	Wabaunsee	5.91	271,590
100	Wallace	3.54	437,001
101	Washington	3.57	478,486
102	Wichita	3.8	441,717
103	Wilson	5.29	242,271
104	Woodson	4.95	196,909
105	Wyandotte	5.38	78,445

79	Republic	3.82	482,329
80	Rice	5.05	406,440
81	Riley	5.17	289,036
82	Rooks	4.53	514,519
83	Rush	5.00	443,088
84	Russell	4.79	391,188
85	Saline	4.86	391,763
86	Scott	3.37	444,474
87	Sedgwick	4.91	554,549
88	Seward	4.00	314,439
89	Shawnee	6.12	299,588
90	Sheridan	3.89	452,429

Estimated Switchgrass Yields in Louisiana and Arkansas

Yield data collected from the NRCS web resources for primary and secondary biomass crops was used to estimate the switchgrass yield by soil types for all the 64 parishes in Louisiana and 58 counties in Arkansas. For some of the counties (17) in Arkansas, there were no crop yield data in the NRCS web resources and so no estimation for switchgrass for these counties could be made. The procedure followed was similar to what was done for estimating the switchgrass yield for Oklahoma and Kansas. The estimation was performed for all the soil types that support crop production (Soil class 1 to soil class 4). All soil types in Soil class I-IV were taken under study assuming that the average of several soil types would better reflect the Switchgrass County yield.

From the literature review, we found that the average switchgrass yield for Dexter Silt Loam in East Feliciana Parish is 4.31 tons/acre on the basis of which switchgrass yield for several other soil types in this county were computed. Then the same yield was assigned for the neighboring Parishes if they had exactly the same soil type. The ratio estimation procedure was employed and average yield for the Parishes calculated. The same procedure was followed until we got the average yield for all the Parishes.

The estimation covered 82% of the total land area of Louisiana. Estimation was performed for as low as 6 soil types for some Parishes (Assumption Parish) and as high as 56 for other Parishes (St. Landry Parish). The number of crops we used for comparison ranged from 4 to 6. The most frequently used crops for comparisons were common bermuda grass, soybean, bahia grass, improved bermuda grass, corn and cotton lint. The estimated switchgrass yield ranged from 2.4 tons/acre (Jackson Parish) to 5.03 tons/acre (East Feliciana Parish).

Arkansas

The switchgrass yield obtained from the literature review for Bowie Fine Sandy Loam in Hempstead County was averaged based on which the switchgrass yield for several other soil

types in this county were computed. The switchgrass yield for Logan County was also obtained from literature review but since the soil classification was not mentioned in the literature we did not use the yield data of this county in yield estimation. Similar procedure of identifying same soil type in the neighboring counties and assigning the switchgrass yield to it was done. The ratio estimation procedure was employed and average switchgrass yield for most of the counties were estimated. Estimation could not be made for some counties (17) which had no crop yield information because ratio estimation procedure could not be employed.

The estimation covered 55% of the total land area in Arkansas. Estimation was performed for as low as 13 soil types for some counties (Garland and Grant County) and as high as 66 for other counties (Pike County). The number of crops used for comparison ranged from 4 to 6. The most frequently used crops for comparisons were common bermuda grass, tall wheat, wheat grazeout, soybean and improved bermuda grass. The estimated switchgrass yield was as low as 2.75 tons/acre (Pike County) and as high as 8.96 tons/acre (Crawford County).

The average switchgrass yield has been mapped using Arc GIS 10. The map is based on the estimated mean yield of switchgrass for several soil types in Louisiana and Arkansas.

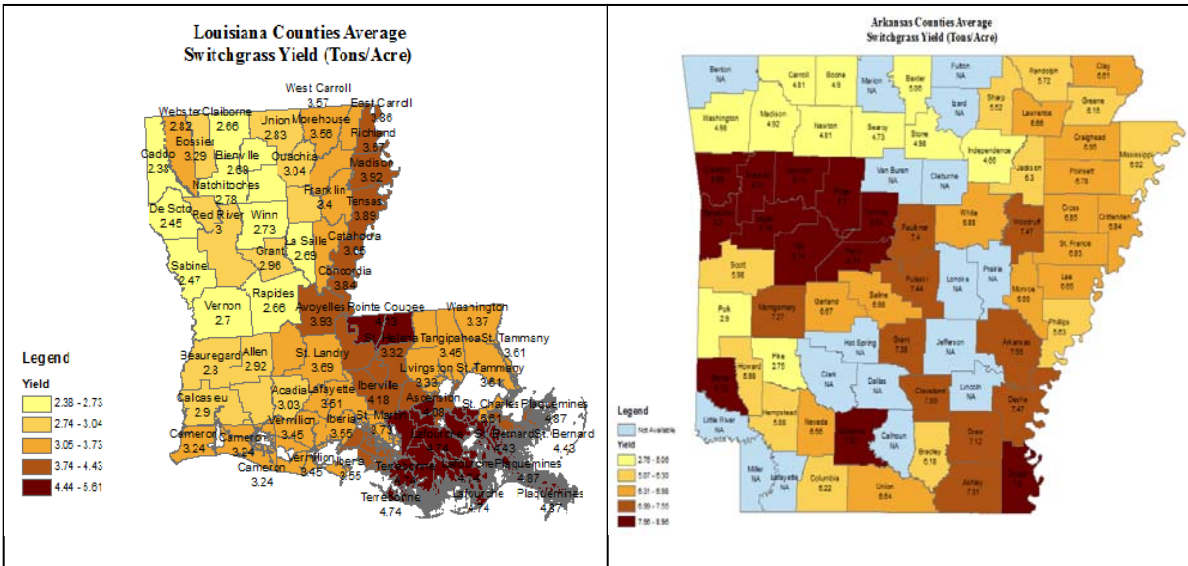


Table 15: Estimates of Switchgrass Yield in Louisiana Parishes

SN	Parish	Yield (Ton/Acre)	Acres	SN	Parish	Yield (Ton/Acre)	Acres
1	Acadia	3.03	506527	33	Madison	3.92	459713
2	Allen	2.92	729186	34	Morehouse	3.56	542907
3	Ascension	4.08	128627	35	Natchitoches	2.78	517134
4	Assumption	4.98	88841	36	Orleans	3.47	49617
5	Avoyelles	3.93	499505	37	Ouachita	3.04	329869
6	Beauregard	2.8	873013	38	Plaquemines	4.87	59262
7	Bienville	2.69	398657	39	Pointe Coupee	4.13	371915
8	Bossier	3.29	416587	40	Rapides	2.66	638148
9	Caddo	2.38	537741	41	Red River	3	287477
10	Calcasieu	2.9	894588	42	Richland	3.57	464359
11	Caldwell	2.93	410949	43	Sabine	2.47	320679
12	Cameron	3.24	170056	44	St. Bernard	4.43	19383
13	Catahoula	3.65	417735	45	St. Charles	5.61	40781
14	Claiborne	2.66	246976	46	St. Helena	3.32	362238
15	Concordia	3.84	478215	47	St. James	4.93	60852
16	De Soto	2.45	388239	48	St. John the Baptist	4.24	33193
17	East Baton Rouge	3.85	266450	49	St. Landry	3.69	627122
18	East Carroll	3.86	258562	50	St. Martin	3.73	192313
19	East Feliciana	5.03	315040	51	St. Mary	4.26	142757
20	Evangeline	3.42	575622	52	St. Tammany	3.61	442922
21	Franklin	3.4	516808	53	Tangipahoa	3.45	1137394
22	Grant	2.96	364625	54	Tensas	3.89	506567
23	Iberia	3.55	155542	55	Terrebonne	4.74	109903

24	Iberville	4.18	201089
25	Jackson	2.4	335033
26	Jefferson	5.5	72498
27	Jefferson Davis	2.95	596021
28	Lafayette	3.51	173307
29	Lafourche	4.74	174825
30	La Salle	2.69	308801
31	Lincoln	2.41	241168
32	Livingston	3.33	403890

56	Union	2.83	290575
57	Vermilion	3.45	447219
58	Vernon	2.7	600921
59	Washington	3.37	394006
60	Webster	2.82	292508
61	West Baton Rouge	4.11	130902
62	West Carroll	3.57	373251
63	West Feliciana	4.85	165748
64	Winn	2.73	398665

Table 16: Estimates of Switchgrass Yield in Arkansas Counties

SN	County	Yield (Ton/Acre)	Acres
1	Arkansas	7.55	600271
2	Ashley	7.31	575800
3	Baxter	5.06	353350
4	Benton	NA	NA
5	Boone	4.9	130297
6	Bradley	6.18	366728
7	Calhoun	NA	NA
8	Carroll	4.81	127120
9	Chicot	7.9	366084
10	Clark	NA	NA
11	Clay	6.61	362778
12	Cleburne	NA	NA
13	Cleveland	7.09	328934
14	Columbia	6.22	395624
15	Conway	8.08	242378
16	Craighead	6.95	452310
17	Crawford	8.96	129692
18	Crittenden	6.84	375870
19	Cross	6.85	398545
20	Dallas	NA	NA
21	Desha	7.47	524611
22	Drew	7.12	517442
23	Faulkner	7.4	300847

SN	County	Yield (Ton/Acre)	Acres
41	Little River	NA	NA
42	Logan	8.79	228941
43	Lonoke	NA	NA
44	Madison	4.92	120531
45	Marion	NA	NA
46	Miller	NA	NA
47	Mississippi	6.02	860490
48	Monroe	6.55	563040
49	Montgomery	7.27	136717
50	Nevada	6.56	290195
51	Newton	4.81	52937
52	Ouachita	7.91	337537
53	Perry	8.14	148630
54	Phillips	5.63	417730
55	Pike	2.75	193224
56	Poinsett	6.78	484795
57	Polk	2.9	164016
58	Pope	8.3	214122
59	Prairie	NA	NA
60	Pulaski	7.44	299448
61	Randolph	5.72	333350
62	St. Francis	6.83	455970
63	Saline	6.98	264936

24	Franklin	8.31	204934
25	Fulton	NA	NA
26	Garland	6.67	83009
27	Grant	7.38	250559
28	Greene	6.15	372480
29	Hempstead	5.88	375640
30	Hot Spring	NA	NA
31	Howard	5.98	195490
32	Independence	4.66	308766
33	Izard	NA	NA
34	Jackson	6.3	538428
35	Jefferson	NA	NA
36	Johnson	8.11	138820
37	Lafayette	NA	NA
38	Lawrence	6.66	366690
39	Lee	6.65	363060
40	Lincoln	NA	NA

64	Scott	5.98	185088
65	Searcy	4.73	77710
66	Sebastian	8.2	195708
67	Sevier	8.12	237768
68	Sharp	5.52	174751
69	Stone	4.98	86923
70	Union	6.64	706451
71	Van Buren	NA	NA
72	Washington	4.98	260859
73	White	6.88	517604
74	Woodruff	7.47	358958
75	Yell	8.14	348858

Estimated Switchgrass Yields for Texas

Yield data collected from the NRCS web resources for primary and secondary biomass crops were used to estimate the switchgrass yield by soil types for all the 254 counties in Texas and 114 counties in Missouri. For some of the counties (56) in Texas, there were no crop yield data in the NRCS web resources and so no estimation for switchgrass for these counties could be made. We will explore other suitable methodologies in next quarter to estimate yield for these counties. The procedure followed in estimating yield for rest of the counties was similar to procedure applied for estimating switchgrass yield for Oklahoma, Kansas, Louisiana and Arkansas in previous quarters. The estimation was performed for all the soil types that support crop production (Soil class 1 to soil class 4). All soil types in Soil class I-IV were taken under study assuming that the average of several soil types would better reflect the Switchgrass County yield.

We found switchgrass yield for five different counties (Erath, Dallas, Bell, Brazos and Bee) in Texas from the literature review. The yields were from the experiment stations and were for a particular soil type. These yields were averaged and used for yield estimation for other counties by the ratio estimation method as was used previously. The procedure was followed until we got the average yield for all the counties. This method could not be applied for 56 counties as they did not have any yield information for other crops and no comparison could be made. The estimation covered almost $3/4^{\text{th}}$ of the total land area of Texas. The estimated switchgrass yield ranged from 1.42 tons/acre (Ochiltree) to 10.44 tons/acre (Brazoria).

Texas Counties Average Switchgrass Yield (Tons/Acre)

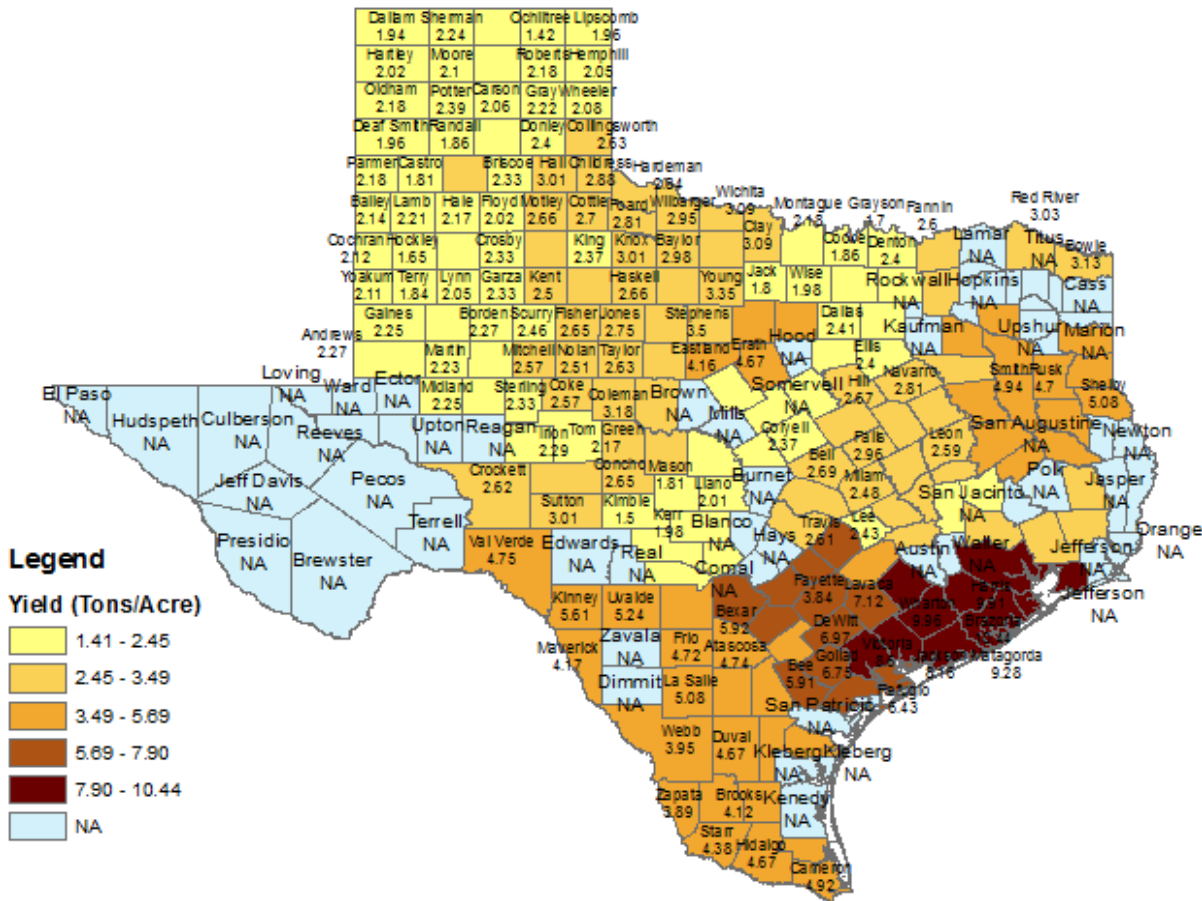


Figure 15: Texas Switchgrass Yields

Table 17: Estimates of Switchgrass Yield in Texas Counties

SN	County	Yield
1	Anderson	4.38
2	Andrews	2.27
3	Angelina	5.20
4	Aransas	NA
5	Archer	3.19
6	Armstrong	2.20
7	Atascosa	4.74
8	Austin	NA
9	Bailey	2.14
10	Bandera	1.87
11	Bastrop	7.90
12	Baylor	2.98
13	Bee	5.91
14	Bell	2.69
15	Bexar	5.92
16	Blanco	NA
17	Borden	2.27
18	Bosque	2.16
19	Bowie	3.13
20	Brazoria	10.44
21	Brazos	2.85
22	Brewster	NA
23	Briscoe	2.33
24	Brooks	4.12

SN	County	Yield
46	Comal	NA
47	Comanche	2.02
48	Concho	2.65
49	Cooke	1.86
50	Coryell	2.37
51	Cottle	2.70
52	Crane	NA
53	Crockett	2.62
54	Crosby	2.33
55	Culberson	NA
56	Dallam	1.94
57	Dallas	2.41
58	Dawson	1.97
59	Deaf Smith	1.96
60	Delta	NA
61	Denton	2.40
62	DeWitt	6.97
63	Dickens	2.54
64	Dimmit	NA
65	Donley	2.40
66	Duval	4.67
67	Eastland	4.16
68	Ector	NA
69	Edwards	NA

SN	County	Yield
91	Grayson	1.70
92	Gregg	NA
93	Grimes	2.37
94	Guadalupe	7.74
95	Hale	2.17
96	Hall	3.01
97	Hamilton	2.16
98	Hansford	1.92
99	Hardeman	2.84
100	Hardin	NA
101	Harris	9.91
102	Harrison	5.69
103	Hartley	2.02
104	Haskell	2.66
105	Hays	NA
106	Hemphill	2.05
107	Henderson	2.97
108	Hidalgo	4.67
109	Hill	2.67
110	Hockley	1.65
111	Hood	NA
112	Hopkins	NA
113	Houston	5.04
114	Howard	2.30

25	Brown	NA
26	Burleson	2.76
27	Burnet	NA
28	Caldwell	7.55
29	Calhoun	5.87
30	Callahan	3.16
31	Cameron	4.92
32	Camp	NA
33	Carson	2.06
34	Cass	NA
35	Castro	1.81
36	Chambers	9.49
37	Cherokee	5.01
38	Childress	2.88
39	Clay	3.09
40	Cochran	2.12
41	Coke	2.57
42	Coleman	3.18
43	Collin	2.45
44	Collingsworth	2.63
45	Colorado	8.50

70	Ellis	2.40
71	El Paso	NA
72	Erath	4.67
73	Falls	2.96
74	Fannin	2.60
75	Fayette	3.84
76	Fisher	2.65
77	Floyd	2.02
78	Foard	2.81
79	Fort Bend	10.29
80	Franklin	NA
81	Freestone	2.65
82	Frio	4.72
83	Gaines	2.25
84	Galveston	10.00
85	Garza	2.33
86	Gillespie	2.05
87	Glasscock	2.37
88	Goliad	6.75
89	Gonzales	6.43
90	Gray	2.22

115	Hudspeth	NA
116	Hunt	2.52
117	Hutchinson	2.11
118	Irion	2.29
119	Jack	1.80
120	Jackson	8.16
121	Jasper	NA
122	Jeff Davis	NA
123	Jefferson	NA
124	Jim Hogg	4.25
125	Jim Wells	4.95
126	Johnson	2.29
127	Jones	2.75
128	Karnes	5.16
129	Kaufman	NA
130	Kendall	2.01
131	Kenedy	NA
132	Kent	2.50
133	Kerr	1.98
134	Kimble	1.50
135	King	2.37

SN	County	Yield
136	Kinney	5.61
137	Kleberg	NA
138	Knox	3.01

SN	County	Yield
181	Orange	NA
182	Palo Pinto	4.25
183	Panola	5.14

SN	County	Yield
226	Tom Green	2.17
227	Travis	2.61
228	Trinity	5.18

139	Lamar	NA
140	Lamb	2.21
141	Lampasas	1.99
142	La Salle	5.08
143	Lavaca	7.12
144	Lee	2.43
145	Leon	2.59
146	Liberty	3.02
147	Limestone	2.71
148	Lipscomb	1.96
149	Live Oak	5.21
150	Llano	2.01
151	Loving	NA
152	Lubbock	2.16
153	Lynn	2.05
154	Madison	2.57
155	Marion	NA
156	Martin	2.23
157	Mason	1.81
158	Matagorda	9.28
159	Maverick	4.17
160	McCulloch	3.22
161	McLennan	2.86
162	McMullen	5.26
163	Medina	5.04
164	Menard	2.85

184	Parker	4.68
185	Parmer	2.18
186	Pecos	NA
187	Polk	NA
188	Potter	2.39
189	Presidio	NA
190	Rains	NA
191	Randall	1.86
192	Reagan	NA
193	Real	NA
194	Red River	3.03
195	Reeves	NA
196	Refugio	6.43
197	Roberts	2.18
198	Robertson	2.85
199	Rockwall	NA
200	Runnels	2.76
201	Rusk	4.70
202	Sabine	NA
203	San Augustine	NA
204	San Jacinto	NA
205	San Patricio	NA
206	San Saba	1.78
207	Schleicher	2.64
208	Scurry	2.46
209	Shackelford	3.11

229	Tyler	2.62
230	Upshur	NA
231	Upton	NA
232	Uvalde	5.24
233	Val Verde	4.75
234	Van Zandt	4.83
235	Victoria	8.60
236	Walker	2.36
237	Waller	NA
238	Ward	NA
239	Washington	2.61
240	Webb	3.95
241	Wharton	9.96
242	Wheeler	2.08
243	Wichita	3.09
244	Wilbarger	2.95
245	Willacy	4.96
246	Williamson	2.68
247	Wilson	6.18
248	Winkler	NA
249	Wise	1.98
250	Wood	5.02
251	Yoakum	2.11
252	Young	3.35
253	Zapata	3.89
254	Zavala	NA

165	Midland	2.25
166	Milam	2.48
167	Mills	NA
168	Mitchell	2.57
169	Montague	2.18
170	Montgomery	2.68
171	Moore	2.10
172	Morris	NA
173	Motley	2.66
174	Nacogdoches	4.84
175	Navarro	2.81
176	Newton	NA
177	Nolan	2.51
178	Nueces	5.18
179	Ochiltree	1.42
180	Oldham	2.18

210	Shelby	5.08
211	Sherman	2.24
212	Smith	4.94
213	Somervell	NA
214	Starr	4.38
215	Stephens	3.50
216	Sterling	2.33
217	Stonewall	2.74
218	Sutton	3.01
219	Swisher	2.78
220	Tarrant	2.29
221	Taylor	2.63
222	Terrell	NA
223	Terry	1.84
224	Throckmorton	3.11
225	Titus	NA

Estimated Switchgrass Yield in Missouri

Switchgrass yield for only one county (St. Louis) could be obtained from the literature review. The soil type was Hartwell Silt loam/Hartwell Silty Clay loam. But since no slopes were mentioned in the literature review for this soil type and we had several soil types for St. Louis that was collected from the NRCS web resources with the same name with different slopes corresponding to different crops yield for different crops, the yield from the literature review could not be used. Therefore, we started from a county in Kansas (Doniphan) which had a matching soil type with the neighboring county in Missouri (Holt). Then similar procedure of identifying same soil type in the neighboring counties and assigning the switchgrass yield to it was done. The ratio estimation procedure was employed and average switchgrass yield for all the counties were estimated. The estimated switchgrass yield was as low as 3.27 tons/acre (Scotland County) and as high as 5.97 tons/acre (Holt County).

Missouri Counties Average Switchgrass Yield (Tons/Acre)

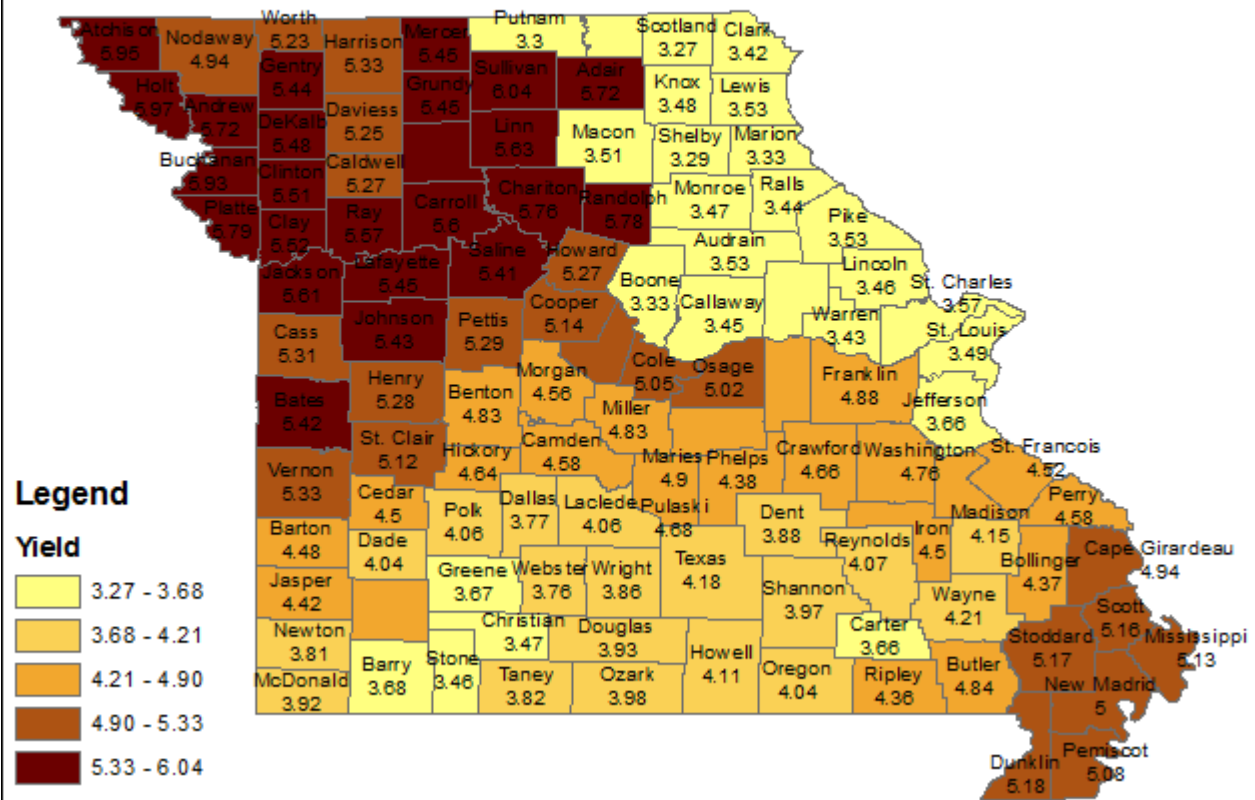


Figure 16: Missouri Switchgrass Yields.

Table 18: Estimates of Switchgrass Yield in Missouri Counties

SN	County	Yield
1	Adair	5.72
2	Andrew	5.72
3	Atchison	5.95
4	Audrain	3.53
5	Barry	3.68
6	Barton	4.48
7	Bates	5.42
8	Benton	4.83
9	Bollinger	4.37
10	Boone	3.33
11	Buchanan	5.93
12	Butler	4.84
13	Caldwell	5.27
14	Callaway	3.45
15	Camden	4.58
16	Cape Girardeau	4.94
17	Carroll	5.60
18	Carter	3.66
19	Cass	5.31
20	Cedar	4.50
21	Chariton	5.76
22	Christian	3.47
23	Clark	3.42
24	Clay	5.52

SN	County	Yield
46	Howell	4.11
47	Iron	4.50
48	Jackson	5.61
49	Jasper	4.42
50	Jefferson	3.66
51	Johnson	5.43
52	Knox	3.48
53	Laclede	4.06
54	Lafayette	5.45
55	Lawrence	4.89
56	Lewis	3.53
57	Lincoln	3.46
58	Linn	5.63
59	Livingstone	5.43
60	Macon	3.51
61	Madison	4.15
62	Maries	4.90
63	Marion	3.33
64	McDonald	3.92
65	Mercer	5.45
66	Miller	4.83
67	Mississippi	5.13
68	Moniteau	5.09
69	Monroe	3.47

SN	County	Yield
91	Ripley	4.36
92	Saline	5.41
93	Schuyler	3.31
94	Scotland	3.27
95	Scott	5.16
96	Shannon	3.97
97	Shelby	3.29
98	St. Charles	3.57
99	St. Clair	5.12
100	St. Francois	4.52
101	St. Louis	3.49
102	Ste. Genevieve	4.86
103	Stoddard	5.17
104	Stone	3.46
105	Sullivan	6.04
106	Taney	3.82
107	Texas	4.18
108	Vernon	5.33
109	Warren	3.43
110	Washington	4.76
111	Wayne	4.21
112	Webster	3.76
113	Worth	5.23
114	Wright	3.86

25	Clinton	5.51
26	Cole	5.05
27	Cooper	5.14
28	Crawford	4.66
29	Dade	4.04
30	Dallas	3.77
31	Daviess	5.25
32	Dent	3.88
33	DeKalb	5.48
34	Douglas	3.93
35	Dunklin	5.18
36	Franklin	4.88
37	Gasconade	4.79
38	Gentry	5.44
39	Greene	3.67
40	Grundy	5.45
41	Harrison	5.33
42	Henry	5.28
43	Hickory	4.64
44	Holt	5.97
45	Howard	5.27

70	Montgomery	3.34
71	Morgan	4.56
72	New Madrid	5.00
73	Newton	3.81
74	Nodaway	4.94
75	Oregon	4.04
76	Osage	5.02
77	Ozark	3.98
78	Pemiscot	5.08
79	Perry	4.58
80	Pettis	5.29
81	Phelps	4.38
82	Pike	3.53
83	Platte	5.79
84	Polk	4.06
85	Pulaski	4.68
86	Putnam	3.30
87	Ralls	3.44
88	Randolph	5.78
89	Ray	5.57
90	Reynolds	4.07

Estimated Switchgrass Yield in Colorado and New Mexico

Yield data collected from the NRCS web resources for primary and secondary biomass crops was used to estimate the switchgrass yield by soil types for all the 64 counties in Colorado and 33 counties in New Mexico. The geographical nature of these two states does not favor much of the crop growth. For most of the counties in these two states no crop yield data were available in the web resource and no comparison for those counties could be made. The switchgrass yield estimation could therefore be made for only 7 counties in New Mexico and only 24 counties in Colorado. Suitable methodologies will be explored in next quarter to estimate the missing yield for these counties. The procedure followed in estimating yield for rest of the counties was similar to the procedure used before for estimating switchgrass yield in Oklahoma, Kansas, Louisiana, Arkansas, Missouri and Texas. The estimation was performed for all the soil types that support crop production (Soil class 1 to soil class 4). All soil types in Soil class I-IV were taken under study. For yield comparison only non-irrigated crop yield was used.

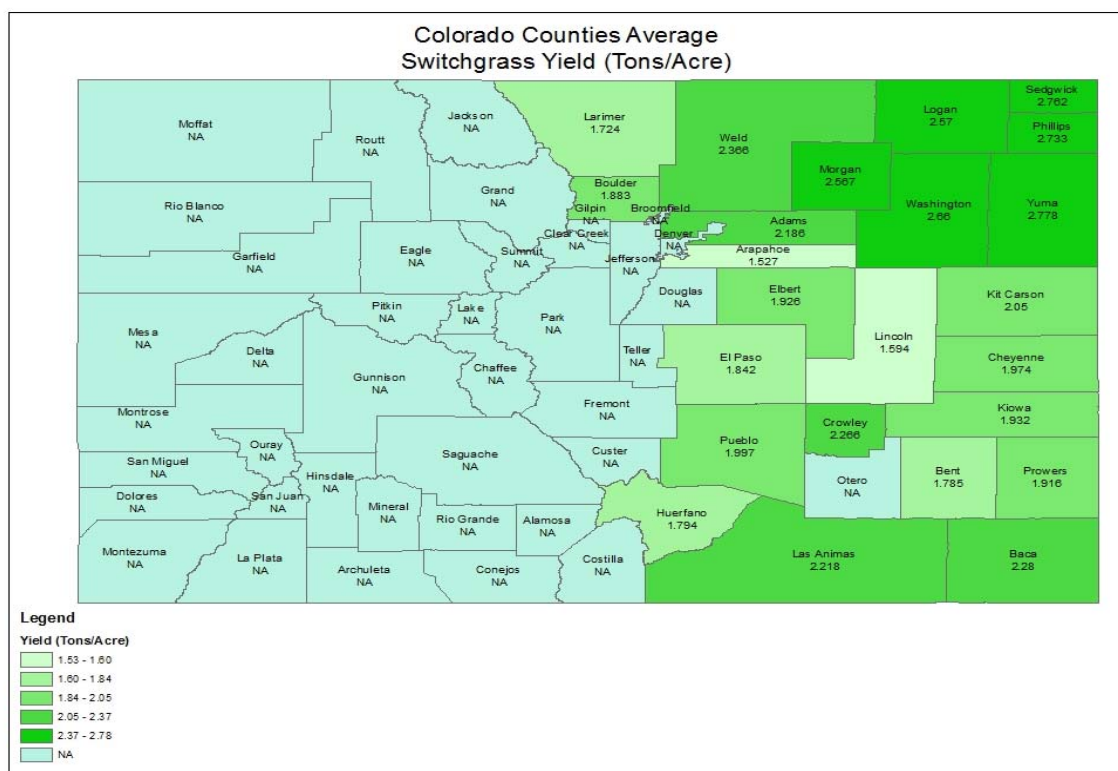


Figure 17: Colorado County Switchgrass Yields

The switchgrass yield data for the same soil type in Baca County in Colorado was found from the same soil type in the neighboring county (Morton County) in Kansas. This yield data was used as a basis for comparison and yield estimation. Then yield for several other soil types were compared and estimated. Yields for several soil types in one county were averaged and was referred to as the county average. Another same soil type was identified for one of the neighboring county of Baca and the same yield was assigned. Then switchgrass yield for that county was estimated. Similar procedure was followed until we got the average yield for most of the counties in eastern Colorado. The method could not be applied for several other counties in western Colorado as they did not have any yield information for other crops and no comparison could be made. The estimated switchgrass yield ranged from 1.52 tons/acre (Arapahoe) to 2.78 tons/acre (Yuma).

Table 19: Estimates of Switchgrass Yield in Colorado Counties

SN	County	Yield	SN	County	Yield
1	Adams	2.186	13	Larimer	1.724
2	Arapahoe	1.527	14	Las Animas	2.218
3	Baca	2.28	15	Lincoln	1.594
4	Bent	1.785	16	Logan	2.57
5	Boulder	1.883	17	Morgan	2.567
6	Cheyenne	1.974	18	Phillips	2.733
7	Crowley	2.266	19	Prowers	1.916
8	Elbert	1.926	20	Pueblo	1.997
9	El Paso	1.842	21	Sedgwick	2.762
10	Huerfano	1.794	22	Washington	2.66
11	Kiowa	1.932	23	Weld	2.366
12	Kit Carson	2.05	24	Yuma	2.778

Switchgrass Yield Estimation in New Mexico

Switchgrass yield for only seven counties in New Mexico could be estimated. No crop yield data for other remaining counties in New Mexico were available in the NRCS web resources. This is because we were trying to work only between soil class I to IV and so no crop yield data were obtained from the NRCS web resources. The geographical nature of the state also does not support crop growth in most of the counties. For the seven counties the switchgrass yield for a particular soil type in one of the neighboring counties in Texas was compared and obtained. Then ratio estimation method used to estimate yields. Similar procedure was used to estimate yield for other counties. The estimated switchgrass yield was as low as 1.48 tons/acre (Harding County) and as high as 2.52 tons/acre (Union County).

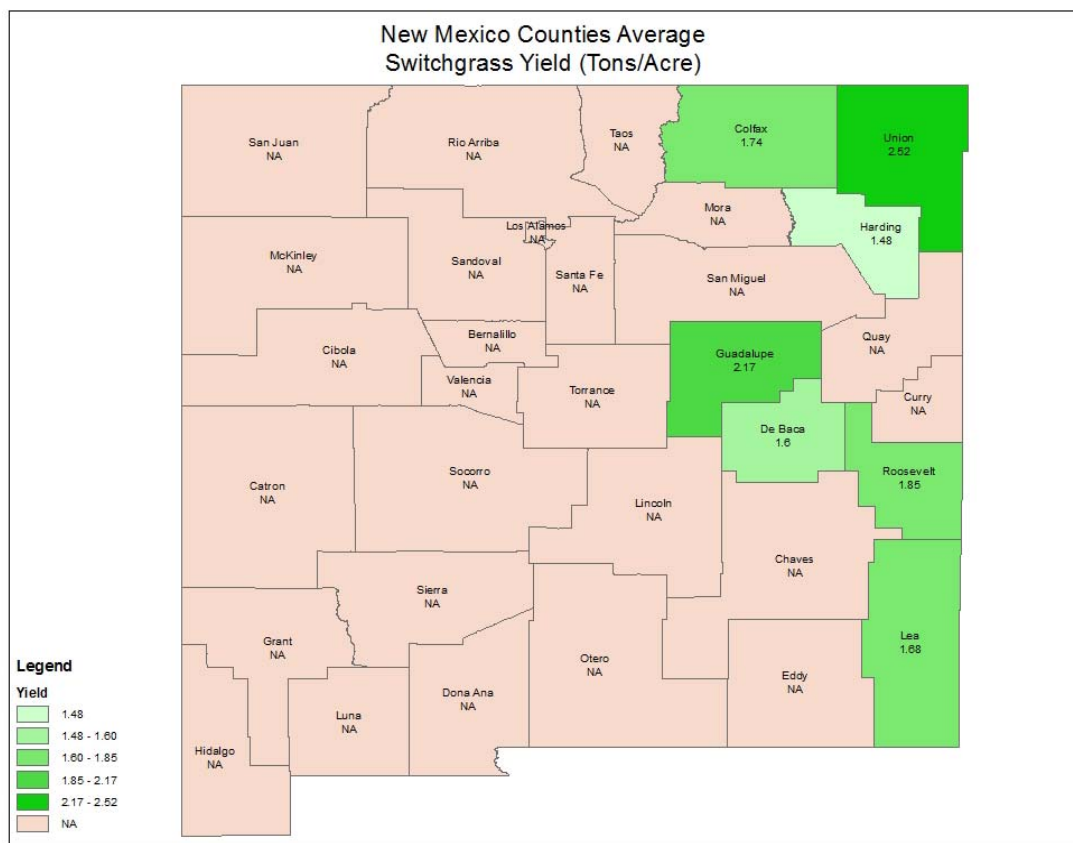


Figure 18: New Mexico Switchgrass Yields, Selected Counties

Table 20: Estimates of Switchgrass Yield in New Mexico Counties

SN	County	Yield
1	Colfax	1.74
2	De Baca	1.6
3	Guadalupe	2.17
4	Harding	1.48
5	Lea	1.68
6	Roosevelt	1.85
7	Union	2.52

Summary of Switchgrass Yield Estimates in the South Central Region

The previously estimated yields were updated by revisiting the literature reviews and previous calculation. Wherever the estimates looked off or abnormal detail checks were made. ArcGIS 9.2 was used extensively to map the estimated data for each of the states separately and the distribution of the data was observed. Other crops data like the Common Bermuda Grass, Improved Bermuda Grass and Wheat Grazeout etc which were frequently used for ratio estimation and calculation were also mapped for each of the state by county. Their distribution was compared with the distribution of the switchgrass yield. When the distribution looked satisfactory we mapped the switchgrass yield data for whole South Central Region. This distribution shows that the maximum switchgrass yield are obtained in the north eastern region of the S. Central, mostly in eastern Kansas and Oklahoma, Central and Western Missouri and Arkansas. Yields in Colorado and New Mexico were too low (<2.55 tons/acre) and the average yield in Texas was around 3 tons/acre. Table 21 provides summarized the estimated yield.

Table 21: Regional Switchgrass Production Estimates, by State.

SN	State	Min Yield (Tons/Acre)	Max Yield (Tons/Acre)	Mean Yield (Tons/Acre)
1	Missouri	3.71	7.98	6.08
2	Arkansas	3.39	6.60	5.51
3	Louisiana	2.53	7.18	4.89
4	Kansas	2.79	6.99	4.68
5	Oklahoma	2.14	6.12	4.43
6	Texas	1.68	5.08	3.02
7	Colorado	1.61	3.38	2.25
8	New Mexico	1.36	2.55	1.81

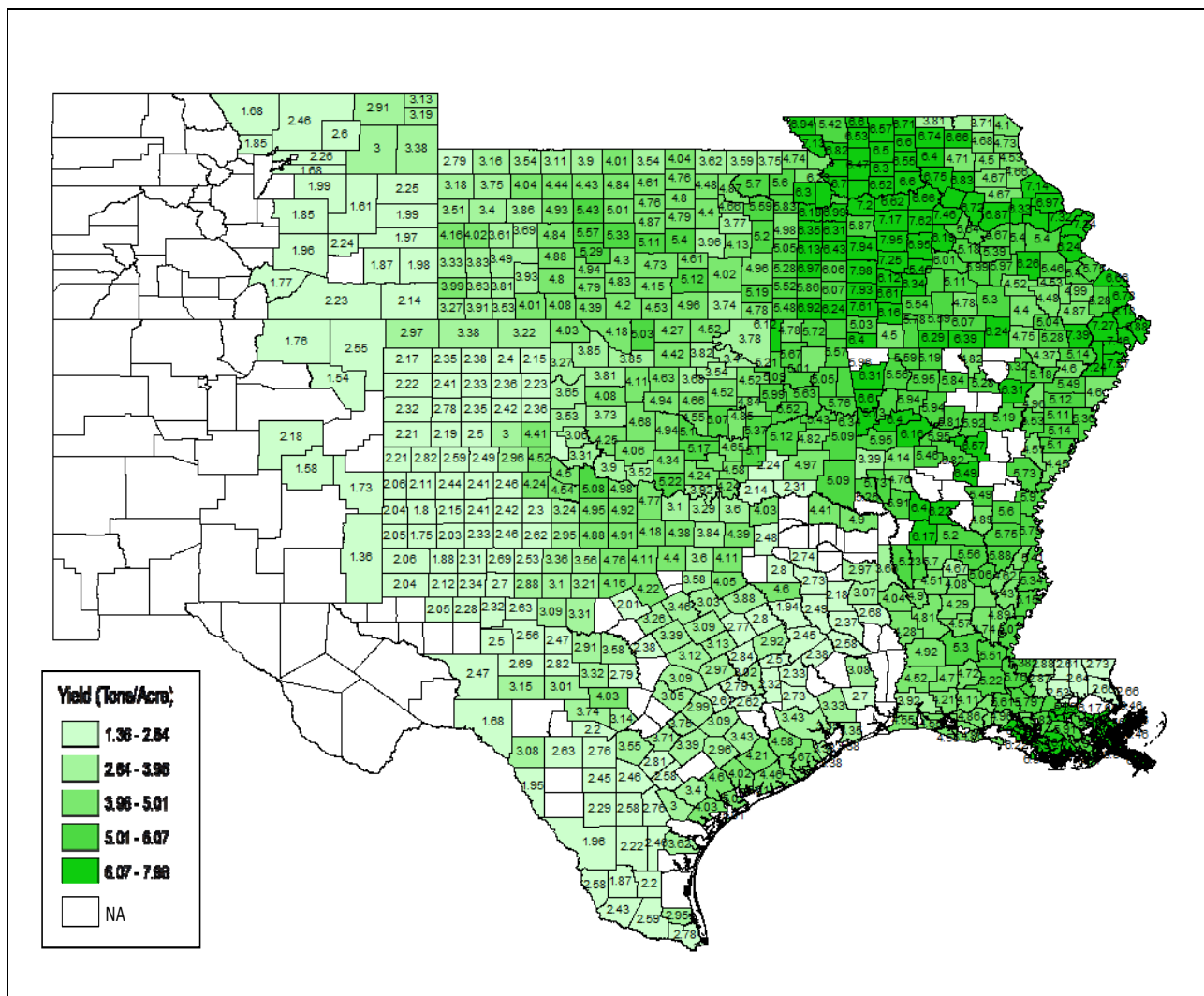


Fig 19: S. Central Switchgrass Yield Estimates (Tons/Acre)

Conclusions: Biomass Supply

Given the mandates of EISA 2007, it is necessary to assess the potential supply of switchgrass for cellulosic conversion to ethanol. Currently there is insufficient yield and costs data to project the regional supply of switchgrass under commercial production. A database of switchgrass yields is important to assess the biomass feedstock resource base and inform

potential investors of the regional cellulosic feedstock supply potential. The methodology described in this section illustrates how such a database of switchgrass yields can be developed. Estimating the available feed stock supply is an essential element for the development of a commercial biofuel industry. The section has outlined a methodology to use limited data coupled with soil and crop yield to estimate switchgrass yields.

References

- Bellow, M. E. 2003. Comparison of model-based methods for county-level estimation of crop yields. In FCSM Statistical Policy Working Paper 37: FCSM Research Conference, 2003. Washington, D.C.: Federal Committee on Statistical Methodology
- Caddel, J. ,G. Kakani, D. Porter, D. Redfearn, J. Malone, N. Walker, J. Warren, Y. Wu, H. Zhang. 2010. Switchgrass Production Guide for Oklahoma. Oklahoma Cooperative Extension Service. Division of Agricultural Sciences and Natural Resources. Oklahoma State University. Stillwater, OK, USA.
- De La Rosa, D., F. Cardona and J. Almorza. 1980. Crop Yield Predictions based on Properties of Soils in Sevilla, Spain. *Geoderma*, 25 (1981) 267-274
- Dicks M.R., J. Campiche, D. D. Torra Ugarte, C. Hellwinckel, H. L. Bryant and J. W. Richardson. 2009. Land Use Implications of Expanding Biofuel Demand. *Journal of Agricultural and Applied Economics*. 41,2 (August 2009): 435-453
- Doraiswamy, P. C., B. Akhmedov, L. Beard, A. Stern and R. Mueller. 2007. Operational Prediction of Crop Yields Using MODIS Data and Products. ISPRS Archives XXXVI-8/W48 Workshop Proceedings: Remote Sensing Support to Crop Yield Forecast and Area Estimates.
- Garcia-Paredes, J. D., K. R. Olson and J. M. Lang. 2000. Predicting Corn and Soybean Productivity for Illinois Soils. Department of Natural Resources and Environmental Sciences, University of Illinois at Urbana-Champaign, Urbana, USA.
- Guiling, P., D. Doye, and W. Brorsen, 2010. Oklahoma Agricultural Crop versus Pasture Land Values. Division of Agricultural Sciences and Natural Resources. URL: <http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-5524/AGEC-253web.pdf> [Accessed 10 December 2010]. Oklahoma State University. Stillwater, OK.
- Gunderson, C. A , E. B. Davis, H. I. Jager, T. O. West, R. D. Perlack, C. C. Brandt, S. D. Wullschleger, L. M. Baskaran, E. G. Wilkerson and M. E. Downing. 2008. Exploring

Potential US Switchgrass Production for Lignocellulosic Ethanol. Environmental Sciences Division. Oak Ridge National Laboratory.

Landau, S., R. A. C. Mitchell, V. Barnett, J. J. Colls, J. Craigon and R. W. Payne. 1999. A Parsimonious, Multiple-Regression Model of Wheat Yield Response to Environment. *Agricultural and Forest Meteorology* 101 (2000) 151-166

Olson K. R. and G. W. Olson. 1986. Use of Multiple Regression Analysis to Estimate Average Corn Yields Using Selected Soils and Climatic Data. University of Illinois, Urbana, USA.

Poldaru, R., J. Roots and A. H. Viira. 2005. Artificial Neural Network as an Alternative to Multiple Regression Analysis for Estimating the Parameters of Econometric Models. Institute of Economics and Social Sciences, Estonian University of Life Sciences, Estonia. *Agronomy Research* 3(2), 177-187.

Prasad, A. K. , L. Chai, R. P. Singh and M. Kafatos. Crop Yield Estimation Model for Iowa Using Remote Sensing and Surface Parameters. *International Journal of Applied Earth Observation and Geoinformation* 8 (2006) 26-33

Taliaferro, C.M. 2002. Breeding and Selection of New Switchgrass Varieties for Increased Biomass Production. ORNL/SUB-02-19XSY162C/01 2002:

Thomason, W. E., W. R. Raun, G. V. Johnson, C. M. Taliaferro, K. W. Freeman, K. J. Wynn and R. W. Mullen. 2004. Switchgrass Response to Harvest Frequency and Time and Rate of Applied Nitrogen. *Journal of Plant Nutrition*. Vol. 27, No. 7, pp. 1199–1226.

FEASIBILITY ASSESSMENT OF BIOMASS HARVESTING COOPERATIVE

Introduction

The renewable fuel standard mandates 16 billion gallons of fuel to be derived from advanced biofuels such as lignocellulosic biomass by 2022 [1]. This mandate has contributed to the continued growth of grain based ethanol plants. The first generation ethanol plants accessed grain feed stocks that could be easily purchased from the open market. Second generation biofuel industries will use dedicated energy crops like switchgrass for which a supply chain must be developed. Epplin et al. [2] suggest three alternatives for supply of biomass to ethanol facility. One alternative is to have producers grow, harvest and store biomass and provide it to the biorefinery on the basis of spot market prices or long term contracts. Another alternative is for the biorefinery to lease land from landholders and operate a large scale integrated production, harvest and storage operation. The third alternative is for the producers to form a biomass harvesting cooperative.

The structure of the harvesting, storage and transportation aspects of biomass supply chain has implications for agricultural producers and rural communities. A study of the economic impact of farmer-owned ethanol plants concluded that the contribution of a farmer-owned plant to the local economy is over 50% larger than an absentee owned corporate plant [3]. Miranowski et al. [4] found that for each one percent reduction in ethanol plant ownership, one less job is created in a local community. In the early stages of the grain-based ethanol industry, projects were funded by local producers and rural investors [5]. However, as the scale and capital requirements of ethanol projects increased the investment shifted to institutional investors and equity funds [5]. Second generation ethanol plants are projected to have a much higher capital

cost per gallon of capacity relative to grain based projects [6]. Participating in production, harvest and storage activities may be the best opportunities for producers and rural residents to benefit from the emerging cellulosic ethanol industry. The need to perform these activities under an efficient structure is critical. Larson et al. [7] discuss substantial technical barriers related to the pre and post production of lignocellulosic feedstocks and emphasize that the cost to harvest, store and transport switchgrass would affect the total cost of ethanol because of the bulkiness of switchgrass.

An efficient, coordinated biomass harvesting, transportation and storage infrastructural can be developed while maximizing benefits to agricultural producers and rural communities by the creation of biomass harvesting cooperatives. Farm equipment cooperatives have been common in Europe and Canada for many years and have been very successful in reducing machinery cost. Research done by Harris and Fulton [8] in Saskatchewan found machinery cooperatives had expected machinery cost savings of 35% per acre relative to individual ownership. Similar research in the Southern Plains [9] concluded that wheat producers could achieve machinery related cost savings of 23-54% through the formation of machinery cooperatives.

A recent national survey of farmers interested in growing switchgrass found that 77% were interested in participating in a farmer owned cooperative that harvests, stores and markets switchgrass [10]. In light of this apparent interest of producers in biomass cooperatives, there is a need to examine the structure and benefits of biomass supply through cooperatives. Researches who evaluated the costs of harvesting, storing and transporting lignocellulosic feedstock have not evaluated these costs in a cooperative framework [11-17].

This section assesses the potential cost savings of a harvesting and transportation of biomass of a cooperative relative to the individual operations. Switchgrass which has been identified as a model energy crop by the U.S. Department of Energy for ethanol production [18] will be considered as a biomass in this study. The study examines the capital investment requirement, optimal machinery compliments for both the producer and various scales of cooperative operations. It also investigates alternative structures for the cooperative including the minimum size needed to capture scale economies and the harvesting and transportation costs of an optimal (least cost) scaled cooperative. Sensitivity analysis is conducted to examine the impact of field size, impact of distance between producers, impact of biomass yield, impact of equipment operating speeds and impact of labor rate.

Materials and Methods

A feasibility template (Fig. 1) was developed in MS Excel to model the operations and costs of a biomass harvesting cooperative. While the template is designed as a decision tool for producers investigating the formation of a harvesting cooperative, it also provides a convenient platform to project harvesting and transportation costs under a cooperative structure. The template has 12 worksheets with several input cells to enter values and in-built formulas to perform calculations. Online resources [19,20] are extensively used to collect the baseline data used in the template. The template allows users to model the costs of harvesting and transporting biomass for storage to a warehouse at both the producers and cooperative level. The template can be used to model biomass transportation directly from an infield stacks to a refinery. The template does not model the costs of producing biomass (switchgrass) such as the cost of seed, fertilizer, pesticides, labor, machinery or land charges etc. All costs calculations are the post production activities of producing switchgrass which includes the cost for harvesting switchgrass (mowing, raking and

baling) and transporting it to the warehouse. Variable costs include costs for fuel and lube, hired labor, repair and maintenance, equipment transportation and hauling costs. Fixed costs include insurance and housing, interest, property tax and depreciation.

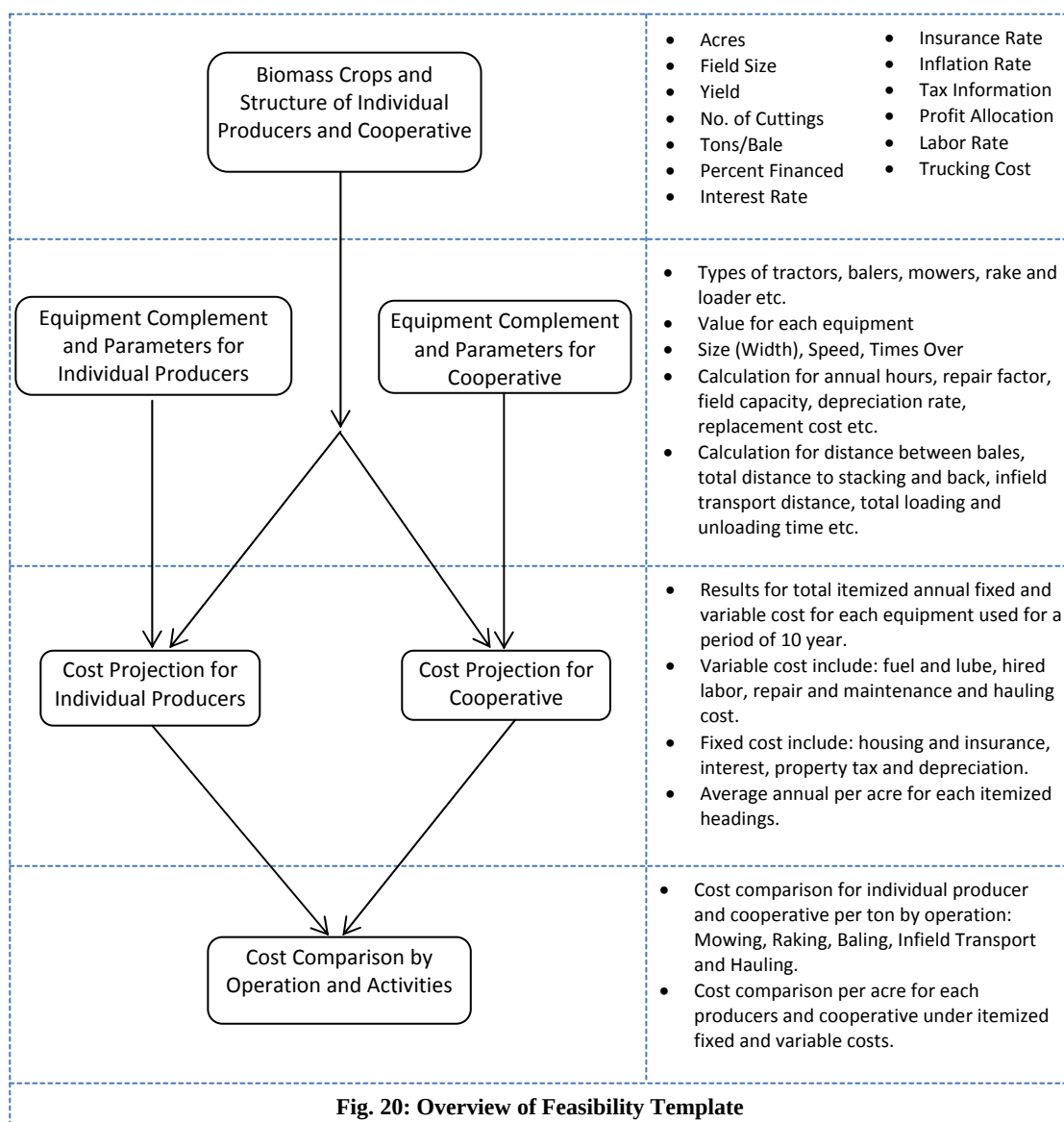


Fig. 20: Overview of Feasibility Template

The cost projections were based on a set of base-line assumptions. The cooperatives are assumed to have five members with 1000 acres of land each with field size of 100 acres. The biomass yield is assumed to be 2 tons per acre and each bale is assumed to contain 1/2 tons of biomass. Only one cutting (harvest) per year is assumed. Switchgrass can be harvested using traditional hay swathers and balers [18]. The baseline assumptions reflect the use of a high speed rotary mower and side delivery rake and round baler for the individual producer scale of operations. The cooperative scale complement of equipment includes a self-propelled windrower, side delivery rake and large rectangular baler (4 ft * 4 ft * 6 ft). In order to harvest the production of all five members, the cooperatives are assumed to use 2 windrowers, 2 rakes and 2 balers. The details of equipment complements are presented in Tables 22 and 23.

Table 22: Equipment Complement for Individual Producers

Equipments	Width	Speed	Value	Capacity	HP	Field Eff. (%)
Tractor (2WD, 80-149 HP)			\$ 58,000		85	
Mower, Rotary	9 ft	6 mph	\$ 20,000			80
Rake, Side Delivery	9 ft	6 mph	\$ 6,000			80
Baler, Round	9 ft	5 mph	\$ 39,500			65
Wagon		6 mph	\$ 5,000	10 bales		65
Skid Steer Loader		6 mph	\$ 7,500			80

Table 23: Equipment Complement for Cooperative

Equipments	Width	Speed	Value	Capacity	HP	Field Eff. (%)
Tractor (2WD, 80-149 HP)			\$ 58,000		85	
Windrower, Self-propelled	20 ft	5 mph	\$ 100,000		85	80
Rake, Side Delivery	30 ft	6 mph	\$ 19,891			80
Baler, Large Rectangular	30 ft	5 mph	\$ 100,000			80
Stacker		6 mph	\$ 150,000	15 bales	100	80

The procedure followed to calculate the distance travelled by the equipments in our study is in some way similar to the procedure applied by Kumar and Sokhansanj [14]. We first calculated the infield transport distance which is the total distance travelled by the equipment (mower, rake and baler) in the field during mowing, raking and baling. This distance depends on the distance between the bales and the total number of bales in the field. The distance between the bales was calculated assuming the field as a grid and bales distributed uniformly over it as also followed by Kumar and Sokhansanj [14]. Then for example, if the total area of the field is 100 acres and there are 400 bales or 4 bales per acre, the distance between the bales would be 104.35 ft. The infield transport distance would be total no. of bales times the distance between

the bales. Second, we calculated the distance travelled by the loading and unloading equipment. In the cooperative scenario, stacker is assumed to collect and load the produced bales and stack them on the edge of field for future hauling to the warehouse. Wagon and skid steer loader are assumed to do this job in the individual producers. This distance travelled by the stacker and wagon/skid steer loader was calculated by assuming that the equipment would travel from the center of the field somewhere to the middle of either side of the field. For example, if the total area of the field is 100 acres then this distance would be 1043.55 ft which represents the distance traveled by the stacker or wagon/skid steer loader to move the bales to the field edge. Infield transportation costs depend on this distance, capacity of the stacker or loader and the total no. of bales in the field. The final category of transportation cost modeled is transportation from the field edge to a centralized warehouse. An average distance of 20 miles between field and warehouse was used in the baseline assumptions.

The machinery days for the equipments are based on the annual hours the equipments are used in the field with the assumption of 10 working hours per day. The annual hours of the equipments however depend on the total acres, yield, field size and field speed of the equipment. Fuel and lube cost are calculated with the assumption of \$2.50 per gallon of diesel. The repair and maintenance cost for tractors and equipments are based on the American Society of Agricultural Engineering (ASAE) [21] methods. The annual repair cost is calculated by using the price of the equipment, annual hours used in the operation and the repair factors. The hired labor rate is assumed to be \$20 per hour for the cooperative and \$10 per hour for the individual producers. The labors are based on the no. of tractors used and equipments that need tractor and equipments that do not need tractor. Modified straight line method of depreciation is used in the

study with a depreciation rate of 10% and inflation rate of 1%. The insurance rate is modeled at 2% of the equipment value per year.

In the cooperative structure, the members share the equipments compliment which must be transported from one producer's location to another. The costs associated with this kind of transportation are included in the trucking cost and equipment operation costs. The self propelled equipment was assumed to be driven from one producer location to another with the travel operation included in the total annual hours of operation. The baler and rake were assumed to be trucked to the next location with the costs reflected in the trucking costs. The remainder of the trucking costs reflected the costs of transporting the bales from the stacks at the field edge to the warehouse. It was calculated by multiplying the no. of trips the truck has to make with the average distance from the stacking to the warehouse and the trucking cost per mile. The number of trips depends on the total yield and the capacity of the trucks per load.

Fifty percent of the investment is assumed to be financed with a loan term of 5 years and long term interest rate of 6 %. The loan amount is exactly the same as the total investment as half of the investment was financed. The baseline structure of the cooperative was five members each having a 20% share of ownership and 1,000 acres of production. The total investment for the baseline situation was estimated to be \$368,391 for the cooperative and \$61,750 for the producers. All these investments are made for the purchase of harvest and transport equipments (Table 24 and 25). No costs for lands and buildings were assumed.

Table 24: Capital Requirements for Cooperative and Producer

	Cooperative	Producer
Total Investment	\$368,391	\$61,750
Long Term Interest Rate	6 %	6 %
Percent Financed	50 %	50 %
Loan Amount	\$368,391	\$61,750
Loan Term	5 Years	5 Years
Total Plant, Property & Equip	\$736,782	\$123,500

Results

The results provide interesting insights into the structure of the cooperatives to harvest and transport biomass. Preliminary results indicate that even small scale (3-5 members) biomass harvesting cooperatives could have substantial cost savings versus individual member operations. The total cost was estimated to be \$18.00 per ton for the cooperative and \$25.53 per ton for the individual producers.

Table 25: Itemized Cost/Dry Ton

	Cooperative	Producer
Fuel & Lube	\$ 1.35	\$ 4.22
Hired Labor	\$2.50	\$3.96
Repair & Maintenance	\$ 1.03	\$ 4.61
Equipment		
Transportation	\$0.18	-
Hauling Cost	\$2.40	\$2.40
Total Variable Costs	\$ 7.47	\$ 15.19
Insurance & Housing	\$ 1.54	\$ 1.42
Interest	\$ 0.82	\$ 1.38
Property Tax	\$ 0.39	\$ 0.36
Depreciation	\$ 7.79	\$ 7.19
Total Fixed Costs	\$ 10.53	\$ 10.34
Total Cost	\$ 18.00	\$ 25.53

The total fixed cost was almost similar in both the cooperative and the individual producers but the total variable cost was about twice in the individual producers than in the cooperative. The costs for fuel and lube, hired labor and repair and maintenance costs were all significantly higher for the individual producers than the cooperative.

Table 26: Itemized Cost/Dry Ton by Activities

Operation	Cooperative		Producer	
	Cost Per	Machinery	Cost Per	Machinery
	Ton	Days	Ton	Days
Mowing	\$ 4.97	26	\$ 5.71	28
Raking	\$ 2.00	14	\$ 3.94	19
Baling	\$ 5.85	17	\$ 11.16	19
In-field Transport	\$ 2.60	5	\$ 2.33	5
Hauling	\$ 2.40		\$ 2.40	

The harvesting cost per ton was found to be \$15.42 in the cooperative and \$23.13 in the individual producers. The transportation cost was \$2.40 per ton in both the scenarios.

The breakdown of costs by field activities showed that most of the cost would go for baling for both the cooperative (\$5.85 per ton) and individual producer's (\$11.16 per ton) and least cost would be for raking (\$2.00 per ton) in cooperative and for in-field transport (\$2.33 per ton) in the individual producers. The cost per ton for baling and raking in the individual producer scenario was almost twice the cost in the cooperative scenario. The cost per ton for mowing was almost a dollar higher in the individual producer than the cooperative. The infield transport cost was higher in the cooperative (stacker) than in the individual producers which were because the equipment compliments were not fairly being utilized for the acres it should have covered.

The estimated days of machinery operation showed that the harvesting and transporting of biomass in the cooperative structure could be achieved in fewer days compared to the individual producer's scenario. Under the cooperative structure, raking could be accomplished in 5 fewer days relative to operations by the individual producers. Likewise mowing and baling could be

completed 2 fewer days but the infield transport of the loading/unloading equipment would be same (5 days) for both the scenarios. The fewer machinery days in the cooperative structure would lower the overall variable costs compared to individual producer and help achieve economies of scale.

1.1 *Sensitivity Analysis*

The sensitivity analysis evaluated and compared the changes in the total cost per ton because of changes in any factors considered important in the study. These factors are impacts on total costs due to changes in yield of the crop, field size, distance between the producers, field operation speed and labor rate per hour.

One ton per acre change in the yield of the crop had a significant impact on the total cost per ton. Increasing the yield from one ton/acre to two tons/acre would lower the cost by approximately 50% but this rate would not be consistent as we increase the yield. In both the cooperative and individual producer's scenario, with the increase in yield the total cost per ton would decrease in decreasing rate. The field size did not have as much effect on the total cost per ton. An increase in the field size from 50 acres to 200 acres would increase the total cost just by \$0.10 for cooperative and by \$0.44 for the individual producers.

Table 27: Sensitivity Analysis

	Total Cost/Ton	
	Cooperative	Producers
<i>Impact of Yield</i>		
1 ton/acre	33.41	47.63
2 ton/acre*	18.00	25.53
3 ton/acre	12.86	18.16
4 ton/acre	10.29	14.48
5 ton/acre	8.75	12.26
<i>Impact of Field Size</i>		
50 acre	17.96	25.35
100 acre*	18.00	25.53
150 acre	18.03	25.67
200 acre	18.06	25.79

* Baseline yield and field size.

The results were also not sensitive to the distance between the producers. The total cost per ton would increase just by \$0.24 if the distance between the producers would increase from 10 miles to 40 miles. The field speeds of the stacker also did not have a major impact on the total cost per ton. When the field speed was increased from 10 mph to 30 mph the total cost decreased only by \$0.33 per ton. There were two different labor rates use in the study- one for the cooperative and one for the individual producers. However, wage rates did not have a significant impact on the total cost per ton. When compared to their individual impacts, the labor rates in the

individual scenario were more than the cooperative scenario. An increase in labor rate from \$16 to \$24 per hour in the cooperative increased the total cost by almost \$1.00 and increase of labor rate from \$8 to \$12 in the individual producers increased the total cost by \$1.58.

Table 28: Sensitivity Analysis

	Total Cost/Ton	
	Cooperative	Producers
<i>Impact of distance between producers</i>		
10 miles	\$17.93	
20 miles*	\$18.00	
30 miles	\$18.08	
40 miles	\$18.17	
<i>Impact of field operation speed (Stacker)</i>		
10 mph	\$18.25	
15 mph	\$18.08	
20 mph*	\$18.00	
25 mph	\$17.95	
30 mph	\$17.92	
<i>Impact of Hired Labor Rate (Coop.)</i>		
\$16	\$17.50	
\$18	\$17.75	
\$20*	\$18.00	
\$22	\$18.25	
\$24	\$18.50	
<i>Impact of Hired Labor Rate (Producers)</i>		
\$8		\$24.74
\$9		\$25.14
\$10*		\$25.53
\$11		\$25.93
\$12		\$26.32

* Baseline distance between the producers; field speed of the stacker; hired labor rate for cooperative and producer.

Discussion

The results obtained in our study are compared with the results obtained in several other similar studies. The harvest cost estimates of \$23.13 for individual producers in our study is very close to the estimates made by Duffy and Nanhou [25] who estimated the total harvesting cost of

\$26.05 per ton in Iowa. Their estimated cost for mowing (\$2.18), raking (\$1.03), staging and loading (\$6.51) per ton are lower than our estimates but their baling cost (\$16.34) estimates are higher. In another study by Kumar and Sokhansanj [14], the total cost for square bales was estimated to be \$24.10 per ton and \$22.62 per ton for round bales. This cost estimates included the cost to swathing, raking, baling, road siding, stacking and tarping. Similarly, Thorsell et al. [11] estimated the cost of mowing, raking, baling, gathering and stacking in-field from \$11.26 to \$14.01 per ton depending upon the biomass yield. Both of these studies do not include the hauling costs. Our study assumes that the bales would be transported to a storage site which is 20 miles away from the field and estimates this cost to be \$2.40 per ton. The University of Kentucky (U.K.) Extension [22] estimates the hauling cost of \$11.50 per ton for a distance of 50 miles. Brechbill and Tyner [23] in their study estimate a series of transportation costs for a range of 5 miles to 50 miles for field size of 500 acres, 1000 acres, 1500 acres and 2000 acres. Their cost estimates for 20 miles is \$5.27 for 500 acres, \$4.74 for 1000 acres, \$4.56 for 1500 acres and \$4.47 for 2000 acres. The per ton cost in their study increases almost by \$0.10 to \$0.20 as the field size increase by 500 acres and almost by a dollar if the distance to the plant increases by 5 miles. The hauling cost in our study shows a uniform change of \$0.60 per ton for a change of 5 miles in the transportation distance.

Perlack et al. [24] estimated fixed and variable costs for switchgrass production and harvesting in the southeast U.S. with average dry yield of 6.1 tons per acre. The fuel and lube cost per acre were estimated as \$9.09, \$12.22 and \$16.48 for year-1, year-2 and year-3 which appear significantly higher than what we have estimated (\$1.33 and \$4.17). Similar estimates for year-1, year-2 and year-3 are \$12.39, \$16.91 and \$23.63 for repairs, \$6.10, \$12.20 and \$18.30 for twine, \$2.95, \$2.18 and \$2.86 for insurance, housing, taxes, \$5.04, \$2.45 and \$2.48 for

interest (operating loan), \$60.0, \$60.0 and \$60.0 for land rent and \$21.56, \$15.17 and \$18.62 for labor. The estimates for repairs, housing and insurance, interest and labor were all higher than our estimates. The U.K. Extension [22] have estimated total fixed costs of \$12.5 for full switchgrass production (years 3 to 6) and yield of 6 tons/acre which is higher than our estimates of \$10.53 and \$10.34 for cooperative and individual producers respectively. Their estimates of labor cost per ton of \$5.66 were also higher than the estimates of our labor cost of \$2.47 and \$3.91 for cooperative and individual producers respectively.

Conclusion

The renewable fuel standard mandate has resulted in a continued growth of ethanol plants in recent years. Unlike first generation ethanol plants, second generation will require a dedicated source of feedstock supply to meet the mandates of the renewable fuel standards and second generation ethanol plants are forecasted to cost 3-4 times more than grain based ethanol. This may limit farmer ownership of the actual processing plant. The best avenue for farmer participation and value-added returns may be farmer ownership in the supply chain. A commonly suggested structure for the biomass supply chain is an integrated business model owned by the biorefinery. Producer ownership of harvesting operations generates increased economic impact for producers and rural communities. However, this structure fails to capture the economies of scale in equipment ownership and operations. Another alternative is the formation of biomass harvesting and transportation cooperatives. This paper has attempted to model the cost of harvesting and transporting biomass (switchgrass) in this type of cooperative structure. A cost comparison with equipment ownership and operations by individual producers is provided. The results show that even small scale biomass harvesting cooperative could have substantial cost savings versus individual member operations. For a five member cooperative the total cost of

harvesting and transporting biomass was estimated to be \$18.00 per ton and it was estimated to be \$25.53 per ton for the individual producers. The harvesting cost per ton was \$15.42 in the cooperative and \$23.13 in the individual producers. Sensitivity analysis indicated that biomass yield, had the most significant impact on per ton cost while minimal impacts were observed for field size, distance between producers, labor rates and field speed of the bale pick up equipment. Sharing of equipments and forming a cooperative to harvest and transport biomass allows spread of costs among producers and helps achieve economies of scale. Similar cost savings could therefore be achieved and wider economic impact could be made by involving local producers and forming cooperative rather than harvesting and transporting biomass individually.

References

- [1] U.S. Congress, House of Representatives. Section 111, Subtitle A, Renewable Fuels, Consumer Protection and Energy Efficiency Act of 2007, H.R. 6 (EAS). 2007.
- [2] Epplin FM, Clark C, Roberts R, Hwang S. Challenges to the development of a dedicated energy crops. *American Journal of Agricultural Economics* 2007; 89(5):1296-1302.
- [3] Urbanchuk JM. Economic impact on the farm community of cooperative ownership of ethanol plants. National Corn Growers Association, September 2006. Available from: <http://www.cccm.coop/upload/cccm/editor/asset/library.pdf> [accessed 09.10.2011].
- [4] Miranowski J, Swenson D, Eathington L, Rosburg A. Biofuel, the rural economy, and farm structure. Risk, infrastructure and industry evolution. English BC, Menard RJ, Jensen K, eds. Farm Foundation Press, Washington, D.C. 2008.
- [5] Kenkel P, Holcomb RB. Conditions necessary for private investment in the ethanol industry. *Journal of Agricultural and Applied Economics* 2009; 41(2):455-64.
- [6] Taheripour F, Tyner WE. Ethanol policy analysis – what have we learned so far? *Choices* 2008; 23(3):6-11. Available from: http://www.choicesmagazine.org/magazine/pdf/article_38.pdf [accessed 09.11.2011].
- [7] Larson JA, Yu T-H, English BC, Mooney DF. Cost evaluation of alternative switchgrass producing, harvesting, storing and transporting systems and their logistics in the southeastern USA. *Agr Finance Rev* 2010; 70(2):184-200. Available from: <http://www.emeraldinsight.com/journals.htm?articleid=1876532> [accessed 09.10.2011].

- [8] Harris A, Fulton M. Farm machinery cooperatives: an idea worth sharing. Centre for the Study of Cooperatives, University of Saskatchewan, Saskatoon, SK, CA. 2000. ISBN 0–88880–415–6. Available from: <http://www.usaskstudies.coop/pdf-files/Idea%20Worth%20Sharing.pdf> [accessed 09.11.2011].
- [9] Long G, Kenkel P. Feasibility of machinery cooperatives in the southern plains region. Selected paper presented at the 2007 Southern Agricultural Economics Association meetings in Mobile, AL, Feb. 4-7, 2007. Available from: <http://ageconsearch.umn.edu/bitstream/34832/1/sp07lo02.pdf> [accessed 09.10.2011].
- [10] Jensen KL, Clark CD, English BC, Menard R J. Preferences for marketing arrangements by potential switchgrass growers. *Journal of Cooperatives* 2011; 25: 16-43. Available from: <http://www.agecon.ksu.edu/accc/ncera210/JOC%20pdfs/V25/MarketingArrangementsSwitchgrass.pdf> [accessed 09.25.2011].
- [11] Thorsell S, Epplin FM, Huhnke RL, Taliaferro CM. Economics of a coordinated biorefinery feedstock harvest system: lignocellulosic biomass harvest cost. *Biomass and Bioenergy* 2004; 27:327-37. Available from: <http://www.sciencedirect.com/science/article/pii/S0961953404000467> [accessed 09.10.2011]
- [12] Bransby D, Smith A, Taylor R, Duffy P. Switchgrass budget model: an interactive budget model for producing & delivering switchgrass to a bioprocessing plant. *Industrial Biotechnology* 2005; 1(2):122-5.
- [13] Mapemba L, Epplin FM, Taliaferro C, Huhnke R. Biorefinery feedstock production on conservation reserve program land. *Review of Agricultural Economics* 2007; 29:227-46.
- [14] Kumar A, Sokhansanj S. Switchgrass (*Panicum virgatum*, L.) delivery to a biorefinery using integrated biomass supply analysis and logistics (IBSAL) model. *Bio resource Technology* 2007; 98(5):1033-44. Available from: <http://www.greencropnetwork.com/media/pdf/webcourse/16%20Kumar%20and%20Sokhansanj.pdf> [accessed 09.10.2011]
- [15] Popp M, Hogan Jr R. Assessment of two alternative switchgrass harvest transport methods. Paper presented at the Biofuels, Food, and Feed Tradeoffs Conference, Farm Foundation, St. Louis, MO, 12–13 April 2007. Available from: <http://www.farmfoundation.org/news/articlefiles/364-Popp%20Switchgrass%20Modules%20SS%20no%20numbers.pdf>. [accessed 09.12.2011]
- [16] Perrin R, Vogel K, Schmer M, Mitchell R. Farm scale production cost of switchgrass for biomass. *Bioenergy Research* 2008; 1:91-7.
- [17] Epplin FM. Cost to Produce and Deliver Switchgrass Biomass to an Ethanol-Conversion Facility in the Southern Plains of the United States. *Biomass and Bioenergy* 1996; 11(6):459-67. Available from: <http://www.sciencedirect.com/science/article/pii/S0961953496000530> [accessed 09.10.2011]

- [18] Caddel J, Walker N, Kakani G, Warren J, Porter D, Wu Y, Redfearn D, Zhang H. Switchgrass production guide for oklahoma. E-1012 Oklahoma Cooperative Extension Service. Division of Agricultural Sciences and Natural Resources. Oklahoma State University. 2010.
- [19] Eddwards W. Estimating farm machinery cost. Ag decision maker. Iowa State University Extension. 2009. Available from <http://www.extension.iastate.edu/publications/pm710.pdf> [accessed 07.26.2011]
- [20] Stiles S, Griffin T. Estimating farm machinery costs. Agricultural and Natural Resources. University of Arkansas, Division of Agriculture. Available from http://www.uaex.edu/Other_Areas/publications/PDF/fsa-21.pdf [accessed 07.26.2011]
- [21] ASAE. American Society of Agricultural Engineering (ASAE) Standards. ASAE D497.4. 2003. Available from: http://www3.abe.iastate.edu/ae340/2006/ASAE_D497.4.pdf [accessed 07.26.2011].
- [22] U.K. Extension. Switchgrass for biomass. University of Kentucky, College of Agriculture, Cooperative Extension Service. 2009. Available from <http://www.uky.edu/Ag/CDBREC/introsheets/switchgrass.pdf> [accessed 09.20.2011].
- [23] Brechbill SC, Tyner WE. The economics of biomass collection, transportation, and supply to indiana cellulosic and electric utility facilities. Bioenergy Research 2011; 4:141-52. Available from: <http://www.springerlink.com/content/83x51u67m832600n/fulltext.pdf> [accessed 09.25.2011].
- [24] Perlack RD, Turnhollow AF, Eaton LM. Switchgrass production in the USA. Promising resources and systems for producing bioenergy feedstocks. IEA bioenergy task 43:2011:03. Available from: http://142.150.176.36/task43/library/promisingresources/IEA_Bioenergy_Task43_PR2011-03.pdf [accessed 10.16.2011]
- [25] Duffy, M. and V.Y. Nanhou. Costs of producing switchgrass for biomass in southern Iowa". Iowa State University Extension. 2001. Available from: http://iowaswitchgrass.com/_docs/pdf/Costs%20of%20Switchgrass.pdf [accessed 09.16.2011].

CHALLENGES IN FINANCING THE BIOFUEL SUPPLY CHAIN

The conversion of biomass feed stocks into biofuels is obviously an essential aspect of the biofuel supply chain. A variety of platforms for conversion have been developed and successfully demonstrated at the bench scale or pilot scale level. Lignocellulosic materials can be enzymatically hydrolyzed enabling effective cellulose breakdown into sugars which can be fermented into ethanol or other alcohol chains. The enzymatic hydrolysis process generally requires a pretreatment step such as pretreatment with dilute acid. There are also a variety of thermochemical platforms where the carbon in the biomass feedstock is converted into a “syngas” consisting of monoxide, carbon dioxide and hydrogen through partial combustion. The gases can then be fermented into biofuels through the use of microorganisms or fed into a catalytic reactor where a thermochemical process creates ethanol and other higher alcohols. Other conversion systems focus on pyrolysis which uses a high temperature-low oxygen environment to decompose biomass into gas and liquid products and a high carbon bi-product referred to as “bio-char”.

While the previous list of biofuel conversion platforms is by no means exhaustive it demonstrates the complexity of commercialization. Financing the development and expansion of the cellulosic-based ethanol industry will be a greater challenge relative to financing grain-based ethanol. Cellulosic ethanol technology has not been standardized. Cellulosic ethanol and advanced biofuel refineries are likely to use a variety of feedstocks (corn stover, switchgrass, miscanthus, wood waste) with the optimal feedstock depending on regional availability. The optimal scale of a cellulosic plant involves a tradeoff between feedstock transportation and processing economies. The determination of optimal plant size is just one aspect of the standardization desperately needed in order to attract private capital.

Cellulosic ethanol will require a higher capital investment per gallon of capacity. On 28 February 2007, the U.S. Dept. of Energy announced \$385 million in grant funding to six cellulosic ethanol plants (McAloon et. al.) This grant funding accounts for 40% of the investment costs. The remaining 60% comes from the promoters of those facilities. The total of \$1 billion will be invested for approximately 140 million gallons of capacity. This translates into \$7/annual gallon production capacity in capital investment costs for pilot plants, although construction costs are likely to decrease as the technology is commercialized. Taheripour and Tyner estimate the cost of a 100 million gallon cellulosic facility at \$400 million (\$4/gallon of annual production capacity). Even using this conservative estimate, the capital cost of an additional 25 billion gallons of capacity (the difference between the capacity of currently operating and plants under construction and the 36 billion gallon target of the renewable fuel standard) will be \$100 billion.

Meeting the renewable fuel mandate of the 2007 Act will require an investment in facilities, transportation and storage infrastructure, and feedstock production that could total over \$100 billion in a timeframe of just over a decade. The development of this infrastructure will be one of the greatest challenges for rural America since the advent of rural electrification in the 1930's. Rural electrification was originally funded by a \$40 million loan program established by the Rural Electrification Act (REA) of 1936 (Carmody). Depending upon the inflator used, the original REA program value would equate to \$480 million in current dollars, or less than five percent of the anticipated investment to establish cellulosic ethanol and advanced biofuels to meet the mandates of the 2007 Act. Unlike rural electrification, meeting the mandates of the 2007 Act requires the commercialization of currently competing technologies for deriving ethanol from biomass. An entire industry, required by mandate, has yet to be formed. Despite the extensive discussion of biomass values and cellulosic ethanol production issues in the current

literature, the challenge of financing the expansion of the U.S. renewable fuel infrastructure has not been adequately addressed.

An impediment to raising all of this capital required for the cellulosic ethanol industry is the *legitimacy* of the industry. Aldrich and Fiol refer to “legitimacy” as an additional hurdle faced by start-up ventures in an industry so young that few if any precedents exist for these ventures to follow. They point out that, in addition to the typical pressures associated with a start-up venture in an established industry, a new industry with questionable legitimacy also requires new ventures to “carve out a new market, raise capital from skeptical sources, recruit untrained employees, and cope with other difficulties stemming from their nascent status.” Lawrence adds to this concept by pointing that certain “legitimizing” steps must be taken as part of an industrial strategy to overcome the skepticism from both those who might be capital contributors to the venture and those who might become customers of the firm. A more simplistic way to make the point may be to use the cliché about the settling of the Old West: “Pioneers got the arrows, but settlers got the land.” Private investors in individual biofuel ventures are looking to capture both market share and economic rents from technology by being early entrants in the industry, but venture capitalists and philanthropic investors alike still fear what Herrick calls the “cash flow ‘valley of death’” that exists between pilot scale technological assessment and commercial scale production.

Cellulosic ethanol and other biofuel ventures in the category referred to as “Advanced Biofuels” by the RFS face challenges gaining legitimacy. Cellulosic ethanol and advanced biofuel technologies are unproven on a commercial scale, there are accordingly no established industry norms for these “second generation” technologies, and in general there is a lack of

industry leadership. Cellulosic feedstocks do not align with the interest of commodity and producer groups which help promote grain based ethanol.

Grain-based ethanol ventures of the late 1970s likewise suffered from legitimacy issues, but during the past decade grain-based ethanol found ways to gain legitimacy, and thus capture greater levels of private investment. Sociopolitical legitimacy (Aldrich and Fiol) was gained through the buy-in of commodity and producer organizations, along with legislative action to promote both ethanol production and utilization, which made ethanol a norm in parts of the country. External legitimacy was gained by successful operation of a handful of Corn Belt ethanol plants, which worked collectively to educate the public, producers, politicians, and private investors. Technologies became standardized which greatly enhanced the ability of potential investors to assess project feasibility. The process of feasibility assessment also became standardized. This facilitated project development and encouraged a wider pool of potential investors to evaluate ethanol projects. Standardized methods of feasibility assessment were a necessary ingredient for the influx of private investment from both Main Street and Wall Street into the grain-based ethanol industry during the first half of this decade.

As in any industry, private investment capital will flow to cellulosic ethanol and advanced biofuels if biorefinery projects are projected to be sufficiently profitable. The economic feasibility of a biofuel project depends upon a number of factors including feed stock costs, harvest, transportation and storage systems, conversion rates and the fixed and variable costs of the biorefinery operation. Information on many of these factors, including feed stock yields, conversion rates and capital investment costs continues to be refined as new technology becomes available. Decision aids such as feasibility templates can assist entrepreneurs, community leaders and project developers in making the preliminary assessment as to whether a

biorefinery project with a particular conversion technology and feed stock package appears feasible for their situation.

DEVELOPMENT OF FEASIBILITY TEMPLATES FOR BIOFUEL PROJECTS

As the previous section discussed, project financing is a major, and often underappreciated, impediment to the development of a commercial advanced biofuel industry. Streamlining the process of project feasibility assessment can be one factor in facilitating investment. Spreadsheet-based feasibility templates assist entrepreneurs, community leaders and project developers in identifying potentially feasible biofuel projects. They also facilitate analysis of the impact of changes in conversion rates, enzyme costs and other key inputs. The templates also provide cost projections that can be incorporated into supply chain models that determine the optimal size and location of biorefineries. Three biofuel feasibility templates were developed for this project. They model the feasibility of cellulosic ethanol, sweet sorghum to ethanol conversion and oilseed crushing and biodiesel production. The templates are available at <http://fapc.okstate.edu/services/agribusiness>. Brief descriptions of the feasibility templates, taken from the templates themselves, are provided in the following pages of this section.

Cellulosic Ethanol Feasibility Template

How to Use the Template

This template is designed to assist you in analyzing the feasibility of an enzymatic hydrolysis, lignocellulosic ethanol plant. Some of the key inputs include 1) the capacity of the plant, 2) the feedstock(s) utilized in the manufacturing process, 3) information related to equipment costs, and 4) personnel for operating the plant. This information is entered on the input page along with other cost factors. The base-line estimates that is used for illustration purpose represents an 8 ton/hour plant operating 5 ½ months processing forage and 5 ½ months processing hay and producing only alfalfa pellets.

Entering Data

Begin on the inputs page and enter information designated in green cells. The information currently entered in these cells represents rough estimates of costs based upon numerous previous studies and suggestions from researchers. If you do not have some of the information this baseline information may be a reasonable estimate. The cells that are not in green are currently protected because they are formulas rather than input cells. If you wish to adjust the template to fit your project in a more customized way please do so by un-protecting the sheets. If you do customize the template, we encourage you to save it under another file. By doing so, you will be able to revisit the original template for reference.

Moving within the Template

As you move through the pages of this template, please note the “Menu” that is located on each page, usually in the upper left hand corner, for your convenience. These buttons will take you to the page identified and allows for you to move more easily about the template.

Input Values

This page contains the majority of the data entry in this template. Begin in the upper left hand corner, and work your way down the columns. We recommend that you research these cost variables for your particular operation. The current data represent rough estimates that may or may not be appropriate for your proposed venture.

Many entrepreneurs fail to consider the amount of working capital (short-term funds) that will be required. A cell is provided for the user to add an additional amount of working capital contingency funds. This entry could be used to reflect capital required during a construction or start-up period. The projected working capital requirements should provide a general estimate of the amount of short-term funds that may be needed. Interest costs on working capital are automatically transferred to the appropriate sheets within the template. However, the estimated cash flow does not consider any additions or repayments of working capital.

The anticipated price inflation for the two possible products (ethanol and electricity) are intended to allow the user to account for projected changes in these products' values over the planning period.

Cellulose & Conversion

This sheet is where the user inputs information related to the expected gallons of ethanol from a ton of each feedstock, as well as costs related to catalysts and other chemicals and inputs that go into the creation of denatured ethanol. There are several options for the pretreatment of lignocellulosic biomass that are intended to break down the feedstock into more easily convertible sugars. These options include the use of varying levels of dilute acid, lime, hot water, and other possible pretreatments. Each pretreatment option comes with its own particular costs and equipment requirements. To aid in the understanding of these pretreatment options, a sampling of technical papers related to various options is included at the end of this document.

Other Inputs

The template also requires a few inputs (in the green cells) on the "Personnel Expenses" page, the "Expense Projection" page, and the "Depreciation" page. The discussion below will outline in more detail the information needed in each of these pages.

Personnel Expense

The items on the personnel expense page calculate the annual labor expense of the operation. Enter the general position categories, the number of people required for each category, and the projected salaries for a person in each category. The template will then calculate benefits based on the percentage of benefits identified on the inputs page. The third entry on this page is the percentage of overtime each category will have on average. This overtime column can also be used as a "bonus percentage" column for administrative personnel. The template then calculates the overtime/bonus wage costs. These totals will automatically transfer to their appropriate places in other worksheets.

Expense Projection

The expense projection sheet has only four data entry points. You have the option for entering costs related to supplies and miscellaneous items for both the facility's start-up phase and for the first year of full production. These Year 1 costs will then be adjusted for all following years using an inflation factor provided on the "Input Values" sheet. The ability to adjust these expenses will allow you to consider "what if" situations.

Depreciation

Data on all building/structure costs, equipment costs, and vehicle costs are entered on this sheet. The other entries are the salvage value cost of the buildings, and the total land cost. The appropriate annual depreciation costs are automatically calculated and transferred to the appropriate places in the other worksheets. Because it is a non-cash expense, depreciation is

added back to net profit/loss as part of the annual cash flow calculations. In keeping with the accepted practices of investment analysis, depreciation expenses are not considered in the net present value and internal rate of return calculations.

Sensitivity Analysis

Another key step in feasibility assessment is determining how the projected profits will be affected by changes in internal and external factors. Sensitivity analysis is the systematic process of asking: “What If?” By adjusting key factors in the spreadsheet you can analyze the sensitivity of your profitability to certain factors. Factors you might consider in your sensitivity analysis include:

- Ethanol price
- Electricity price
- Feedstock costs
- Chemical and catalyst costs

The template provides a space for you to enter your results at various levels of the key cost and price variables. Users may also want to create additional tables summarizing the impact of variables that are particularly important to their unique situation.

Analyzing the Projected Returns

Common methods for determining whether a project is generating sufficient returns to justify the initial investment include the internal rate of return, the net present value, and the payback period. A description of these measures is provided below.

In the feasibility template these measures are summarized on the “Return on Investment” sheet.

Payback Period

Payback period is the simplest method of evaluating an investment. It measures the length of time an investment takes to pay for itself by dividing the cost of the investment by the annual cash flows generated by the investment. The shorter the payback period, the better. There is no exact benchmark for an acceptable payback period. In considering risky projects, many managers use a general rule of thumb to invest in opportunities with a payback of less than three years. A company that is looking for a quick turnaround on their investment will find payback period to be very useful; however it has a major weakness. It ignores the cash flow beyond the payback period. The payback period is therefore a poor measure of the long-run value of a project.

Internal Rate of Return

The internal rate of return looks at the cash flows over the life of the project. It also considers the interest rate, or time-value of the money, which is a measure of what the company

could be earning had they invested elsewhere. The internal rate of return basically reflects the compounded returns from the project. Companies should invest in projects with rates of return higher than the firm's required rate of return. The required rate of return should reflect the interest rate paid on capital plus a premium for risk. One method of selecting a required rate of return is to determine the rate you would reasonably expect to receive if you purchased stock in companies with the same risk as your project.

Net Present Value

The net present value is similar to the internal rate of return in that it considers cash flows over the life of the project and adjusts for the time value of money. The net present value represents the dollar value of a project at a given discount rate (risk adjusted interest rate). The template user enters a chosen discount rate on the "Input Values" sheet, but that rate is also shown at the top of the "Return on Investment" page. The discount rate impacts the penalty placed for funds received at a later time period relative to currently received funds. Managers should accept projects with a positive net present value. Net present value calculations supplement internal rate of return estimates by indicating the magnitude of the profitability of the project. For example, a small project with a high internal rate of return would still have a positive but relatively small net present value.

Reference Materials

To better understand the costs associated with this type of ethanol facility and the options for pre-treating lignocellulosic feedstocks, template users may want to read the following studies and reports, which represent only a sample of available resources:

Aden, A., M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, and B. Wallace. (2002) "Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover." National Renewable Energy Laboratory report NREL/TP-510-32438. Available online at <http://www.nrel.gov/docs/fy02osti/32438.pdf>.

Busby, D.P., A.L. Phillips, and C.W. Herndon, Jr. (2008) "Construction Cost Sensitivity of a Lignocellulosic Ethanol Biorefinery." Selected paper presented at the 2008 Southern Agricultural Economics Association meeting in Dallas, TX (Feb. 2-5, 2008). Available online at <http://ageconsearch.umn.edu/bitstream/6784/2/sp08bu08.pdf>.

Eggeman, T., and R.T. Elander. (2005) "Process and Economic Analysis of Pretreatment Technologies." *Bioresource Technology* 96:2019-2025.

Kadam, K.L., C.Y. Chin, and L.W. Brown. (2008) "Flexible Biorefinery for Producing Fermentation Sugars, Lignin, and Pulp from Corn Stover." *J. Ind. Microbiol. Biotech.* 35:331-341.

Petrolia, D.R. (2006) "The Economics of Harvesting and Transporting Corn Stover for Conversion to Fuel Ethanol: A Case Study for Minnesota." University of Minnesota,

Department of Agricultural Economics Staff Paper P06-12. Available online at <http://ageconsearch.umn.edu/bitstream/14213/1/p06-12.pdf>.

Suryawati, L., M.R. Wilkins, D.D. Bellmer, R.L. Huhnke, N.O. Maness, and I.M. Banat. (2008) Simultaneous Saccharification and Fermentation of Kanlow Switchgrass Pretreated by Hydrothermolysis Using *Kluyveromyces marxianus* IMB4.” *Biotechnology and Bioengineering* 30:1-9.

Tembo, G., F.M. Epplin, and R.L. Huhnke. (2003) “Integrative Investment Appraisal of a Lignocellulosic Biomass-to-Ethanol Industry.” *J. of Agricultural and Resource Econ.* 28,3:611-633.

For comments or suggestions on this template please contact:

Rodney Holcomb: rodney.holcomb@okstate.edu, (405) 744-6272
Phil Kenkel: kenkel@okstate.edu, (405) 744-9818

Feasibility Template for On-Farm Ethanol Production from Sweet Sorghum

Introduction

The advancement of biofuel production in the U.S. has spawned hundreds of proposed and/or established ethanol plants. Although the Renewable Fuel Standards call for an increase in the production of ethanol from cellulosic materials, practically all of current ethanol production utilizes corn or grain sorghum as a feedstock. However, there are also opportunities to produce ethanol from sugar beets, sugarcane, and sweet sorghum. While the price of sugar makes the use of sugar beets and sugarcane an expensive alternative, the low production costs of sweet sorghum and its ability to grow in a wide array of climates has drawn interest from both researchers and agricultural producers.

Sweet sorghum produces carbohydrates in a form that is ready to be fermented and distilled (i.e. juice pressed from the stalks), whereas corn is comprised of complex starches that must be broken down into simple sugars prior to fermentation. Sweet sorghum provides high biomass yield with low irrigation and fertilizer requirements, whereas corn requires high amounts of agrichemicals and water not only for growing but also for ethanol production. Corn ethanol plants require high capital costs and high production volumes to maintain economic competitiveness, but the ready-to-ferment juice from sweet sorghum may provide opportunities for smaller-scale ethanol production at a competitive price.

In the sweet sorghum to ethanol process, the stalks are pressed, and the juice is fermented and distilled to make ethanol. The process yields two direct co-products: the leftover stalk, called bagasse, and residual liquid called vinasse. The bagasse can be converted to silage for feed or can potentially be burned to provide process heat energy for the sorghum processing/ethanol plant and to co-generate electricity. However, co-generation is not economically feasible for a small processing facility because of the high additional capital cost associated with co-generation equipment. Other alternatives are to dry and pelletize the bagasse to create a readily marketable feedstuff. Vinasse contains phosphorus and other materials potentially beneficial as soil amendments, and distributing the vinasse back on the fields is a viable option. Some studies also suggest that the vinasse has value as a feedstuff if a majority of the water content can be removed.

While sweet sorghum processing has potential, the sweet sorghum ethanol system has several potential disadvantages and uncertainties. The crop is bulky to transport and must be processed within 24 hours of harvest to prevent loss (oxidation) of the sugar content. The timing of the harvest must be matched with the processing capacity, creating trade-offs between production scale economies at the plant level and the logistical difficulties and transportation costs associated with bringing in sweet sorghum from distant fields. Sweet sorghum also has a limited harvest window, which (with multiple planting dates) may range from 2-3 months in the Midwest to 6-7 months in the Southeast.

This template is designed to help agricultural producers and other interested parties examine the feasibility of small-scale, on-farm production of ethanol from sweet sorghum. Sections of the template require the user to input certain production, processing, and handling

parameters for sweet sorghum. Careful consideration of inputs, equipment, and co-product costs are necessary prior to implementing an on-farm ethanol production enterprise. This document takes the user through the components of the template, explaining the operations of the template and identifying the areas where user-defined data is required – i.e. the light green shaded cells.

Sweet Sorghum Production

A number of sweet sorghum production budgets have been made publicly available by state agricultural experiment stations and land-grant universities. Examples include, but are not limited to, enterprise budgets from Mississippi State University (msucares.com), Louisiana State University (Ricaud, 1990), the University of Kentucky (Bitzer and Fox, 1987), and various other state-specific sweet sorghum enterprise budgets. It is recommended that users of this template examine one or more enterprise budgets, check with their state agricultural experiment station for region-specific enterprise budgets, and consult an extension crop specialist prior to planting a sweet sorghum crop.

The “Sweet Sorghum Production” sheet in the template is where users provide the specific crop production inputs used, costs of inputs used, expected average biomass yield per acre, and the number of acres planted.

Input Value

The “Input Value” sheet is a basic input area where a number of user-defined processing and operational parameters are entered. Categorically, these inputs are divided into groups associated with debt financing, input and output prices, transportation cost parameters, conversion parameters (going from sweet sorghum stalks to ethanol and co-products), inflation factors for 10-year projections, and ethanol production tax credits.

It is recommended that users of the template consult one of the many research publications related to ethanol production from sweet sorghum (see examples listed at the end of this document) prior to choosing input values. Each potential processing system carries with it a unique set of operational parameters that will need to be entered in the “Input Value” sheet and other sheets. Additionally, users are advised to contact state/federal agencies regarding the availability and duration of tax credits, which are possibly subject to short-notice changes or discontinuation.

Processing Equipment

The “Processing Equipment” sheet provides template users the opportunity to input the number and costs of all equipment related to pressing, fermentation, distillation, and product storage. This equipment may also include any number of pumps for moving juice, ethanol, and/or a denaturant from one tank to another. The sheet also includes a section for irrigation equipment, which may be necessary to remove the vinasse (liquid separated from the ethanol after fermentation) and distribute it on fields/pastures.

There are three primary technology options for extracting juice from sweet sorghum stalks: a screw press, a roller drum mill, and a diffuser. A twin-screw press is the most basic processing option, whereby sorghum stalk billets are subjected to gradually increasing pressure created by two screws and the juice is forced out through a screen. Roller drum mills, which have been used in sugar cane processing for years, require that the billets be shredded in a hammer mill prior to pressing so that plant cells will break open and allow a greater portion of the juice/moisture content of the stalks to be captured. A diffuser system (often used with sugar beets) also requires billet preparation using a hammer mill, but additionally requires water as an input to dissolve sugars as it percolates through the shredded sorghum. Each method has advantages and disadvantages, but the system incorporated as the base case for this template is the twin-screw press because of its lower capital and operating costs.

Distillation systems also vary in their operational methods, throughput capacities, capital costs, space requirements (i.e. more distillation columns require more building space), and utility requirements. A number of distillations systems are available for large-scale ethanol production, and a handful of small-scale systems have been developed. These small-scale systems may be more applicable for on-farm processing or (as an example) small manufacturers wishing to generate biofuels from their waste streams. It is recommended that a user of this template contact an applications engineer or a representative of a state's manufacturing alliance program to identify an appropriate distillation system.

Disposal of the vinasse and any potable water used in the ethanol production may create problems for an on-farm ethanol production facility. Presumably, an on-farm operation will not have access to a public wastewater disposal system (i.e. a sewer system), and the large quantity of wastewater makes the use of septic tanks unfeasible. Irrigation of the vinasse and other wastewater on cropland or pastures is the best option, depending upon the makeup of the discharge and state/federal environmental laws related to the discharge of wastewater. Users of this template are advised to check with state environmental agencies prior to implementing a wastewater disposal system.

Purchase prices for equipment can vary greatly, depending upon the competitiveness of suppliers and the availability of used and/or refurbished equipment. Because most equipment prices do not include a delivery charge, the "true" cost of purchased equipment must include charges associated with transporting the equipment from a manufacturer/distributor to the farm and the installation/setup of the equipment. It is not uncommon for some freight and installation costs to equal the actual sticker price of the equipment, depending on the distance between sites and the installation requirements. For each category of processing equipment purchased, the template allows users to establish an installation and freight cost as a percent of the purchase price.

Utilities

The utility requirements of an ethanol system vary by the type of equipment, the primary sources of energy used for the equipment, and highly variable energy prices. The template distinguishes utility requirements by their use (pressing, distillation, wastewater irrigation, and in-plant machinery) and power source. Because most of these activities do not necessarily take

place at the same time or for the same duration, calculations are performed for each and combined for a total annual energy/utility expense. “Annual Fuel for In-Plant Machinery” allows the user to capture the additional energy requirements for items such as forklifts, loader tractors, or other items not easily categorized.

Personnel Expenses

Personnel requirements vary by the size and scale of operation. The number of people needed to carry out specific activities is directly impacted by the type of processing system used, and the number of labor hours attributed to each activity depends on the amount of sweet sorghum to be processed. Thus, the hourly wage rates and number of employees necessary for each production/processing activity are entered on this sheet, but the annual labor hours associated with each activity are derived from the amount of sweet sorghum to be processed and the capacities of the equipment being used.

The category for “Administration” allows the user to input a desired payment to the producer (i.e. a return to management) for undertaking the activity. Likewise, any other administrative duties fulfilled by an employee or family member can be accounted for via a salary.

Depreciation

The sheet entitled “Depreciation” combines the expenses of the pressing/distillation/irrigation equipment with those of fixed facilities, special purpose buildings, light trucks/vehicles, and the cost of the land on which the processing operation will be located. All values of equipment are carried over from the “Equipment” sheet, but the user provides information related to new or expanded fixed facilities, vehicles, and storage buildings. Each capital input category has its own depreciate schedule, based off of generally accepted accounting practices.

The template also allows a user to add the costs of additionally purchased equipment during any of the ten years. For this template, these purchases are treated as small cost items, and are fully depreciated by the template in the year of purchase.

Expense Projection

The “Expense Projection” sheet captures the expenses calculated from other sheets, but it also contains input cells related to permits/regulatory expenses, supplies, and miscellaneous expense not captured elsewhere. Permits and regulatory compliance issues and costs are hard to calculate, because they vary by the type/size of the facility and state versus federal requirements. However, it should be noted that a fuel production facility potentially faces two distinct registration processes: the registration of the *facility*, and the registration of the *fuel* itself.

Ethanol does not meet the requirements of a “fuel” according to 40 C.F.R. §§ 79.32 and 79.33 which designate “motor vehicle gasoline” and “motor vehicle diesel fuel” for registration.

However, because ethanol can be defined as a “fuel additive” according to 40 C.F.R. § 79.2(e), ethanol would still need to be registered as an additive according to 40 C.F.R. § 79.31.

For a general overview of biofuel production feasibility, including the regulatory requirements for establishing a biofuel facility, see Ferrell, Kenkel, and Holcomb (2009).

Market Projection and Loan Amortization

These two sheets require no inputs from the user. They simply provide a summary of information. The “Market Projection” sheet provides a summary of annual purchases and sales (both volume and dollar value), along with the input and output prices projected for each year. The “Loan Amortization” sheet simply provides the calculations for annual loan payments, including a breakdown of interest and principal payments.

Operations Summary and Return On Investment

The last two sheets in the template provide the overall summary of financial activity and provide different measures of returns on investment in the venture. Neither of these sheets requires input from the template user, instead drawing upon the inputs and calculations from other sheets to generate measures of economic feasibility.

“Operations Summary” is a profit/loss statement, but it also provides an estimate of annual cash flow. Users will note the inclusion of state and federal tax liabilities, as well as the incorporation of tax credits. Because federal biofuel tax credits are not tradable, and state tax credits are typically not marketable, the tax credits provide no real benefit when the operation incurs a loss. However, their ability to cover tax liabilities in profitable years can greatly benefit a venture.

The “Return On Investment” sheet provides different measures of a venture’s viability. Payback period is the simplest method of evaluating an investment, measuring the length of time an investment takes to pay for itself. The internal rate of return (IRR) basically reflects the compounded returns from the project. The net present value (NPV) also considers cash flows over the life of a project and adjusts for the time value of money. Unlike the IRR (a percentage), which computes the project’s rate of return, the NPV (dollar calculation) is based upon a given discount rate (risk-adjusted interest rate), which the user provides on the “Input Value” sheet. As a means of comparison, the IRR is the discount rate at which the NPV equals zero.

References

The following publications and online resources represent a portion of the suggested input sources for users of this template. Online libraries of information related to sweet sorghum production can also be accessed via organizations such as the Agricultural Marketing Resource Center (www.agmrc.org) and AgricultureB2B.com.

Bennett, A.S., and R.P. Anex. 2009. "Production, Transportation, and Milling Costs of Sweet Sorghum as a Feedstock for Centralized Bioethanol Production in the Upper Midwest." *Bioresource Technology* 100:1595-1607.

Bitzer, M. J., and J. D. Fox. 1992. "Processing Sweet Sorghum For Syrup." AGR 123, Cooperative Extension Service: University of Kentucky.

Ferrell, S.L., P. Kenkel and R. B. Holcomb. 2009. "Economic Aspects of Biofuel Assessment: A Feasibility Approach to Project Evaluation." Louisiana Natural Resources Symposium Shupe, T.F. and M.A. Dunn (eds), LSU AgCenter, Baton Rouge, LA. ISBN 0-9763632-3-2, pp 32-52.

Hunter, E.L., Anderson, I.C. 1997. "Sweet Sorghum." *Horticultural Reviews* 21:73–104.

Kuepper, G. 1992. *Sweet Sorghum: Production and Processing*. Kerr Center for Sustainable Agriculture, Poteau, OK.

Mississippi State University Extension Service, *Crops: Sorghum*. Accessed October 11, 2006, from <http://msucares.com/crops/sorghum/descriptions.html>

Monroe, G.E., Sumner, H.R. 1983. "A Harvest and Handling System for Sweet Sorghum." ASAE Paper No. 84-3551. American Society of Agricultural Engineers annual meeting, St. Joseph, MI.

Ricaud, R. 1990. "Sweet Sorghum Research on Biomass and Sugar Production in 1990." Louisiana Agricultural Experiment Station, Report of Projects:136-9.

Worley, J.W., Cundiff, J.S. 1992. "Ethanol from Sweet Sorghum: A Comparison of Four Harvesting/Processing Systems." *Liquid Fuels from Renewable Resources*, Cundiff, J.S. (ed.), ASABE, St. Joseph, MI, pp. 40–49

Biodiesel Feasibility Template

Guide to Using the On-farm Biodiesel Production Feasibility Template

Overview

The on-farm biodiesel production feasibility template is designed to examine the financial or economic performance of an on-farm biodiesel production from oilseed crops. This simple to use template is constructed using Microsoft Excel to project the cost and return of an on-farm processing of canola, soybean and sunflower into biodiesel. The main objective of developing the template is to aid producers and other interested parties in the decision making process. The template can help interested parties in getting answer to question like “Should I start the on-farm biodiesel production?” or “If the investment will be profitable or not”.

The structure of the on-farm biodiesel feasibility template is based on the other kinds of feasibility template previously developed by Drs. Bowser, Kenkel and Holcomb at Oklahoma State University. The data used in the template is collected from several sources to create spreadsheets used in the feasibility study. The template contains eleven different worksheets for inputs and outputs. Five worksheets require input information like basic capital structure, biodiesel production size and capacity, production costs, equipment scheme and personal expenses. The user-supplied information and assumptions made for the model is used in the financial calculations. The calculations include market and expense projections, loan amortization, operation summaries, and return on investment which are calculated for ten year period.

Using the Template

The first step in using the feasibility template is to enter the values of interest by the users. Values can only be entered in cells highlighted in **green color**. Rest of the cells is protected and cannot be changed. Calculations are made based on the values entered in the green colored cells. To enter the data, the users can start from the “Input Value” page and then they can move to the other pages and enter the values of their interest in other pages. Once the values are entered in the input pages the outputs can be seen in the output pages.

Input Pages

1. Input Value
2. Cost of Production
3. Equipment
4. Utilities
5. Personnel Expenses
6. Capital Assets

Output Pages

7. Market Projection
8. Loan Amortization
9. Expense Projection
10. Operation Summary
11. Return on Investment

While changing the values in the green colored cells, sometime users may get lost and may want to see the default or baseline values for the respective variables. So, some important cells have comments inserted within which includes the baseline or default values for the respective cells.

How does the template look?

The detail of how the template looks and how it can be used is explained for each page below:

INPUT PAGES

“Input Value” Page

The “input value” page is the first page in the feasibility template and it takes much of the input information required for calculations. The page looks as shown below.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													
30													
31													
32													
33													
34													
35													
36													
37													
38													
39													
40													
41													
42													
43													
44													
45													
46													
47													
48													
49													
50													
51													
52													
53													
54													
55													
56													
57													
58													
59													
60													
61													
62													
63													
64													
65													
66													
67													
68													
69													
70													
71													
72													
73													
74													
75													
76													
77													
78													
79													
80													
81													
82													
83													
84													
85													
86													
87													
88													
89													
90													
91													
92													
93													
94													
95													
96													
97													
98													
99													
100													

Input Value
Page

Other Input and Output
Pages

The cells colored in green are used to enter the input information which is carried to other worksheets for the required calculations. Basic information like which crop is to be used for biodiesel production, what capital structure is used, what are the numbers and capacities of the equipments, what are the raw and final product prices, what is the oil content of the crop, what are the utilities cost, what are the tax credits, what is the inflation rate and similar others are included in this page. Users have access to use the values provided in the cell or they can change the values in the green colored cells and use their own values. They may start by selecting the crop of their choice to be used. If they are going to make biodiesel using only canola, then they have to enter 100% in cell D5 in above example leaving 0% in cell C5 and E5. If they are going to use soybean and sunflower, then they have to enter 50% in cell C5 and E5 leaving 0% in cell D5. Next they can enter the information on equipments in table H2:L9. They can start entering from the days of operation per year and hours per day for the oilseed crusher and the biodiesel processor.

The template is designed for three scales of operation. So, users may have to be careful while selecting the no. of oilseed crushers or the no. of biodiesel processors and their capacities as provided in the dropdown list (I6, J6, K6 and L6). The medium scale uses two oilseed crusher of the same capacity as the small scale. So, for medium scale “2” should be selected in the no. of oilseed crusher category (Cell I6) but the capacity of the oilseed crusher should remain same as the small scale in Cell J6. Small scale and cooperative scale will take just “1” in the no. of oilseed category along with their respective capacities (0.3 for small scale and 1 for coop. scale). The table presented below provides clearer picture of this description.

Scale of Equipments	Oilseed Crusher		Biodiesel Processor	
	Number	Capacity	Number	Capacity
1. Small Scale	1	0.3	1	24
2. Medium Scale	2	0.3	1	55
3. Cooperative Scale	1	1	1	110

Based on the information entered for the equipments the values might change for the target biodiesel production or annual biodiesel production (C4), oilseed crushed (L14), oil produced from crushing (L16), excess oil from crushing (L18) and additional oil to be purchased (L20) .

After entering the values for the equipments, information on capital structure can be given which include percentage financed (C11), long term and short term interest rate (C12 and C18), loan term (C13), working capital (C21, C22 and C24) etc. Next the users may enter the values for raw product prices (F10 to F15), final product prices (F18 to F27), crushing assumptions (I24 to I33), basic utilities cost (F30 to F34), inflation rates (F39 to F45), biodiesel tax credits (C32 to C36), transportation costs (C40 to C48) and others. After doing with all these the users are set to move forward to the next page.

“Cost of Production” Page

This is the second input page in the template and this page includes simple calculations for producing soybean, canola and sunflower. Like in the input value page, users have access to change the values in this page for cells colored in green. The basic expense data used in this page

Cost of Production					Cost of Production					
2										
3	Soybean	Units	Price	Quantity	\$/Acre	Sunflower	Units	Price	Quantity	\$/Acre
4	Yield per acre	Lbs		1,272		Yield per acre	Lbs		1,500	
5	Carbon Credits	Dollars		0		Carbon Credits	Dollars		0	
6	Soybean seed	Acre	\$40.00	1	\$40.00	Sunflower seed	Acre	\$17.40	1	\$17.40
7	Fertilizer	Acre	\$0.00	1	\$0.00	Fertilizer	Acre	\$70.71	1	\$70.71
8	Custom harvest	Acre	\$27.06	1	\$27.06	Custom harvest	Acre	\$25.58	1	\$25.58
9	Pesticide	Acre	\$32.00	1	\$32.00	Pesticide	Acre	\$29.00	1	\$29.00
10	Crop Insurance	Acre	\$4.41	1	\$4.41	Crop Insurance	Acre	\$0.00	1	\$0.00
11	Annual operating capital	Dollars	7.00%	27.12	\$1.90	Annual operating capital	Dollars	7.00%	46.75	\$3.27
12	Machinery labor	Hrs	\$8.35	0.35	\$2.92	Machinery labor	Hrs	\$8.35	0.47	\$3.92
13	Custom hire	Acre	\$0.00	1	\$0.00	Custom hire	Acre	\$4.61	1	\$4.61
14	Machinery fuel, lube, repair	Acre	\$10.09	1	\$10.09	Machinery fuel, lube, repairs	Acre	\$14.62	1	\$14.62
15	Other expense	Acre	\$39.69	1	\$39.69	Other expense	Acre	\$81.83	1	\$81.83
16	Cost per acre				\$158.07	Total cost				\$250.95
17	Total acres to be grown				0.00	Total acres to be grown				0.00
18	Total cost of production				\$0.00	Total cost of production				\$0.00
19										
20	Canola	Units	Price	Quantity	\$/Acre					
21	Yield per acre	Lbs		2,000						
22	Carbon Credits	Dollars		0						
23	Canola seed	Acre	\$16.00	1	\$16.00					
24	Fertilizer	Acre	\$76.37	1	\$76.37					
25	Custom harvest	Acre	\$34.1	1	\$34.10					
26	Pesticide	Acre	\$19.30	1	\$19.30					
27	Crop Insurance	Acre	\$14.00	1	\$14.00					
28	Annual operating capital	Dollars	7.00%	98.85	\$6.92					
29	Machinery labor	Hrs	\$8.35	0.77	\$6.43					
30	Custom hire	Acre	\$19.55	1	\$19.55					
31	Machinery fuel, lube, repair	Acre	\$22.22	1	\$22.22					
32	Other expense	Acre	\$65.11	1	\$65.11					
33	Cost per acre				\$280.00					
34	Total acres to be grown				570.00					
35	Total cost of production				\$159,599.43					

This page includes cost estimation for the oilseed crusher and the biodiesel processor. It has list of all necessary equipments and their accessories. For the oilseed crusher, this includes pre-cleaner, extruder, expeller, conveyor, filters, tanks (for meal and oil storage), spare part kits and miscellaneous items. Similarly, different capacities of the integrated biodiesel processor, tanks

for methanol, glycerol and biodiesel and other accessories are included for the biodiesel processor.

This page also has the option to include the number of pieces of oilseed crushers and the biodiesel processors or their accessories. But care has to be taken here since it depends on the scale of operation the users have chosen in the “Input value” page. Whichever variables that have (1) in parenthesis in cells in column C are made for small scale. Likewise, (2) is made for medium scale and (3) is made for cooperative scale. So, if users have chosen equipment setting for small scale and have entered nos. and capacities of the processors for small scale in the “Input value” page then they will have to enter values for quantity for those variables which have (1) included in parenthesis and enter “0” for those variables which have (2) or (3) included in the parenthesis. It means if the users have selected small scale of operation in the “Input value” page then they will have to enter “1” or other values of interest in cells E7, E23, E26, E41, E46 and E49 in the example below and enter “0” for those variables which have (2) or (3) included in the parenthesis. The same explanation follows for medium scale and cooperative scale. Once entering these informations the users may enter the cost of their choice for the equipments and their accessories or may leave the default values in the template. If users are interested they may also change the values for the horse power (HP) and electricity (KW/hr) used by the equipment or the horse power (HP) and electricity (KW/hr) used by its accessories. Beside this, if users feel any important items are missing in the list, they may include them in the miscellaneous section.

	A	B	C	D	E	F	G	H	I	J
3		SN	OIL SEED CRUSHER	Equipment Description	Qty	Price Estimate	Total New Price Est.	HP	KW/ hr	Source
4		1	Raw Material Preparation							
5			Pre cleaner	Aspirated cleaner	0	10,000.00	0.00			
6			Grain Storage Bin (1)	30 ton	1	3,500.00	3,500.00			
7			Grain Storage Bin (2)	75 ton	0	8,750.00	0.00			
8			Grain Storage Bin (3)	150 ton	0	17,500.00	0.00			
9										
10		2	Extraction							
11			Extruder (1 or 2)	0.3 ton/hr	1	28,298.00	28,298.00	50	40	INSTA-PRO International
12			Expeller (1 or 2)	0.3 ton/hr	1	31,434.00	31,434.00	20	16	
13			Extruder (3)	1 ton/hr	0	62,344.00	0.00	0	0	INSTA-PRO International
14			Expeller (3)	1 ton/hr	0	62,869.00	0.00	0	0	
15			Conveyor	Transfers material from extruder to expelle	1	4,659.00	4,659.00	1	0.8	
16				Installation and Freight			6,439.10			
17										
18		3	Clarification							
19			Filter	To remove particles from oil	2	500.00	1,000.00			
20			Drum Strainer	200 micron	2	20.00	40.00			B100 Supply LLC
21										
22		4	Packaging and Storage							
23			Oil storage tank (1)	1000 gal	1	1,781.00	1,781.00			CHEM-TAINER Industries, Inc
24			Oil storage tank (2)	2000 gal	0	2,633.00	0.00			CHEM-TAINER Industries, Inc
25			Oil storage tank (3)	5000 gal	0	5,952.00	0.00			CHEM-TAINER Industries, Inc
26			Meal storage tank (1)	25 ton	1	105.00	105.00			
27			Meal storage tank (2)	50 ton	0	196.00	0.00			
28			Meal storage tank (3)	100 ton	0	369.00	0.00			
29										
30		5	Miscellaneous							
31			Spare parts kit	For extruder/expeller	1	500.00	500.00			
32										
33										
34										
35						Sub-Total	77,756.10	71	56.8	
36										
37		SN	BIODIESEL PROCESSOR	Equipment Description	Qty	New ea Price	Total New Price Est.	HP	KW/ hr	Source
38		1	Preparation							
39			Titration supplies	Biodiesel titration kit and chemicals	1	100.00	100.00			B100 Supply LLC
40			Lab glass ware	Burettes, Pipettes, Beaker	1	100.00	100.00			B100 Supply LLC
41			Purchased oil storage tank (1)	750 gallons	1	1,074.00	1,074.00			
42			Purchased oil storage tank (2)	1500 gallons	0	2,207.00	0.00			
43			Purchased oil storage tank (3)	3000 gallons	0	3,195.00	0.00			
44										
45		2	Storage							
46			Methanol tank (1)	250 gallon	1	370.00	370.00			B100 Supply LLC
47			Methanol tank (2)	350 gallon	0	611.00	0.00			
48			Methanol tank (3)	1000 gallon	0	1,073.00	0.00			
49			Biodiesel storage tank (1)	1000 gallon	1	1,781.00	1,781.00			B100 Supply LLC
50			Biodiesel storage tank (2)	Biodiesel storage tank (2)	0	2,633.00	0.00			
51			Biodiesel storage tank (3)	Biodiesel storage tank (3)	0	5,952.00	0.00			
52			Glycerol tank (1)	Glycerol tank (1)	1	1,397.00	1,397.00			
53			Glycerol tank (2)	Glycerol tank (2)	0	2,531.00	0.00			
54			Glycerol tank (3)	Glycerol tank (3)	0	3,504.00	0.00			
55										
56		3	Reacting/Processing/Washing							
57			Integrated Biodiesel Processor (1)	240 gallon/day (1/2hp, 110V, 2.75amp, 12g	1	24,500.00	24,500.00	0.5	0.4	EZ Biodiesel
58			Integrated Biodiesel Processor (2)	550 gallon/day (220 V, 60 gpm)	0	47,000.00	0.00	0	0	EZ Biodiesel
59			Integrated Biodiesel Processor (3)	1100 gallon/day (220 V, 60 gpm)	0	94,000.00	0.00	0	0	EZ Biodiesel
60				Installation and Freight			2,450.00			
61										
62		4	Miscellaneous							
63			Biodiesel test kit	B5/B20 Phase one, Field test kits	1	200.00	200.00			B100 Supply LLC
64			Scale	KD 7000 Digital Scale	1	50.00	50.00			B100 Supply LLC
65			pH meter	Digital pH meter	1	45.00	45.00			B100 Supply LLC
66			Safety equipment	Dust mask, splash guard googles, apron	1	500.00	500.00			B100 Supply LLC
67			Drum strainer	200 micron	5	20.00	100.00			B100 Supply LLC
68			Pipes and Fittings	Sets if pipes and fittings	1	500.00	500.00			B100 Supply LLC
69			Spare parts kit		1	500.00	500.00			
70										
71										
72										
73										
74						Sub-Total	33,667.00	0.5	0.4	
75						Grand Total	111,423.10	72	57	

“Utilities” Page

This page includes detail cost estimation for electricity, heat exchanger and water. It also includes cost estimates for sewage disposal and telephone. The cost for electricity is based on the

HP or KW/hr used by the equipments, the values for which come from the equipment page. The calculation for natural gas consumption is based on the total BTUs estimation required per gallon of biodiesel for the simplest biodiesel reaction and methanol recovery system.

Like in other pages users have access to change the values in cells colored in green. Users have opportunity to use either electricity or natural gas for the heat exchanger. For this they can select “1” or “2” from the dropdown list provided in cell F8. They may also change the values for the efficiencies (C4, C14 and C26) if they feel it necessary. If users don’t want to dry glycerine they may select “2” in cell C23 or select “1” if they want to dry glycerine. It is assumed that one gallon of biodiesel production will require two gallons of water (Cell C33) and the KW per HP is assumed to be 80% (F22) the values for which can be changed by the users.

Finally, the total utility per year and total utility per gallon are calculated using the summed cost estimation from electricity, natural gas, water usage, telephone and waste disposal.

	A	B	C	D	E	F	G
1							
2		BTUs Calculation			Heat Exchanger		
3		Temperature change (65F to 270F)	205		BTUs reqd. per gal for the reator	1631.54	
4		BTU/lb/F for mixture of 65% canola and 35% methano	0.51		BTUs reqd. per gal oil-methanol condensor	766.56	
5		Efficiency	0.75		BTUs reqd. per gal for glycerine drying	0.00	
6		Reactor			BTUs reqd. per gal for biodiesel production	2398.09	
7		Adjusted BTU per lb per degree F	0.68		Total BTUs reqd. for taget biodiesel production	87,482,464.26	
8		mixture of methanol & oil as % of final biodiesel	1.54		Choose source of heat (1=Natural Gas, 2=Elec. Resista	2	
9		lbs mixture/gallon of biodiesel	11.704		Natural Gas	1	
10		BTUs per gallon for the reactor	1631.54		Energy reqd. to produce 100,000 BTUs of heat (ccf)	1.33	
11		Methanol Condensor			Energy reqd. to produce reqd. BTUs (ccf)	1163.52	
12		Methanol percentage by weight	0.13		Natural gas cost per ccf	1.2	
13		Heat of vaporization BTU/lb	506		Total cost for natural gas	\$0.00	
14		Efficiency	0.75		Electric Resistance		
15		Adjusted heat of vaporization BTU/lb	674.67		1 Kw Hr will produce (BTUs)	3412	
16		Mixture of methanol & biodiesel/% of final biodiese	1.15		Target gal of biodiesel will require (BTUs)	87,482,464.26	
17		Lbs of methanol & biodiesel/gal final biodiesel	8.74		KW's reqd. to produce needed BTUs	25,639.64	
18		BTUs per gallon for methanol recovery	766.56				
19		Total BTUs per gallon of biodiesel for simplest	2398.09				
20		biodiesel reaction and methanol recovery system					
21							
22		Glycerine Drying			Electricity		
23		Choose 1 "if glycerine Drying", 2 "if no glycerine drying"	2		KW/HP	0.80	
24		Temperature change (65F to 180F)	115		HP/hour (Oilseed Crusher)	71.00	
25		BTU per lb/F for mixture of 83% glcerin 17% water	0.65		HP/hour (Biodiesel Processor)	0.50	
26		Efficiency	0.75		Total HP per hour	71.50	
27		Adjusted BTU/lb/F	0.87		Kw/year (Oilseed Crusher)	113,600.00	
28		Glycerin as % of oil	0.09		Kw/year (Biodiesel Processor)	26,279.64	
29		Lbs per gallon	7.6		Total Kw/year	139,879.64	
30		BTU per gallon for glycerin drying	68.172		Electricity Cost/KW	\$0.11	
31					Electricity Cost/ Year	\$15,386.76	
32		Water	Usage (Gal/year)		Total Utility Costs		
33		Water required per gallon of biodiesel	2		Electricity	\$15,386.76	
34		Drinking water	500		Natural gas	\$0.00	
35		Wash/Cleanup	1000		Water	\$153.15	
36		Degumming crude vegetable oil	2116		Telephone per year	\$2,000.00	
37		Water treatment	76,076		Sewer	\$285.29	
38		Total net water (Gallon)	76,576		Total Utility/year	\$17,825.20	
39		Water rate/1000 gallon	\$2.00		Total Cost of Utility/gallon	\$0.49	
40		Water cost/year	\$153.15				

“Personnel Expenses” Page

This page looks as shown below and includes payroll information (Cell C3 to C7) and staffing details for administrative and production sections. The payroll information includes some percentages for taxes, staff benefits and wage inflation. The administrative and production sections include position of staffs, their numbers, staff salaries, overtime percentage and total salary calculations. The cells colored in green include percentages in payroll information, staff numbers, their salaries and overtime percent and so the users can change their values if they wish to do so. If there are no staffs for the positions included below, “0” can be entered to nullify it and if there are staffs for the particular position other numbers based on the availability of staffs to work can be entered.

	A	B	C	D	E	F	G	H	I
1									
2		PAYROLL INFORMATION							
3		% of payroll tax to salaries	5%						
4		% of retirement tax to salaries	15%						
5		% of employee INS tax to salaries	10%						
6		Benefits as % of salaries	30%						
7		Wage inflation	1%						
8									
9		Administrative							
10		Occupation	Number	Salary	Tot Salary	Benefits	Overtime%	Overtime	Total
11									
12		Manager/clerical	0	\$60,000	\$0	\$0	0%	\$0	\$0
13		Asst. Mgr./Clerical	0	\$35,000	\$0	\$0	0%	\$0	\$0
14		Total Administrative Cost			\$0	\$0		\$0	\$0
15									
16		Production	Per shift						
17		Position	Number/shift	Wage	Tot Salary	Benefits	Overtime%	Overtime	Total
18		Crushing-Operator	1	\$12	\$24,000	\$7,200	0%	\$0	\$31,200
19		Crushing-Meal Handler	0	\$12	\$0	\$0	0%	\$0	\$0
20		Biodiesel-Operator	0	\$10	\$0	\$0	0%	\$0	\$0
21		Receiving/Shipping	0	\$12	\$0	\$0	0%	\$0	\$0
22		Total Production			\$24,000	\$7,200		\$0	\$31,200
23									
24			Total personnel costs		\$31,200.00				

“Capital Assets” Page

This is the last input page and it calculates depreciation on a yearly basis. The depreciable assets used for calculation includes buildings, special purpose buildings, equipments and heavy rolling stocks, and light trucks and vehicles. Buildings are depreciated on a 39 year straight line. Special purpose buildings are depreciated on a 10 year straight line. Equipments and heavy rolling stocks are depreciated on a 7 year life using MACRS (Modified Accelerated Cost Recovery System) and light trucks and vehicles are depreciated on a 5 year life using MACRS.

Options to enter values for land (C3), buildings, special purpose buildings and light trucks and vehicles are provided. If the study does not assume any land or buildings for biodiesel production or if it is using an already existing infrastructure, then “0” can be entered in the respective cells. Similarly, if no light trucks or vehicles are used “0” can be entered or if they are used some other related values or descriptions can be entered in the respective cells.

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2												
3		Land	\$0.00			Buildings						
4		Total PP & Equip.	\$111,423.10			Cost	\$0					
5		Total Land, PP & Equip.	\$111,423.10			Salvage	\$0.00					
6						Period	39					
7						Depreciation per year for 39 yrs	\$0					
8		Buildings	Value	Salvage								
9		Building shell	\$0.00	\$0.00		Special Purpose Buildings						
10		Site prep				Cost	\$0.00					
11						Salvage	\$0.00					
12						Period	10					
13		Total Buildings	\$0.00	\$0.00		Depreciation per year for 10 yrs	\$0					
14												
15		Special Purpose Buildings	Value	Salvage		Equip. & Heavy Rolling Stock						
16		#1	\$0.00	\$0.00		Year	Depreciation	Rate				
17		#2				1	\$15,922	14.29%				
18		#3				2	\$27,288	24.49%				
19		Total Special Purpose Buildir	\$0.00	\$0.00		3	\$19,488	17.49%				
20						4	\$13,917	12.49%				
21		Equip. & Heavy Rolling Stock	Description	Value		5	\$9,950	8.93%				
22						6	\$9,939	8.92%				
23		OIL SEED PROCESSING		\$77,756.10		7	\$9,950	8.93%				
24		BIODIESEL PROCESSING		\$33,667.00		8		4.46%				
25												
26		Total Equip. & Heavy Rolling Stock		\$111,423.10		Light Trucks & Vehicles						
27						Year	Depreciation	Rate				
28		Light Trucks & Vehicles	Description	Value		1	\$0	20.00%				
29		#1	Loader Tractor	\$0.00		2	\$0	32.00%				
30		#2				3	\$0	19.20%				
31		#3				4	\$0	11.52%				
32		Total Light Trucks & Vehicles		\$0.00		5	\$0	11.52%				
33						6	\$0	5.76%				
34												
35												
36												
37		Annual Total Depreciation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
38		Buildings	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
39		Special Purpose Buildings	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
40		Equipment & Heavy Rolling Stock	\$15,922	\$27,288	\$19,488	\$13,917	\$9,950	\$9,939	\$9,950	\$0		
41		Light Truck & Vehicles	\$0	\$0	\$0	\$0	\$0	\$0	\$0			
42		Total Depreciation	\$15,922	\$27,288	\$19,488	\$13,917	\$9,950	\$9,939	\$9,950	\$0	\$0	\$0
43		Additional Assets Purchase	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

OUTPUT PAGES

“Market Projection” Page

The first output page is the market projection page and it displays information on the yearly prices for raw and final products, quantities sold and purchased and dollars amount received from the sales and dollars amount spent from the purchases in detail. The raw and final products prices include prices for grain, oil, meal, hull, biodiesel, additional oil, glycerine, alcohol and catalyst. The prices for these products for other years are calculated based on the information provided in the previous year and the inflation rates.

The products that are sold include meal, oil, hulls, biodiesel and glycerine. The total quantities sold for each of them are calculated. Beside this, the dollars amount received from each of these quantities sold are also calculated. Similarly, the items that are purchased include additional oil, methanol and NaOH. The total quantity purchased for each of these products and the dollar amounts spent on these purchases are also calculated. Finally, gross margins are calculated from

the information obtained from the total amount spent on purchases and total amount received from sales. All the calculations are made for ten year period.

“Loan Amortization” Page

This page calculates and displays details on loan principal and interest payments. The data used for calculation in this page are obtained from the “Input value” page. The page displays beginning and ending balance for every year for ten year period. It displays interest rates and interest amounts both short term and long term and it calculates annual amount paid and total interest expenses on an annual basis.

“Expense Projection” Page

This page projects yearly expense for ten year period in detail. The information needed for this projection is obtained from the previous worksheets. Total variable expenses are calculated by summing the sub-totals for personnel expenses, trucking expenses, expenses for utilities, and cost of production for the oilseed crops. Similarly, the expenses for maintenance, insurance, property tax and others are summed to get the fixed expenses. There are also some input cells included in this page to include values for regulatory/permit fees, other expense supplies and miscellaneous expenses. Finally, the totals for variable expenses, fixed expenses and other miscellaneous expenses are added together to obtain the total expenses. So, users have access to see in detail the variable, fixed and miscellaneous expenses for each category in detail on an annual basis in this page.

“Operation Summary” Page

This page summarizes the total income and expenses on an annual basis for a ten year period. It uses the “Market projection” page to obtain the gross sales and cost of goods sold and “Expense projection” page to obtain the expenses. It calculates earning before and after tax based on the information on income, expenses, carbon credits, tax credits and income taxes.

In this page, the users also have an access to see simple projections of cash flows which are made by adjusting annual after tax profits for depreciation expenses and loan principal payments.

“Return on Investment” Page

This is the last output page and is the most important one as it summarizes the feasibility of the biodiesel production facility. This page calculates five feasibility measures for final results. They are internal rate of return (IRR), net present value (NPV), return on assets (ROA), return on equity (ROE) and payback period. All five measures are determined by using the standard formula for calculations. These measures test the feasibility of the on-farm biodiesel production. Simple descriptions of what these measures are and what their values mean have been explained below.

The *Internal Rate of Return (IRR)* is an interest rate at which the cost of investment leads to the benefits of the investment or it is an interest rate for an investment which will turn the net present value (NPV) to zero. The IRR is generally a compounded return from the project and is a measure of what the company could be earning had they invested elsewhere. It is generally better to invest in projects where rates of return are higher than the firm's required rate of return. The generally acceptable rate of return is 7-8%.

The *Net Present Value (NPV)* is a sum of the difference between the present value of cash inflows and the present value of cash outflows. NPV compares the dollar value of a project today to the value of that same dollar in the future at a given discount rate. It is similar to IRR in that it considers cash flows and adjusts for the time value of money. A positive NPV is generally acceptable for a project.

The *Return on Assets (ROA)* measures how profitable a firm is relative to its asset. It gives an idea of how efficiently management is using its assets to earn profits. But ROA does not provide a perfect measure of profitability because it is impacted by depreciation and other tax issues and the owner's return is also impacted by the firm's use of debt and equity capital.

The *Return on Equity (ROE)* measures how profitable a firm is relative to the owner's equity. It measures how much profit a firm generates to the money invested by the shareholders. Like ROA, it is also impacted by depreciation and other tax related issues. Compared to NPV or IRR, ROE is less useful in evaluating a potential project although it is widely accepted measure of firm performance because ROE is impacted by the amount of leverage, two firms with different ratios of debt and equity in their capital structure would project different ROEs for an identical project.

The last measure is the payback period which measures the length of time which is required to cover the cost of an investment. There is no general benchmark for an acceptable payback period however three years or less is generally accepted.

Additional Information

Customer Support

Please contact Dr. Phil Kenkel by e-mail at phil.kenkel@okstate.edu if any problems are experienced or if further information is needed

Disclaimer

The template has been designed and developed for the sole purpose of assisting producers for examining the feasibility of an on-farm biodiesel production from oilseed crops. User's discretion is required to use the template and authors do not bear any risk arising from the use of the template.

A COMPREHENSIVE SUPPLY CHAIN MODEL FOR THE PRODUCTION OF CELLULOSIC ETHANOL IN OKLAHOMA

Introduction

Over the past few years, the federal government has announced various policy targets and provided incentives for production of large-scale biofuel from cellulosic feedstock, including switchgrass. In 2006, Pacheco [1], who was the Director, of the Department of Energy's National Bioenergy Center, National Renewable Energy Laboratory (NREL) reported to a U.S. Senate committee that "...Our goal is to reduce the cost of producing cellulosic ethanol from \$0.59 L in 2005, to \$0.28 in 2012...." (\$0.35 in 2012 dollars). In anticipation of an economically viable feedstock production and conversion system, the U.S. Energy Independence and Security Act (EISA) of 2007 was passed by the Congress and signed by President Bush. Original mandated EISA targets for cellulosic ethanol were 379, 757, and 946 x 10⁶ L in 2010, 2011, and 2012, respectively. Meeting this target remains a significant challenge as economically viable domestic biomass feedstock logistics (feedstock production, harvest, storage, transportation) system and technology to convert biofuel from lignocellulosic feedstock has not been developed as was expected initially. As a result, the original mandated EISA targets for cellulosic biofuels of 379, 757, and 946 x 10⁶ L for 2010, 2011, and 2012 were reduced to 25 for 2010 and 2011 and to a range between 11 and 45 x 10⁶ for 2012. The \$0.35 L⁻¹ goal by 2012 was not achieved.

The NREL \$0.35 L⁻¹ of ethanol estimate was based on the assumption that a flow of feedstock would be delivered to the biorefinery for a cost of \$39 Mg⁻¹ (2002 dollars; \$49 in 2012 dollars). The Department of Energy has proposed that dedicated energy crops such as switchgrass produced on marginal lands could provide a substantial quantity of low cost

feedstock [USEPA 2010]. Given an expected conversion rate of 350 L Mg^{-1} , a $189 \times 10^6 \text{ L yr}^{-1}$ biorefinery would require 1,542 Mg of switchgrass biomass per day [Dutta et al. 2011]. To put this into some perspective, such a biorefinery would require 114 ha of harvested switchgrass biomass per day, assuming 13.5 Mg ha^{-1} of yield can be realized ha^{-1} . The logistics of producing, harvesting, storing, transporting, and delivering this quantity of biomass could be daunting. Especially, for switchgrass, the infrastructure for production, harvest, storage, and transportation is virtually nonexistent [Epplin et al. 2007]. The NREL estimates ignore these biomass logistics issues as well as the expected increase in feedstock cost as the demand for switchgrass biomass increases.

A well-established production, harvesting, storage and transportation system does not exist for lignocellulosic feedstock. There is a limited body of published research that evaluated the cellulosic biomass logistics systems, i.e. production, harvesting, storing, and delivering biomass to the refinery [Tembo, Epplin, and Huhnke, 2003, Mapemba et al. 2007, Mapemba et al. 2008, Wu, Sperow and Wang 2010, Haque and Epplin 2012]. For instance, Tembo, Epplin, and Huhnke [2003] built a multi-region, multi-period, mixed integer mathematical programming model that evaluated production, delivery, and processing methods for alternative cellulosic feedstocks including switchgrass but ignored complexities of harvesting systems. Mapemba et al. [2007, 2008] made some modifications to Tembo, Epplin, and Huhnke's model by incorporating harvesting systems and suitable monthly harvest days into the model. Mapemba [2007, 2008] used the coordinated set of harvest machines designed by Thorsell [2004] to estimate the cost of harvesting. Epplin et al. [2007] modified the model by separating harvesting activity for mowing and baling operations. Haque and Epplin [2011] expanded the model by taking in to account for differences in nitrogen requirements dependent on months of harvest for

switchgrass. Wu, Sperow and Wang [2010] modeled logistics (production, harvesting, storage, transporting) activities involved in handling woody biomass. It is noteworthy to emphasize that while these studies focused on modeling cellulosic biomass logistics issues, none of these considered the consequences on the breakeven price of ethanol due to increasing number of biorefineries for production of cellulosic biomass feedstock.

The objectives were to determine (1) the cost of delivering switchgrass biomass, the breakeven price of ethanol, optimal biorefinery locations, and an optimized logistics plan (production, harvest, storage, transportation) for switchgrass feedstock; and to assess (2) the consequences of increasing the number of biorefineries demanding switchgrass biomass at the breakeven price. Information gathered from this research provides a vision for production of ethanol from a potential cellulosic feedstock and provides useful detail regarding how complexities of delivering vast quantities of cellulosic biomass to the biorefinery can be handled by developing a coordinated logistics plan (production, harvesting, storage, and transportation) centrally managed by the respective authorities. In addition, this research provides useful information regarding the impact on feedstock delivered cost, the price of ethanol, and the whole logistics plan due to an increase in the number of biorefineries and all these information would be helpful for prudent investors or policy makers whose goal is to produce biofuel from potential cellulosic feedstock.

Data and Assumptions

To date, an infrastructure for production, harvest, transportation, storage and marketing is well developed for corn but not for switchgrass or other cellulosic biomass. Due to non-existent spot market for switchgrass a vertically integrated system similar to that used by timber

industries [Weyerhaeuser 2012, Barros and Weintraub 1982, Jones and Ohlmann 2008, Wu, Sperow and Wang 2010] is assumed for modeling purposes. Modeling was based on an assumption that biorefinery that engages in ethanol production would also be centrally managing land lease, biomass production, harvest, storage, transportation of the feedstock to the biorefinery. Parameters and parameter values used to estimate model are presented in Table 29.

Biomass Production and Plant Locations

USEPA [2010] projected that it is economically feasible to produce 3×10^9 L of cellulosic ethanol from switchgrass by 2022. They also envisioned that the majority of switchgrass is projected to likely be grown in Oklahoma. This state has 6.03×10^6 hectares in native prairie, grass, 1.9×10^6 hectares in improved pasture, 0.40×10^6 hectares in the federal government's Conservation Reserve Program, and 3.4×10^6 hectares of harvested cropland. And as switchgrass is a perennial that is naturally drought resistant and grows on marginal land, there is potential to grow switchgrass on improved pasture land. Because of these reasons Oklahoma State was considered as the area for this study. All (seventy-seven) Oklahoma counties were selected as potential switchgrass supply sources and 16 counties were selected as potential biorefinery locations. A map of Oklahoma counties showing 77 potential switchgrass production regions and 16 potential biorefinery locations are presented in Figure 21. In this study, potential locations for switchgrass biomass-based ethanol plants were selected based on biomass feedstock relative density and availability of road infrastructure.

Land Lease and Biomass Yield

It is assumed that biorefinery could lease and produce switchgrass in two land classes in Oklahoma; cropland and improved pasture land. Land areas of cropland and improved pasture land for each county were determined based on the data collected from the Census of Agriculture

[USDA, 2002]. Model also assumed that only 10% of each county's crop land and 10% of each county's pasture land could be used to produce switchgrass. This assumption gives management system flexibility regarding choosing when and where to lease land based on land rental. It is also assumed that biorefinery management could lease cropland and improved pasture land from land owner for 15-20 years at a rate of \$148 ha⁻¹ and \$99 ha⁻¹, respectively which is above average rental rates. The average 2006-10 non-irrigated cropland and improved pasture land cash rental for Oklahoma ranged from \$67-\$69 ha⁻¹ and \$21-\$27 ha⁻¹, respectively [USDA NASS 2009a]. The above average rental assumption was made to account for the uncertainty arising from the long-term lease for the production of switchgrass and to cover the opportunity costs of alternative production options.

Switchgrass yields for 77 counties for cropland and improved pasture land estimated by Basnet et al. [2011] based on information gathered from Natural Resources Conservation Service (NRCS) data base. The expected yield and fertilizer requirements are adjusted depending on month of harvest [Haque, Epplin, and Taliaferro 2009, Epplin and Haque 2011]. Switchgrass harvested in September and October produce higher expected yield and has lower requirement for fertilizers because of nutrient recycling compared to switchgrass harvest in mid-season in July-August. It is also expected that if switchgrass is left to stand in the field there will be 5% dry matter losses per month from November through March.

Harvest, Storage, and Transportation

The model was constructed based on the assumption that switchgrass will be harvested in a wide (nine-month) harvest window from July to March. Harvest operations include mowing, racking, baling and stacking. Harvest days varied between counties and largely depend on weather data [Hwang et al 2009]. Suitable harvest days for mowing and baling by month for 77 Oklahoma

counties were determined by Hwang et al [2009] were used in this study. It is known that at the time of baling the moisture content in the switchgrass biomass should not be more than 15% but that is not the case when it is mowed. As a result, most of time there will be fewer days for baling compared to mowing. For instance, In Grady county switchgrass biomass can be mowed in 16 days but bailed only through 5 days in the month of October. Harvest cost was estimated based on the integrated harvest unit concept developed by Thorsell et al [2004]. Harvest units were included as integer variables in the model and separated as mowing and baling (rake-bale-stack) unit. Mowing unit includes a self-propelled windrower (142 kW) equipped with a 16 foot rotary header and a laborer and a raking-baling-stacking harvest unit includes three wheel rakes, three 41 kW tractors; three balers, three 149 kW tractors; a field transporter; and seven laborers. Three balers are designed to bale 1.33 m x 1.22 m x 2.44 m rectangular solid bales. Salary and benefits of each harvest worker for a nine month season is assumed to be \$25,000 [Thorsell et al. 2004].

Harvested biomass may be stored in “in-field” storage or may be transported to the biorefinery by truck. Storage loss at the field and at the processing facility was assumed to be 1% which indicates that 90% of storage material will be available for processing ethanol [Epplin et al. 2007]. It is also assumed that bales stored in field would be covered by a plastic trap and a \$2.20 Mg⁻¹ cost was included to account for that [Tembo 2003; Epplin et al. 2007]. Shipment and processing of feedstock can be done in any of the twelve months of the year.

Cost of transporting switchgrass biomass from production region to processing facility was estimated by Wang [2009] and used for this study. It is assumed that a 15 Mg semi-tractor trailer is used to transport biomass in the form of solid rectangular bales (1.33 m x 1.22 m x 2.44 m) from production region to processing facility. Transportation cost includes cost of

machinery, diver wage and loading and unloading. Cost of machinery and diver wage includes round trip cost from production region to processing facility. Parameter and parameter values used to estimate cost of transportation was described in Table 29. A diesel fuel price of \$0.68 L⁻¹ (average price over four years from 2005-2008) was used in the computation of harvest and transportation costs [USDA NASS 2009b].

Plant Cost and Assumptions

Biorefinery will produce only one output, which is ethanol and gasification-fermentation technology was considered as the conversion method for converting switchgrass biomass feedstock to ethanol as described by Tembo et al. [2003]. Biorefinery capacity was fixed at 189 x 10⁶ L of ethanol per year with an estimated capital cost of \$379 x 10⁶ and conversion rate of 350 L of ethanol Mg⁻¹ [Dutta et al. 2011]. Operation and maintenance cost of the refinery was assumed \$0.26 L⁻¹, and this cost includes costs for labor, utilities, chemicals, taxes, repairs, and insurance.

Modeling

This study used a multi-region, multi-period, mixed integer mathematical programming model similar to the models used by previous studies [Tembo, Epplin, and Huhnke, 2003, Epplin, Mapemba, and Tembo 2005, Mapemba et al. 2007, Mapemba et al. 2008, Wu, Sperow and Wang 2010, Haque and Epplin 2012]. The objective function is to maximize the net present value of the system with a discount rate of 15 percent. The model assumes that biorefinery will centrally manage switchgrass to ethanol production. This includes switchgrass production, harvest, in-site storage, transport feedstock from production-site to the biorefinery, storage at the refinery site, and production of ethanol. The model is designed and solved to determine the area and quantity of switchgrass harvested by county, the number of harvest machines, and the cost to

procure, harvest, store, and transport a flow of switchgrass biomass to an optimally located and optimally sized biorefinery. Binary variables are included to enable the model to determine the most economical plant locations among 16 counties; Pontotoc, Washing, Canadian, Garfield, Okmulgee, Payne, Blaine, Carter, Grady, Kay, Woods, Comanche, Custer, Jackson, Texas, and Woodward. Integer variables are used to determine the optimal number of harvest machines. The model was solved using generalized algebraic modeling system (GAMS) with the CPLEX solver. A grid search procedure was used to determine breakeven price of ethanol at which net present value of the industry is equal to zero.

The model was initially solved to determine the breakeven ethanol price for a single biorefinery. The number of plants was incremented by one and the model resolved until 10 percent of the cropland and improved pasture land in the 77 counties was converted to switchgrass. It is assumed that plant investment costs would occur in year zero. Biomass harvest and delivery, plant operation, and ethanol production begins in year one and continues through year 20. Activities in years one through 20 are assumed to be identical.

Results and Implications

The model includes about 42,200 activities and 9,000 equations. The breakeven price for each plant, average breakeven ethanol price across plants, ethanol price equivalent to gasoline price, crude oil equivalent price, cost to deliver feedstock and optimal plant locations with increased number of biorefineries are reported in Table 30. Results showed that the breakeven price for a single biorefinery with an annual capacity of 189×10^6 L was estimated to be \$0.74 L^{-1} . This price is substantially more (\$0.39 L^{-1}) than the NREL estimate of \$0.35 indicating that under current feedstock price and conversion technology NREL projected ethanol price could not

be achieved. Moreover, we know that ethanol contains less energy (21.1 MJ L^{-1}) than unleaded gasoline (32 MJ L^{-1}). Based on the energy content of ethanol relative to unleaded gasoline, $\$0.74 \text{ L}^{-1}$ is equivalent to $\$1.13 \text{ L}^{-1}$ of gasoline, which is the expected wholesale price of gasoline if the price of crude oil is $\$146.4$ per barrel. As the number of the plants increase, the breakeven price also increases. For example, the breakeven price is $\$0.76 \text{ L}^{-1}$ for the fifth biorefinery and $\$0.83 \text{ L}^{-1}$ for the ninth biorefinery. On average across plants the estimated break-even price of nine biorefineries is $\$0.77 \text{ L}^{-1}$. Given fixed biorefinery capital, operation and maintenance cost, the break-even price increases due to increase in feedstock delivered cost.

The estimated cost to deliver a Mg of switchgrass feedstock for a single biorefinery was $\$54.92 \text{ Mg}^{-1}$ which is $\$15.92 \text{ Mg}^{-1}$ greater than the NREL's estimate. This result indicates that even though switchgrass was produced on marginal land (improved pasture land) as the Department of Energy proposed, it is not possible to deliver feedstock to the biorefinery at NREL's estimated cost of $\$39 \text{ Mg}^{-1}$. The $\$54.92 \text{ Mg}^{-1}$ cost includes $\$13.33$ (24% of the $\$54.92$) for land rental, $\$15.64$ (28%) for establish and maintenance, $\$0.45$ (1%) for field storage, $\$15.05$ (27%) for harvest, and $\$10.45$ (19%) for transporting the biomass from the field to the biorefinery. As the number of plants increase, on average the cost to deliver feedstock increases. For instance, on average across plants the cost to deliver a Mg of switchgrass feedstock for nine biorefineries is $\$64.79 \text{ Mg}^{-1}$. This cost includes $\$15.87$ (24% of the $\$64.79$) for land rental, $\$18.88$ (29%) for establish and maintenance, $\$0.45$ (1%) for field storage, $\$14.07$ (22%) for harvest, and $\$15.52$ (24%) for transporting the biomass from the field to the biorefinery.

On average, there is an increase of $\$9.88$ (18%) Mg^{-1} of total feedstock delivered cost for nine biorefineries compared to a single biorefinery. As the number of plants increased, biorefineries started located in regions with lower expected yields and hence there was an

increase in land rental, establishment and maintenance costs, and costs of transportation, which in turn raised the cost of feedstock delivery. Land, biomass harvested, and expected yield with increased number of biorefineries are reported in Table 32. For a single biorefinery the average expected yield for switchgrass production region was 10.1 Mg ha⁻¹ but for nine biorefineries the expected yield was 8.5 Mg ha⁻¹. As a result, more lands were harvested to get the required biomass. The cost of transportation was also found to increase because the model was restricted to use only 10% of each counties cropland and improve pastureland. As number of plants increased more biomass were needed and when nearby 10% cropland and 10% improved pasture land were under production, required biomass was collected from the production regions that are far away from the refinery, which in turn raised the cost of transportation.

Average investment on harvest machine was lower when we invest in nine biorefineries compared to one biorefinery. For a single biorefinery, investment on harvest machine is estimated to be \$14,525 thousand. Total investment on harvest machinery for nine biorefineries is estimated to be \$121,593 thousand meaning when nine biorefineries were selected, on average each biorefinery needed to invest \$13,510 thousand on harvest machinery. For a single biorefinery the optimal number of mowing units that includes number of self-propelled windrower is 15 and the optimal number of raking-baling-stacking units includes 36 rakes, 36 balers, 12 field stackers, 36 tractors (41 kW) for rake, and 36 tractors (149 kW) for baler. And for nine biorefineries the optimal number of mowing units was 131 and the optimal number of raking-baling-stacking units included 300 rakes, 300 balers, 100 field stackers, 300 tractors (41 kW) for rake, and 300 tractors (149 kW) for baler.

To fulfill the requirement of a single 189×10^6 L per year capacity biorefinery total of 53,879 hectares were harvested to produce 549,137 Mg biomass. Fig 2 illustrates the eight

optimal switchgrass production and harvest regions and the optimal biorefinery location (Grady county) in which the single biorefinery would be located. It is noteworthy to emphasize that, the quantity of biomass harvested and the number of ha required increases as the number of plants increase. For example, for nine biorefineries given the expected switchgrass yields (8.5 Mg ha^{-1}), more than $4.95 \times 10^6 \text{ Mg}$ of biomass would be produced and total of 0.59×10^6 hectares of land would be required to produce the feedstock. Fig 3 illustrates the optimal biorefinery locations and harvested lands for nine biorefineries.

Given the plant capacity of $189 \times 10^6 \text{ L}$ per year and with the conversion rate of 350 L Mg , the feedstock needed annually is approximately $540,000 \text{ Mg}$ but due to 1% storage loss considered in the model, for a single biorefinery, a total of $549,137 \text{ Mg}$ of biomass would be harvested optimally to fulfill the requirement. Due to the same reason, for nine biorefineries, a total of $88,675$ more biomass was harvested compared to what was used for processing ethanol.

Conclusions

A goal set by National Renewable Energy Laboratory is to produce cellulosic ethanol at a rate of $\$0.35 \text{ L}^{-1}$ by 2012 was not achieved. The NREL ignores the fact regarding cellulosic biomass logistics issues and ignores the expected increase in feedstock cost as the demand for switchgrass biomass increases. This research was conducted to determine (1) the cost to deliver switchgrass biomass, the breakeven price of ethanol, optimal biorefinery locations, and an optimized logistics plan (production, harvest, storage, transportation) for switchgrass feedstock; and to determine (2) the consequences of increasing the number of biorefineries demanding switchgrass biomass on the breakeven price. A multi-region, multi-period mixed integer mathematical programming model designed to maximize the net present value of the biorefinery that includes 77 Oklahoma counties as potential production regions, monthly feedstock

requirements, integer activities for harvest machines, and integer activities for each of 16 potential biorefinery locations, was constructed.

Based on the model, the breakeven price of a single biorefinery with annual capacity of 189×10^6 L was estimated to be $\$0.74 \text{ L}^{-1}$, substantially more than the NREL estimate of $\$0.35$. The estimated cost to deliver an Mg of switchgrass feedstock was $\$55 \text{ Mg}^{-1}$, more than the NREL's estimate. As the number of plants increase, transportation costs increase, and biorefineries are located in regions with lower expected yields. The breakeven price increases with the number of biorefineries. Average breakeven price across plants for nine biorefineries is estimated to be $\$0.77 \text{ L}^{-1}$. This difference is mainly due to increasing transportation cost. As the number of plants increased more biomass were needed and when nearby cropland and improved pasture land were under production required biomass was collected from the production regions that are far away from the refinery, which in turn raised the cost of transportation. A feedstock substantially less expensive than switchgrass with current production costs and yields, and a substantially more cost efficient conversion system would be required to achieve the $\$0.35$ goal.

References

1. Pacheco M (2006) U.S. Senate Full Committee Hearing—Renewable Fuel Standards. National Renewable Energy Laboratory, National Bioenergy Center, 19 June 2006. Internet site: http://energy.senate.gov/public/index.cfm?FuseAction=Hearings.Testimony&Hearing_ID=93dd3004-fc19-42d6-86d8-ed80db687eb&Witness_ID=5a7b62d1-173b-4905-81a0-7f809ed27b16
2. USEPA-U.S. Environmental Protection Agency (2010) Renewable fuel standard program (RFS2) Regulatory Impact Analysis, EPA-420-R-10-006
3. Dutta A, Talmadge M, Hensley J, Worley M, Dudgeon D, Barton D, Groendijk P, Ferrari D, Stears B, Searcy E, Wright C, Hess J. (2011) Process design and economics for conversion of lignocellulosic biomass to ethanol: Thermochemical pathway by indirect gasification and mixed alcohol synthesis. NREL Report No. TP-5100-51400
4. Epplin FM, Clark CD, Roberts RK, Hwang S (2007) Challenges to the development of a dedicated energy crop. *Am J Agric Econ* 89(5):1296-1302
5. Tembo, G, Epplin FM, Huhnke RL (2003) Integrative investment appraisal of a lignocellulosic biomass-to-ethanol industry. *J Agric Res Econ* 28:611-633

6. Mapemba LD, Epplin FM, Taliaferro CM, Huhnke RL (2007) Biorefinery feedstock production on conservation reserve program land. *Rev Agric Econ* 29:227-246
7. Mapemba LD, Epplin FM, Huhnke RL, Taliaferro CM (2008) Herbaceous plant biomass harvest and delivery cost with harvest segmented by month and number of harvest machines endogenously determined. *Biomass Bioenergy* 32:1016-1027
8. Wu J, Sperow M, Wang J (2010) Economic feasibility of a woody biomass-based ethanol plant in central Appalachia. *J Agric Res Econ* 35:522-544
9. Haque M and Epplin FM (2012) Cost to produce switchgrass and cost to produce ethanol from switchgrass for several levels of biorefinery investment cost and biomass to ethanol conversion rates. *Biomass Bioenergy* 46:517-530
10. Thorsell SR, Epplin FM, Huhnke RL, Taliaferro CM (2004) Economics of a coordinated biorefinery feedstock harvest system: Lignocellulosic biomass harvest cost. *Biomass Bioenergy* 22(4):327-337
11. Epplin FM, Haque M (2011) Conversion of millions of acres to the production of biofuel feedstock. *J Agric Appl Econ* 43(2):385-398
12. Weyerhaeuser (2012) Low-cost, high value harvesting. Internet site: <http://www.weyerhaeuser.com/Businesses/Timberlands/OptimizingHarvests> (Accessed 7 February 2012).
13. Barros O, Weintraub A (1982) Planning for a vertically integrated forest industry. *Operations Research* 30(6):1168-1182
14. Jones PC, Ohlmann JW (2008) Long-range timber supply planning for a vertically integrated paper mill. *Euro J Oper Res* 191:558-571
15. USDA-United States Department of Agriculture, Census of Agriculture (2002) Oklahoma state and county data. *Geographic Area Series vol. 1, part 6*
16. USDA, NASS-United States Department of Agriculture, National Agricultural Statistics Service (2010a) Land values and cash rents 2010 summary. Internet site: <http://usda01.library.cornell.edu/usda/nass/AgriLandVa//2010s/2010/AgriLandVa-08-04-010.pdf> (accessed January 17, 2013)
17. Basnet A, Depona T, Hedges W, Dicks MR (2011) Potential biomass yields in the south central US. Southern Agricultural Economics Association Annual Meeting, Corpus Christi, TX, February 5-8, 2011
18. Haque M, Epplin FM, Taliaferro CM (2009) Nitrogen and harvest frequency effect on yield and cost of four perennial grasses. *Agron J* 10:1463-9
19. Hwang S, Epplin FM, Lee BH, Huhnke RL (2009) A probabilistic estimate of the frequency of mowing and baling days available in Oklahoma USA for the harvest of switchgrass for use in biorefineries. *Biomass Bioenergy* 33:1037-45
20. Wang C (2009) Economic analysis of delivering switchgrass to a biorefinery from both the farmer's and processor's perspectives. Master's thesis. The University of Tennessee, Knoxville, Tennessee
21. USDA, NASS-U.S. Department of Agriculture, National Agricultural Statistics Service (2009b) Agricultural prices 2008 summary. Internet site: <http://usda01.library.cornell.edu/usda/nass/AgriPricSu//2000s/2009/AgriPricSu-08-05-2009.pdf> (accessed February 5, 2013)
22. U.S. Energy Information Administration (2010) *Annual U.S. Gulf Coast Conventional Gasoline Regular Spot Price FOB*. Internet site: <http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=p&s=rwtc&f=a>. (accessed January 14, 2013)

Table 29. Parameters and parameters value used to estimate model

Item	Item value
Biorefinery	
Product	Ethanol
Conversion technology	Gasification-fermentation
Each plant capacity, 10^6 L yr^{-1}	189
Capital investment for each plant, \$ x 10^6	\$379.50
Operation & maintenance cost, \$ L^{-1}	0.26
Conversion rate, L of ethanol Mg^{-1}	350
Plant life, years	20
Discount rate, %	15
Feedstock and land	
Cropland rental leased rate, \$ $\text{ha}^{-1} \text{ yr}^{-1}$	148
Improve pastureland leased rate, \$ $\text{ha}^{-1} \text{ yr}^{-1}$	99
Proportion of cropland ha available for switchgrass production, %	10
Proportion of improved pasture land ha available for switchgrass production, %	10
Price of nitrogen, \$ kg^{-1}	1.0
Price of phosphorus, \$ kg^{-1}	1.2
Establishment cost of switchgrass in cropland, \$ ha^{-1}	68.8
Establishment cost of switchgrass in improve pasture land, \$ ha^{-1}	61.8
Maintenance cost, \$ ha^{-1}	10.2
Transportation [†] , harvest, and storage [‡]	
Diesel fuel price, \$ L^{-1}	0.68

Truck speed, kilometers hr ⁻¹	80
Diesel fuel use of the truck, L ha ⁻¹	84
Diver's wage, \$ hr ⁻¹	8.5
Loading time, per load	0.75
Cost of loading and unloading, \$	0.4
Usable proportion of stored biomass at the production locations, %	99
Usable proportion of stored biomass at the plant, %	99
Biomass storage cost at the production locations, \$ Mg ⁻¹	2.2
Other assumptions	
Potential biorefinery locations, number	16
Potential switchgrass production counties, number	77

[†]Adapted from Wang (2009)

[‡]Adapted from Hwang et al. (2009)

Table 30. Average breakeven price of ethanol and optimal locations of the biorefineries with increased number of biorefineries

Biorefinery (number)	Breakeven price for next plant \$ L ⁻¹	Average break even ethanol price \$ L ⁻¹ †	Gasoline equivalent price \$ L ⁻¹ ‡	Crude oil equivalent price \$ barrel ⁻¹ §	Cost to deliver Feedstock, \$ Mg ⁻¹	Locations of the biorefineries
1	0.74	0.74	1.13	146.4	54.92	Grady
2	0.75	0.75	1.14	147.4	56.11	Grady & Garfield
3	0.75	0.75	1.14	147.5	56.43	Grady, Garfield, & Okmulgee
4	0.76	0.75	1.14	147.5	57.56	Grady, Garfield, Okmulgee,& Pontotoc
5	0.76	0.75	1.14	148.4	58.55	Grady, Garfield, Okmulgee, Pontotoc, & Woods
6	0.78	0.76	1.15	149.4	59.88	Grady, Garfield, Okmulgee, Pontotoc, Woods, & Washington
7	0.78	0.76	1.16	150.0	60.86	Canadian, Comanche, Garfield, Okmulgee, Pontotoc, Washington, Woodward

8	0.78	0.76	1.16	150.4	62.03	Blaine, Garfield, Grady, Jackson, Okmulgee, Pontotoc, Washington, Woodward
9	0.83	0.77	1.17	152.0	64.79	Blaine, Grady, Garfield, Jackson, Okmulgee, Pontotoc, Texas, Woods, Washington

[†] Average break-even ethanol price across plants

[‡] Gasoline equivalent price was estimated based on energy content of 21.1 MJ L⁻¹ of ethanol and 32 MJ L⁻¹ of unleaded gasoline

[§] Crude oil price calculated based on estimated value from a regression equation of the annual price of gasoline \$ L⁻¹ on the price of crude oil \$ barrel⁻¹ was estimated using 21 years of historical data [U.S. Energy Information Administration 2010]

Table 31. Estimated costs, number of harvest machines, average investment in harvest machines with increased number of biorefineries

Economic variable	Biorefineries (number)								
	1	2	3	4	5	6	7	8	9
Land rent cost, \$ Mg ⁻¹	13.33	14.18	13.62	13.62	14.18	14.05	14.56	15.23	15.87
Establish and maintenance cost, \$ Mg ⁻¹	15.64	16.08	15.80	16.27	16.63	16.67	17.12	17.93	18.88
Field storage cost, \$ Mg ⁻¹	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Harvest cost, \$ Mg ⁻¹	15.05	14.54	14.57	14.69	14.32	14.64	14.56	14.34	14.07
Transportation cost, \$ Mg ⁻¹	10.45	10.87	11.98	12.52	12.97	14.07	14.16	14.07	15.52
Total cost, \$ Mg ⁻¹	54.92	56.12	56.43	57.56	58.55	59.88	60.86	62.03	64.79
Other results									
Harvest units for mowing (number)	15	30	43	58	72	88	103	117	131
Harvest units for raking-baling-stacking (number)	12	23	35	47	57	70	81	91	100
Average investment in harvest machines (\$,000)	14,525	27,955	42,296	56,822	69,063	84,776	98,205	110,447	121,593

Table 32. Land, biomass harvested, and expected yield with increased number of biorefineries

Biorefineries (number)	Land harvested, ha			Biomass Harvested (Mg)			Average expected yield Mg ha ⁻¹
	Cropland	Improve pasture land	Total	Cropland	Improve pasture land	Total	
1	38,242	15,637	53,879	424,104	125,033	549,137	10.1
2	90,302	19,757	110,059	941,289	157,483	1,098,771	10.1
3	123,038	39,227	162,266	1,328,672	320,666	1,649,337	10.1
4	147,764	76,749	224,513	1,587,588	610,777	2,198,364	9.9
5	203,629	82,607	286,235	2,097,211	651,050	2,748,261	9.6
6	233,078	112,120	345,198	2,425,735	871,394	3,297,128	9.6
7	288,101	125,980	414,081	2,884,859	961,189	3,846,048	9.2
8	344,135	151,182	495,317	3,316,793	1,079,556	4,396,348	9.0
9	390,815	196,205	587,021	3,618,465	1,330,210	4,948,675	8.5

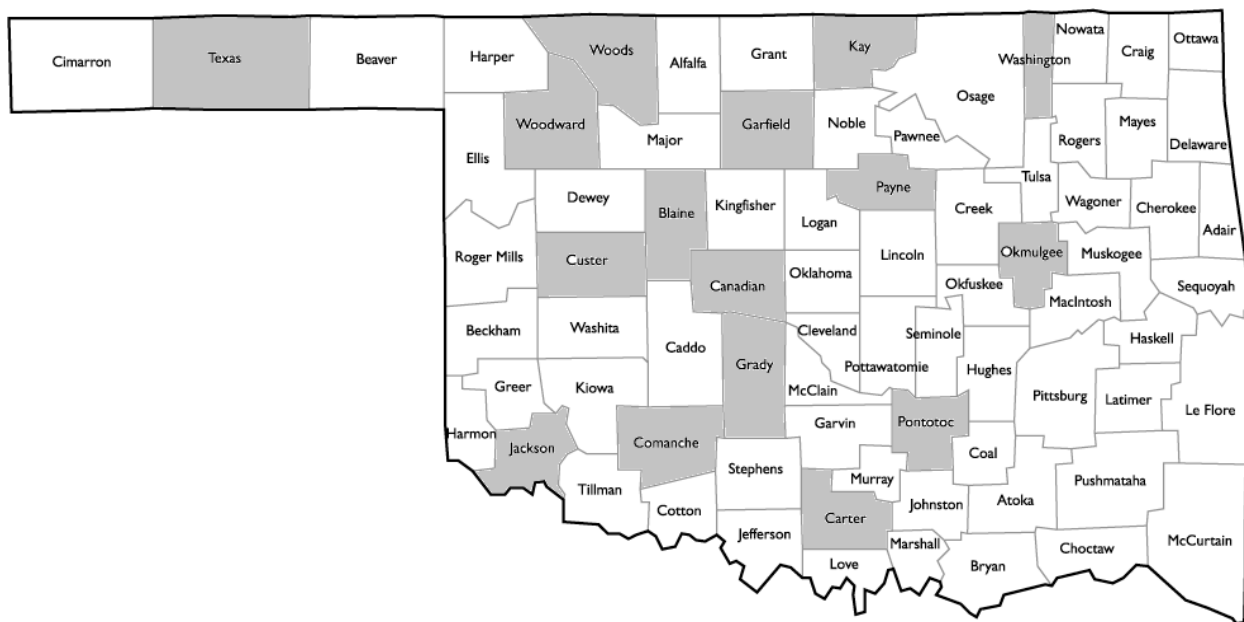


Fig 21. Map of Oklahoma counties showing 77 potential switchgrass production regions and 16 potential biorefinery locations (in gray color).

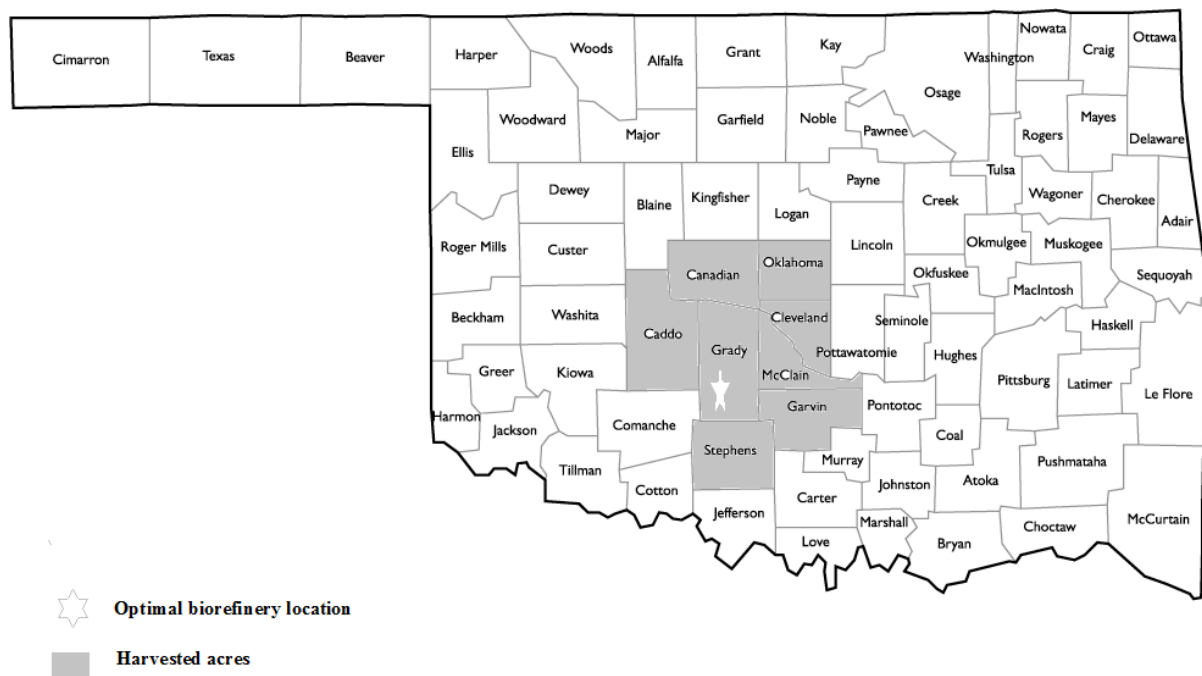


Fig 22. Optimal biorefinery location and harvested lands (cropland/pasture land) for a single biorefinery.



Fig 23. Optimal biorefinery locations and harvested lands for nine biorefineries.

ECONOMIC IMPACT OF CELLULOSIC ETHANOL PRODUCTION UNDER DIFFERENT OWNERSHIP STRUCTURES

Introduction

Government policy such as the Energy Independence and Security Act of 2007 was created to help the country become more energy independent and increase the national production and consumption of biofuels. In Title II, Subtitle A, Section 202, the Renewable Fuel Standard set forth a mandate for 36 billion gallons renewable fuels to be produced in the United States by 2022 (U.S. Congress, 2007). To help meet this rising demand, renewable fuel plants are being built throughout the grain belt in the United States. Because these plants are highly dependent on agricultural inputs, they are usually located in rural communities with easy access to feedstock supplies.

Oklahoma is not a large producer of corn, but the state does have significant grassland acres and the ability to grow various prairie grasses identified as feedstock crops for “second generation” biofuels. Switchgrass has been identified as a viable feedstock for cellulosic ethanol and “drop-in” biofuels, and this species is native to Oklahoma. The production of cellulosic-based biofuels in Oklahoma has been considered for years, but impacts of such industrial activities have received little attention.

Switchgrass (*Panicum virgatum*) is a perennial grass native to North America. It is resistant to many pests and plant diseases, and it is capable of producing high yields with very low applications of fertilizer. Switchgrass also is very tolerant of poor soils, flooding and drought (Burden 2011). Switchgrass yields in some areas can exceed 10 tons per acre with relatively low amounts of inputs (Ugarte, English, and Jensen, 2007). Epplin (2009) also showed that switchgrass lands are not expected to require many farming activities, which could benefit

farmers through collective land use shifts to switchgrass production with lower establishment and operating costs compared to other crops. Given these benefits, switchgrass is considered a leading feedstock for cellulosic ethanol production, but the conversion of cropland and grassland acres to switchgrass production is expected to have direct and indirect impacts on agriculture and rural economies in preferred production areas.

Ethanol production from switchgrass has been projected to have a positive economic impact on the county where the biofuel facility is located and surrounding areas where switchgrass would be sourced. Schlosser et al. (2008) showed through multiple scenarios with changes in sales, increasing employment, detailed budget information, and changes in grain procurement how cellulosic ethanol production positively impacted labor markets for the Great Plains region. Swenson (2006) modeled ethanol plant configuration in a three county region in Iowa based on configuration of input and output accounts for the industry with price, cost, and other regional production factors used to modify IMPLAN® sector accounts. Fulton (2010) determined that the impacts of switchgrass farming and cellulosic ethanol conversion in eastern and western Tennessee would have positive economic impacts on each region's output, employment, and total value added. No previous studies have been conducted to measure the economic impacts of cellulosic biofuel production from switchgrass on the state of Oklahoma, nor have previous studies considered different plant ownership structures and their implications upon the study region.

Related Literature

Economic Impact Assessments

Input-output analysis can be used to measure the direct, indirect, and induced impacts of a biofuel production facility on a region's economy. Most previous studies have focused on impacts of biofuel production from existing biomass or crops, with the biofuel production

representing an alternative use for the feedstock. A review of the literature shows this study to be somewhat unique in that land use changes are incorporated. However, several previous biofuel impact studies provide a foundation for impact assessment.

Swenson (2006) utilized input-output analysis to estimate impacts for ethanol plants for a three county region in Iowa. Focusing his models on accounts for the industries that are sensitive to price, cost and other regional production factors, Swenson (2006) modified industry accounts to show ethanol production. Through this type of analysis, impacts for output, value added, and jobs were measured. Further, Swenson (2006) assumed that, with the production of ethanol, corn production would not increase to meet the demand, but did show an increase of 135 jobs. In utilizing input-output analysis software such as IMPLAN® more in-depth industry details can also be measured to show how industry change can affect additional industries.

Schlosser et al. (2008) evaluated input-output impact projections by taking actual labor impacts from a Kansas ethanol plant opening and comparing them to the projected impacts before the plant was established. In multiple scenarios with projections based on employment or projected sales, Schlosser et al. (2008) showed pre-opening jobs and income estimates exceeded the actual impacts. In other scenarios with more information on actual production technology estimates were more approximate to what actually took place.

Flanders and McKissick (2007) analyzed a proposed operation of a cellulosic ethanol production from wood cellulose in Georgia. Using input-output analysis on Treutlen County for the plant location, impacts for plant construction and ethanol production were measured. With the construction and operation of the plant, 194 jobs would be created on the county level, 432 jobs for an 18 county region, and, on the state level, and 444 jobs. With no viable operating plant to compare projections, these estimations may be off, as in the case of Schlosser et al. (2008).

Petersan (2002) used input-output analysis to estimate employment and economic impacts for the operation of Nordic Biofuels Ethanol Plant in Ravenna, Nebraska. A nine-county model was developed using industry data from 1999. Variables impacting the analysis included labor income, property income, employment, and industry output. Input-output analysis measured employment effects, labor effects, output effects, indirect business tax effects, and retail sale effects.

Fulton (2010) used input-output analysis to measure the impact of cellulosic ethanol production in the western and eastern regions of Tennessee and compare the two. In analyzing the two regions, factors included production, storage, transport, and conversion of switchgrass to ethanol. Using the costs from those factors, the study projected the economic impacts of a cellulosic ethanol facility in the two study regions. Fulton concluded that the implementation of a cellulosic facility in either region would have a positive economic impact for the study area.

Data and Methods

The economic impacts from the operation of cellulosic ethanol facilities in Oklahoma were determined using the input-output analysis software IMPLAN®, following the identification of an optimal biorefinery site and supporting switchgrass production acreage. Switchgrass production was added to IMPLAN® since it is not currently represented in the industry accounts. Industry accounts and study area data were modified to include switchgrass production in the target area. Additionally, for economic impacts it was assumed the biorefinery was already constructed and the operation activity was modeled through operating and depreciation expenditures.

Construction costs for a plant only occur once, thus are temporary and do not sustain long-term employment. Establishment costs for switchgrass stands exist but are sunk costs and

not accounted for in this study. Operating costs for a plant and maintenance costs for switchgrass take place over many years and were measured. Finally, after switchgrass production and cellulosic ethanol plant operations were modeled, economic impacts from the two activities were projected by IMPLAN® for each different ownership scenario.

Switchgrass Production Area and Plant Location Data

For the optimal plant location and switchgrass production areas, this study expanded on the dissertation work of Mohua Haque (2010). A comprehensive mathematical programming model was used to determine optimal locations and production areas. The model was designed to determine the area (acres) and quantity (tons) of switchgrass harvested by county, the number of harvest machines, and the cost to procure, harvest, store, and transport a flow of switchgrass biomass to an optimally located and optimally sized biorefinery (Haque, 2010).

In Haque's model it is assumed that the life of an ethanol plant is twenty years. All plant investment costs occur in year zero. Biomass harvest and delivery, plant operation, and ethanol production take place across a twenty-year horizon. All operation activities in years 1-20 are assumed to be identical. Biorefinery investment costs for a 50 million gallon capacity facility are assumed to be \$275 million. The biorefinery is assumed to operate 350 days per year, and depends entirely on switchgrass as a single feedstock. A conversion rate of 100 gallons of ethanol per dry ton of switchgrass is assumed. Feedstock delivery takes place in all twelve months of the year. In the model six candidate biorefinery locations are considered in Canadian, Garfield, Okmulgee, Payne, Pontotoc, and Washington counties.

For switchgrass stands total harvested acres in each county may not exceed the number of acres available for harvest in the county. Biomass harvested is equal to the available biomass in the field. Haque's original model was limited to the eastern 57 counties of Oklahoma's 77

counties as production regions. The harvest season begins in July and extends through March. Fields harvested in July are expected to require 80 pounds per acre of nitrogen to achieve highest yields while fields harvested in October through March are expected to require only 63 pounds per acre. Switchgrass production is restricted to cropland and improved pasture land and is limited to no more than ten percent of the each production county's cropland and no more than ten percent of the county's improved pasture land. Storage losses at the biorefinery and in the field are assumed to be one percent per month. Also switchgrass dry matter will be of equivalent value to the biorefinery independent of harvest month and time in storage.

Haque's (2010) model was expanded by Haque in post doctoral research to account for switchgrass production in all 77 counties in Oklahoma. The model identified nine possible optimal locations for ethanol plants in an iterative manner, up to the point where 10% of all crop and pasture acres in each county was converted to switchgrass production.

Payroll for all plant employees is assumed to be \$2.7 million for each plant (Hodur and Leistritz, 2009). Biomass is supplied throughout the year. Also it is assumed that switchgrass stands and ethanol plants are already established. Because both are already established the investment costs for switchgrass stands and ethanol plants are not included in the input-output analysis. Only the switchgrass maintenance costs and ethanol plant operation and depreciation costs are included in the study. Maintenance costs for switchgrass are assumed to be identical for both converted cropland and improved pasture land acres. Land use is restricted to no more than 10% of cropland acres or pasture land acres by county as in Haque's (2010) earlier model. Land use is restricted to only 10% to keep land prices from rising as ethanol plants are bidding to lease land for switchgrass production.

Switchgrass Production

In determining specific industry accounts to edit to account for switchgrass production in the study region, a switchgrass maintenance budget developed by Griffith et al. (2010) was utilized to calculate new coefficients for the costs of DAP, Urea, fertilizer application, swathing, bailing, hauling, and operating capital. The cost of DAP was divided by the total value of production for switchgrass to give the new coefficient for IMPLAN® sector 319 (Wholesale trade businesses). Urea cost was divided by the total value of production for switchgrass to give the new coefficient for IMPLAN® sector 130 (Fertilizer manufacturing). The three costs for the activities of fertilizer application, swathing, and bailing are combined and then divided by the total value of production to give the new coefficient under sector 19 (Support activities for agriculture and forestry).

The cost of hauling from field to plant is divided by total value of production to give the new coefficient under sector 335 (Transport by truck). Operating capital is divided by total value of production to give the final needed coefficient under sector 354 (Monetary authorities and depository credit intermediation activities). These new coefficients are entered into industry production account sector 10 (All other crop farming) to show that switchgrass production is in the study region. To complete the model and to account for switchgrass production in the region study area, data under sector 10 was also changed. Griffith (2010) provided the basis for most aspects of the switchgrass production budget, including the land rent values used as proprietor income for impacts estimates. No other property income was included. Employee compensation was based upon a calculation of labor hours converted from machine hours and a fixed hourly wage. IMPLAN estimated the indirect business taxes resulting from switchgrass production. Values used to edit the study area data and production function under sector 10 can be viewed in Table 33. After these changes were made, the model was reconstructed through multipliers.

When the model was reconstructed a new industry change activity was added for the switchgrass supply counties, and an event under this activity was created under sector 10 (All other crop farming). The event year was changed to 2009 and under industry sales the total value for production for switchgrass in that scenario was entered. Total value of production was the sum of cash cost, labor cost, and proprietor income for switchgrass, since market prices do not exist for switchgrass. After the switchgrass activity was put into the model, the direct, indirect, and induced economic effects that take place in the targeted production region due to switchgrass production for each scenario were estimated.

Ethanol Production

Expenditures for ethanol plant operation were taken from a Tennessee cellulosic ethanol plant budget created by Ugarte et al. (2006) to measure the impacts of a 69.3 million gal/year cellulosic ethanol plant. All expenditures were converted to be used for a 50 million gal/year plant for this study by multiplying the original expenditure by a (50/69.3) ratio. Because the budget was from 2006, the IMPLAN® sectors where the expenditures fell had to be edited, as the industry sectors changed from having 509 sectors to 440 sectors. Table 34 shows the converted operating budget for ethanol plants in the current study with corresponding IMPLAN® sectors.

A model was created to estimate the impact of ethanol production for the first plant location identified by Haque's revised model: Grady County, Oklahoma. The study area was limited to the county in which the ethanol plant would be located for two reasons. First, very little of the inputs demanded by the plant were available in the switchgrass production region, so there was little benefit to use this region. Second, restricting the impact of the household spending to Grady County, which is the regional retail center for the region, provides a natural

basis for a conservative estimate of the induced impacts. Since there does not exist a sector in IMPLAN® that closely matches ethanol production, the analysis-by-parts methodology was used to enter the input demands of the ethanol plant. The inputs available locally, their values, and their total direct impact are provided in Table 35.

Once the events were entered for ethanol plant operation under the industry change activity, another activity was created to account for plant employee income in the region. This activity was represented as a labor income change in the region with a new event for payroll. A value of \$2.7 million was used as the total salary for plant employees. This value was taken from Hodur and Leistritz (2009), who analyzed the impacts of a 50 million gal/year cellulosic plant in North Dakota. This salary value was used for each scenario, regardless of ownership scheme. Once these activities were entered with their corresponding events, the model showed the direct, indirect, and induced impacts that cellulosic ethanol production was expected to have in the region for the given scenario.

For the ethanol plant impacts, different management practices were modeled to compare how a 50% cooperative owned ethanol plant and a 100% cooperative owned ethanol plant will impact the region compared to a 100% privately owned ethanol plant. A cooperative business does not retain profits but redistributes them to members through annual cash patronage or qualified stocks. For private ownership, the original steps discussed above were followed. To account for cooperative ownership, we took 50% of the plant's profits and kept them in the region by creating an additional labor income activity with a proprietor income event equal to the percentage of cooperative ownership (50% or 100%).

Profits were calculated by taking the current market price of \$2.29 gallon (Nebraska Energy Statistics, 2012) and adding a dollar tax credit (DOE, 2011) to give a new ethanol price

of \$3.29. The breakeven price from the single plant scenario was \$2.81 (Haque, 2010), and this was subtracted from the new ethanol price of \$3.29 to give a profit of \$0.48 per gallon of ethanol. The \$0.48 profit per gallon was multiplied by the plant capacity of 50 million gal/year to give plant profits of \$24 million, and a portion of the plant profits (either 0%, 50% or 100%) were entered in to the proprietor income event to account for the corresponding share of cooperative ownership. With this, we were able to model cooperative ownership in IMPLAN® through cash returns to producers in the region. Once the cooperative and private ownership models were run separately, results were compared from the two to analyze how the different management schemes might affect Grady County.

Results

It is important to remember that investment costs for both switchgrass stand production and cellulosic ethanol production were treated as temporary costs and not included in the model. Also, switchgrass production and ethanol production were handled separately as two different models, so results are presented separately. Results for the two activities were also summed to show the total impact for the study region. For the results we focus on the total impacts from the two activities, as well as go into detail on how they affect industry employment and output.

For Grady County, we modeled both a cooperative ownership and private ownership structure: 0% cooperative ownership (100% private ownership), 50% cooperative ownership (50% private ownership), and 100% cooperative ownership (0% private ownership). Also, switchgrass production to supply the single ethanol plant was modeled. The impacts from switchgrass production for the three different ownership structures have been provided in respective tables.

Switchgrass production was expected to occur in eight counties of the production region to support the biofuel plant located in Grady County. Industry output for switchgrass production was \$32.2 million in direct effects, \$11.2 million in indirect effects, and \$16.9 million in induced effects. The total industry impacts for the switchgrass production region were \$60.3 million. Employment for switchgrass production was 169 direct employees, 123 indirect employees, and 165 induced employees. This gave an impact of 457 total employees for switchgrass production. All impacts are shown below in Table 36.

Employment results showed that the industries affected the most by switchgrass production fall under IMPLAN sector 10 (All other crop farming), sector 19 (Support activities for agriculture and forestry), sector 335 (Transport by truck), and sector 319 (Wholesale trade businesses). Industries affected by output from switchgrass production are under sectors 10 (All other crop farming), 319 (Wholesale trade businesses), 335 (Transport by truck), and 361 (Imputed rental activity for owner-occupied dwellings). The top ten industries affected by switchgrass production for employment, output, labor income, and value added can be obtained on request from the authors.

Under private ownership for the ethanol plant in Grady County the output impacts were projected at \$5.3 million direct, \$0.68 million indirect, and \$3.7 induced, for total output impacts of \$9.7 million. Employment for the private ownership ethanol plant consists of 52 direct employees, 7 indirect employees, and 40 induced employees, for a total of 99 employees. The region's most affected areas under the 100% private ownership scenario are available upon request from the authors, and are: IMPLAN® sectors 417 (Commercial and industrial machinery and equipment repair and maintenance), 390 (Waste management and remediation services), 368 (Accounting, tax preparation, bookkeeping, and payroll services), and 413 (Food services and

drinking places). Under output the most affected industries are IMPLAN® sectors 417 (Commercial and industrial machinery and equipment repair and maintenance), 31 (Electric power generation, transmission, and distribution), 390 (Waste management and remediation services), and 361 (Imputed rental activity for owner-occupied dwellings).

For an assumed 50% cooperative ownership, where 50% of the profits stay in the region and are distributed as annual cash patronage, industry output is \$5.3 million direct, \$.68 million indirect, and \$11.7 million induced, for a total industry output of \$17.7 million. Employment for the cooperative ethanol plant is 52 direct employees, 7 indirect employees, and 125 induced employees, totaling 184 employees.

The top industries impacted by employment for the 50% cooperative-owned plant are IMPLAN® sectors 417 (Commercial and industrial machinery and equipment repair and maintenance), 413 (Food services and drinking places), 437 (Employment and payroll only, state & local govt, non-education), and 368 (Accounting, tax preparation, bookkeeping, and payroll services). For industry output the top sectors affect by ethanol plant operation are 361 (Imputed rental activity for owner-occupied dwellings), 417 (Commercial and industrial machinery and equipment repair and maintenance), 31 (Electric power generation, transmission, and distribution), and 390 (Electric power generation, transmission, and distribution).

The second cooperative owned cellulosic ethanol plant scenario assumes 100% producer ownership with 100% of the profits staying in the region and distributed as annual cash patronage. Under this cooperative ownership model industry output is \$5.3 million direct, \$.68 million indirect, and \$19.7 million induced, for a total of \$25.7 million. Employment for the cooperative ethanol plant is 52 direct employees, 7 indirect employees, and 210 induced employees, for a total of 269 employees. The top industries impacted by employment for the

cooperative plant are IMPLAN® sectors 417 (Commercial and industrial machinery and equipment repair and maintenance), 413 (Food services and drinking places), 437 (Employment and payroll only, state & local govt, non-education), and 394 (Offices of physicians, dentists, and other health practitioners). For industry output the top sectors affect by ethanol plant operation are 361 (Imputed rental activity for owner-occupied dwellings), 417 (Commercial and industrial machinery and equipment repair and maintenance), 31 (Electric power generation, transmission, and distribution), and 413 (Food services and drinking places).

Comparing the three differing ownership structures for the cellulosic ethanol plant we see a decrease in direct output from the 100% private ownership to 50% cooperative ownership of \$112,823. Indirect industry output decreases by \$45,707. However, induced industry output increases by \$7.4 million. Total industry impacts for output increase by \$7.2 million as the plant changes from 100% private ownership to 50% cooperative ownership. There are no direct or indirect changes in employment as the ownership structures change, but induced employment impacts for the region increase from 40 induced employees for the 100% private management to 124 induced employees for the split private/cooperative management. This gives a total of 84 jobs created through the 50% cooperative ownership scenario.

As the model changes from an assumed 50% cooperative ownership to 100% cooperative ownership we see a no changes in the direct or indirect impacts, but a large increase is shown through the induced impacts. Under induced impacts employment jobs increase from 125 to 210, labor income increases from \$4.2 million to \$6.9 million, total value added increases from \$7.5 million to \$12.7 million, and industry output increases from \$11.7 million to \$19.7 million. With the increase in cooperative ownership there is a large increase in induced impacts from the additional cash returns kept in the study region.

Conclusions and Implications

In the state of Oklahoma switchgrass production for biomass and cellulosic ethanol production could have a possible positive economic impact for differing communities in the state. Currently switchgrass is not commercially grown, so the exact economic effects are unknown. The same is true for cellulosic ethanol production, since no one conversion technology has been proven most effective for switchgrass or similar feedstocks. As a result, there is currently no switchgrass-based biorefinery in Oklahoma or a representative example to show how it would impact the site location community or surrounding communities. These facts notwithstanding, the objective of this study was to project the impacts of proposed switchgrass production and cellulosic ethanol plants on Oklahoma communities under various ownership structures.

Through the use of a comprehensive linear mathematical programming model, Grady County was identified as an optimal cellulosic ethanol plant location, while this county and seven neighboring counties were projected to provide the switchgrass for the facility. Using data for switchgrass maintenance and data for a 50 million gal/year cellulosic ethanol plant, expenditures were entered into IMPLAN® to estimate the direct, indirect, and induced impacts on industries in the study region. Additional impact assessments were made for varying levels of cooperative and private ownership of the facility. By retaining plant profits in the region through cash patronage to producer owners, cooperative ownership impacts were measured for 50% cooperative ownership and 100% cooperative ownership.

For the 100% privately owned no profits are retained in the region. For the 100% privately owned scenario there is a combined industry output for switchgrass production and ethanol production of \$70 million, and a combined employment impact of 556 employees for the

region. In the 100% cooperative owned scenario there is a combined industry output for switchgrass production and ethanol production of \$86.1 million, and a combined employment impact of 726 employees in the region. Because of the induced impacts that result from the cooperative membership model industry output is \$16.1 million higher than the privately owned and employment has 170 more jobs.

Attitudes toward ethanol production from switchgrass in Oklahoma communities were not determined, but would need to be determined before committing resources to plant location decisions. Commercial switchgrass production and cellulosic ethanol production are not currently occurring in Oklahoma. For these activities to be feasible attitudes of producers need to be addressed as well as the willingness to adopt switchgrass for cellulosic ethanol production. Currently the impacts for jobs and income from switchgrass production compared to jobs and income from other crops in Oklahoma are being assessed in an alternate study. The needed incentives to get producers to engage in long term contracts to supply ethanol facilities with biomass would have to be considered.

Further the impacts of ethanol production for multi-year periods are not addressed in the current study. The long term economic effects on the communities where optimal plant locations were found need to be measured. With switchgrass being grown on improved pasture and cropland the Oklahoma livestock market would also see impacts. Studies beyond the present one would need to show if these impacts would be positive or negative on livestock producers and on what scale. Lastly the environmental impacts for both switchgrass production and cellulosic ethanol production need to be analyzed and how they'll affect the involved industries and regions in which they are located.

References

- Beckman, Jayson F., Evans, Samuel, and Sands, Ronald D. 2011. "U.S. Renewable Fuel Standard 2: Impacts of Cellulosic Biofuel Production." Colorado State University. *Selected Paper Prepared for presentation at the Agricultural and Applied Economics Association's 2011 AAEA and NAREA Joint Annual Meeting, Pittsburgh, Pennsylvania July 24-26, 2011.*
- Bransby, David I., H. Arlen Smith, C. Robert Taylor, Patricia A. Duffy. 2005. "Switch grass budget model: An interactive budget model for producing & delivering switch grass to a bioprocessing plant". *Industrial Biotechnology*. Summer 2005, 1(2): 122-125. doi:10.1089/ind.2005.1.122.
- Burden, Dan. "Switchgrass Profile." Agricultural Marketing Resource Center. Malinda Geisler. August 2011. Iowa State University. February 15, 2012
<http://www.agmrc.org/commodities__products/biomass/switchgrass_profile.cfm#>.
- Busby, David P. Philips, Andrew L. Herndon, Cary W., Jr. 2008. "Construction Cost Sensitivity of a Lignocellulosic Ethanol Biorefinery". *Paper prepared for Southern Agricultural Economics Association 2008 Annual Meeting. Dallas, Texas. February 2-6, 2008.*
- Duffy, M., 2008. "Estimated Costs for Production, Storage and Transportation of Switch grass" *Ag Decision Maker* (February 2008) Available at:
<http://www.extension.iastate.edu/agdm/crops/html/a1-22.html> (February 11, 2011)
- Epplin, Francis M. 2009. "Biomass: Producer Choices, Production Costs and Potential." Paper presented at the Transition to a Bioeconomy: The Role of Extension in Energy conference, Little Rock, Arkansas, June 30-July 1, 2009.
- Flanders, Archie and John McKissick, 2007. "Economic Impact of Cellulosic Ethanol Production in Treutlen County." Center for Agribusiness and Economic Development. Center Report: CR-07-07 (April 2007). University of Georgia, 2007.
- Fulton, Adam David, "Economic Impacts of Production, Storage, Transport, and Conversion of Switchgrass for Cellulosic Ethanol in Tennessee." Master's Thesis, University of Tennessee, 2010. http://trace.tennessee.edu/utk_gradthes/621
- Gill, Robert Chope, II. Richardson, James W. Outlaw, Joe L. Anderson, David P. 2003. "An Analysis of Ethanol Production in Texas Using Three Ethanol Facility Sizes and Their Relative Optimal Subsidy Levels". *Selected Paper prepared for presentation at the Southern Agricultural Economics Association 35th Annual Meeting. Mobile, Alabama. February 1-5, 2003.*
- Granja, I., J. Vansickle, L. Ingram, and R. Weldon. 2010. "Critical Economic Factors for Success of a Biomass Conversion Plant for Agricultural Residue, Yard Residue and Wood Waste

- in Florida.” University of Florida. *Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Orlando, FL, February 6-9, 2010.*
- Griffith, Andrew. F.M. Epplin and D.D. Redfearn. 2010. “Cost of Producing Switchgrass for Biomass Feedstock.” Departments of Agricultural Economics and Plant and Soil Sciences, Oklahoma State University. Available at: <http://www.switchgrass.okstate.edu/budget/switchgrassbudgetv2.pdf>.
- Haque, Mohua, "Switchgrass Biomass to Ethanol Production Economics: Field to Fuel Approach." PhD Dissertation, Dept. of Agricultural Economics, Oklahoma State University, 2010.
- Hodur, Nancy M., Larry Leistritz. 2009. “Economic Impacts of Biofuel Development.” AgMRC Renewable Energy Newsletter. February 2009.
<http://www.agmrc.org/renewable_energy/biofuelsbiorefining_general/economic_impacts_of_biofuel_development.cfm> Date accessed: April 9, 2012.
- Kumar, Amit. Shahab Sokhansanj. 2007. “Switch grass (*Panicum virgatum*, L.) delivery to a biorefinery using integrated biomass supply analysis and logistics (IBSAL) model”. Bioresource Technology Volume 98, Issue 5. Pages 1033-1044. March 2007.
- Low, Sarah A., Isserman, Andrew M. 2008. “Ethanol: Implications for Rural Communities.” University of Illinois. *Paper prepared for presentation at the Agricultural Economics Association Annual Meeting, Orlando, FL, July 27-29, 2008.*
- Minnesota IMPLAN Group, Inc. March 19, 2012. Guru PHP. 2012.
<http://www.implan.com/v4/index.php?option=com_glossary&task=list&glossid=13&letter=I&Itemid=12>.
- Mulkey, David. Alan W. Hodges. 2009. “Using Implan to Assess Local Economic Impacts.” Food and Resource Economics Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Source: <http://edis.ifas.ufl.edu/fe168>
- Nebraska Ethanol Board, Lincoln, NE. April 6, 2012. Nebraska Energy Statistics. Accessed: April 7, 2012. Source: <http://www.neo.ne.gov/statshtml/66.html>
- Petersan, Donis N. 2002. “Estimated Economic Effects for The Nordic Biofuels Ethanol Plan in Ravenna, Nebraska.” Economic Development Department Nebraska Public Power District. Columbus, Nebraska. June 2002.
- Popp, Michael. Hogan, Robert J., Jr. 2007. “Assessment of two alternative switch grass harvest and transport methods”. Farm Foundation. Biofuels, Food and Feed Tradeoffs Conference. St. Louis, Missouri. April 12-13, 2007.
- Ragan, Holly R., Kenkel, Philip L. 2007. “The Impact of Biofuel Production on Crop Production in the Southern Plains.” *Southern Agricultural Economics Association Annual Meeting, February 4-7, 2007, Mobile, Alabama.*
- Schlosser, Janet A. & Leatherman, John C. & Peterson, Jeffrey M., 2008. "Are Biofuels Revitalizing Rural Economies? Projected Versus Actual Labor Market Impacts in the

- Great Plains," 2008 Annual Meeting, July 27-29, 2008, Orlando, Florida 6123, American Agricultural Economics Association (New Name 2008: Agricultural and Applied Economics Association).
- Swenson, D. (2006, July). *Input-outrageous: The economic impacts of modern biofuels production*. Paper presented at the Mid-continent Regional Science Association and the Biennial IMPLAN National Users Conference, Indianapolis, IN.
- Tembo, Gelson. Epplin, Francis M. Huhnke. Raymond L. 2003. Integrative Investment Appraisal of a Lignocellulosic Biomass-to-Ethanol Industry. *Journal of Agricultural and Resource Economics* 28(3):6 1 1633
- Thorsel, Sara. Francis M. Epplin. Raymond L. Huhnke. Charles M. Taliaferro. 2004. "Economics of a coordinated biorefinery feedstock harvest system: lignocellulosic biomass harvest cost". *Biomass and Bioenergy* Volume 27, Issue 4. Pg. 327-337. October 2004.
- U.S. Congress. ENERGY INDEPENDENCE AND SECURITY ACT OF 2007. PUBLIC LAW 110-140—DEC. 19, 2007, 110th Congress. Internet site: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_public_laws&docid=f:publ140.110.pdf.
- U.S. Department of Energy, Alternative Fuels & Advanced Data Center. 2011. Cellulosic Biofuel Producer Tax Credit. Excise Tax Branch, U.S. Internal Revenue Service. April 9, 2012
- U.S. Environmental Protection Agency, Assessment and Standards Division, Office of Transportation and Air Quality. 2010. Renewable Fuel Standard Program(RFS2), Regulatory Impact Analysis. Washington DC, February.
- Ugarte, Daniel G. De La Torre., English, Burton C., and Jensen, Kimberly L, Chad Hellwinckel, Jamey Menard, and Brad Wilson. 2006. "Economic and Agricultural Impacts of Ethanol and Biodiesel Expansion." *Study funded in part by the Governors' Ethanol Coalition and the National Commission on Energy Policy*. Department of Agricultural Economics, University of Tennessee, Knoxville. December 2006.
- Ugarte, Daniel G. De La Torre., English, Burton C., and Jensen, Kimberly L. 2007. "Sixty Billion Gallons by 2030: Economic and Agricultural Impacts of Ethanol and Biodiesel Expansion." *Principal Paper Session: Challenges and Policy Implications of Developing an Economically Competitive Bioenergy Production System with Cellulosic Feedstock. Joint Annual Meeting of the AAEE, WAEA, and CAES, Portland, Oregon, July 29 – August 1, 2007*.
- Walsh, Marie E., De La Torre Ugarte, Daniel G., English, Burton C., Jensen, Kimberly L., Hellwinckel, Chad M., Menard, R. Jamey, and Nelson, Richard G. 2007. "Agricultural Impacts of Biofuels Production." *Journal of Agricultural and Applied Economics*, Volume 39, Number 02, Pages 365-372. August 2007.

Table 33. Switchgrass production function and IMPLAN® industry sectors for switchgrass production, Grady County (OK) and surrounding counties.

Counties	Fertilizer DAP*	Fert App., Swathing, Baling	Hauling	Operating Capital	IMPLAN Sector 319	IMPLAN Sector 130	IMPLAN Sector 19	IMPLAN Sector 335	IMPLAN Sector 354
Caddo	\$1,082,736	\$4107,704	\$1,073,803	\$289,525	0.116225108	0	0.440936877	0.1152662	0.031078711
Canadian	\$601,541	\$2,282,138	\$596,578	\$160,853	0.116225108	0	0.440936877	0.1152662	0.031078711
Cleveland	\$218,385	\$828,511	\$216,583	\$58,396	0.116225108	0	0.440936877	0.1152662	0.031078711
Garvin	\$215,020	\$815,746	\$213,246	\$57,497	0.116225108	0	0.440936877	0.1152662	0.031078711
Grady	\$560,187	\$2,125,246	\$555,565	\$149,794	0.116225108	0	0.440936877	0.1152662	0.031078711
McClain	\$374,395	\$1,420,385	\$371,306	\$100,114	0.116225108	0	0.440936877	0.1152662	0.031078711
Oklahoma	\$237,853	\$902,370	\$235,890	\$63,602	0.116225108	0	0.440936877	0.1152662	0.031078711
Stephens	\$450,113	\$1,707,647	\$446,400	\$120,361	0.116225108	0	0.440936877	0.1152662	0.031078711
*DAP = diammonium phosphate. No nitrogen costs were projected.									

Table 34. IMPLAN Expenditures for Ethanol Production from Switchgrass for a Grady County (OK) Biofuel Production Facility.

Type	IMPLAN Sector	Description	Expenditures
Operating	10	All Other Crop Farming	\$16,915,300.87
Operating	33	Water, sewage and other treatment and delivery systems	\$299,333.33
Operating	123	Alkalies and chlorine manufacturing	\$175,063.74
Operating	124	Carbon black manufacturing	\$65,651.29
Operating	125	All other basic inorganic chemical manufacturing	\$997,511.53
Operating	126	Other basic organic chemical manufacturing	\$6,621,177.49
Operating	130	Fertilizer manufacturing	\$154,855.70
Operating	164	Lime and gypsum product manufacturing	\$1,132,948.77
Operating	357	Insurance carriers	\$485,111.83
Operating	368	Accounting, tax preparation, bookkeeping, and payroll services	\$484,497.84
Operating	390	Waste management and remediation services	\$1,500,216.45
Operating	417	Commercial and industrial machinery and equipment repair and maintenance	\$1,714,124.82
Depreciation	35	Construction of new nonresidential manufacturing structures	\$36,602.45
Depreciation	123	Alkalies and chlorine manufacturing	\$572.26
Depreciation	124	Carbon black manufacturing	\$214.61
Depreciation	125	All other basic inorganic chemical manufacturing	\$3,260.75
Depreciation	141	All other chemical product and preparation manufacturing	\$1,114.72
Depreciation	188	Power boiler and heat exchanger manufacturing	\$764,256.85
Depreciation	189	Metal tank (heavy gauge) manufacturing	\$650,420.63
Depreciation	190	Metal can, box, and other metal container (light gauge) manufacturing	\$42,170.27
Depreciation	202	Other fabricated metal manufacturing	\$36,533.91
Depreciation	203	Farm machinery and equipment manufacturing	\$122,575.76
Depreciation	207	Other industrial machinery manufacturing	\$640,788.60
Depreciation	213	Other commercial and service industry machinery manufacturing	\$107,266.96
Depreciation	214	Air purification and ventilation equipment manufacturing	\$1,019,031.02
Depreciation	214	Air purification and ventilation equipment manufacturing	\$17,801.59

Depreciation	215	Heating equipment (except warm air furnaces) manufacturing	\$73,306.64
Depreciation	216	Air conditioning, refrigeration, and warm air heating equipment manufacturing	\$220,336.22
Depreciation	222	Turbine and turbine generator set units manufacturing	\$829,566.38
Depreciation	226	Pump and pumping equipment manufacturing	\$490,205.63
Depreciation	227	Air and gas compressor manufacturing	\$80,202.02
Depreciation	228	Material handling equipment manufacturing	\$1,481,998.56
Depreciation	228	Material handling equipment manufacturing	\$11,934.34
Depreciation	230	Other general purpose machinery manufacturing	\$21,563.49
Depreciation	251	Industrial process variable instruments manufacturing	\$42,852.09
Byproduct	31	Electric power generation, transmission, and distribution	\$4,721,594.52

Table 35. Total Acres and Biomass utilized by County for a Switchgrass Biofuel Facility in Grady County, Oklahoma.

County	Total acres		Total biomass	
	Cropland	Pastureland	Cropland	Pastureland
Caddo	26092.9	12448.6	135719.993	49732.325
Canadian	21412.7		92560.19	
Cleveland	4074.5	3699.2	24094.537	13233.888
Garvin	7653.929		32750.697	
Grady	16645.8	3294.82	90308.865	10200.762
McClain	7062.5	6264.6	35409.963	21299.64
Oklahoma	5525.4	2941.3	33261.803	12375.52
Stephens	6031.1	9991.3	23388.606	30983.021
Total		133,139		605,320

Table 36. Switchgrass Production from the Eight County production region to support a Grady County (OK) Cellulosic Ethanol Plant.

Switchgrass Production				
	Direct Effects	Indirect Effects	Induced Effects	Total Effects
Employment	169	123	165	457
Labor Income	\$9,541,416	\$4,553,850	\$6,356,543	\$20,451,810
Total Value Added	\$9,541,416	\$6,439,878	\$10,746,173	\$26,727,468
Output	\$32,180,907	\$11,239,092	\$16,887,026	\$60,307,026

Table 37. Comparison of 100% Private Ownership, 50% Cooperative Ownership, and 100% Cooperative Ownership Structure on Grady County (OK) Cellulosic Biofuel Plant Impacts.

	Direct Effects	Indirect Effects	Induced Effects	Total Effects
Private Ownership (0% coop ownership)				
Employment	52	7	40	99
Labor Income	\$1,933,639.04	\$228,823.40	\$1,373,056.63	\$3,535,519.08
Total Value Added	\$3,434,784.34	\$355,600.20	\$2,383,011.72	\$6,173,396.25
Output	\$5,336,510.92	\$682,556.55	\$3,687,517.76	\$9,706,585.24
50% Cooperative Ownership				
Employment	52	7	125	184
Labor Income	\$1,933,639.04	\$228,823.40	\$4,158,492.66	\$6,320,955.10
Total Value Added	\$3,434,784.34	\$355,600.20	\$7,527,034.26	\$11,317,418.79
Output	\$5,336,510.92	\$682,556.55	\$11,710,683.67	\$17,729,751.14
100% Cooperative Ownership				
Employment	52	7	210	269
Labor Income	\$1,933,639.04	\$228,823.40	\$6,943,928.51	\$9,106,390.95
Total Value Added	\$3,434,784.34	\$355,600.20	\$12,671,056.49	\$16,461,441.02
Output	\$5,336,510.92	\$682,556.55	\$19,733,849.11	\$25,752,916.59

OVERALL SUMMARY AND CONCLUSIONS

Project activities are concentrated in four major areas. The first focus is on demonstrating the supply of biofuel feedstocks. The supply estimation used crop yield from state research experiment stations test plot trials and the yield data available from the NRCS web resources along with relevant data from the published literatures. A ratio method was used to estimate the switchgrass yields in different locations and soil types based on the relative yield performance of other crops in the location with switchgrass yield data and the other target areas. The average yield of switchgrass was estimated to range from a low of 2.25 Tons/acre in Colorado to a high of 6.08 tons/acre in Missouri. A projection of 49.59 million tons of total potential switchgrass supply was made for Oklahoma for the top five most abundant and productive soils which totaled 12.48 million acres. Total supply for the South Central region was estimated at

The second component of the project involved modeling the harvesting, transportation and storage of biofuel feed stocks. An economic engineering model was developed to project the cost of harvest and transportation of switchgrass at both a farm producer scale and a large scale level. The large scale system was modeled as a producer owned cooperative, although the cost estimations would be similar for an integrated operation owned by the biorefinery. The cost of harvesting and transporting switchgrass was estimated at \$17.82 for the cooperative scale operation and \$25.53 for the producer scale. Sensitivity analysis indicated that logistic cost estimates were sensitivity to switchgrass yield but were relatively insensitive to field size, distance between fields and labor rates.

The third component of the project involved modeling alternative conversion processes. Because the goal of the project was to assist entrepreneurs, community planners and other

interested individuals in assessing the feasibility of biofuel processes and developing commercial projects, this phase focused on the development of feasibility templates. Spreadsheet based feasibility templates were developed for cellulosic ethanol production, sweet sorghum ethanol and an integrated oilseed crushing and biodiesel production facility. Results from the cellulosic ethanol template were used in the next component of the project, the comprehensive supply chain model.

The fourth component of the project involves the development of a comprehensive biofuel supply chain model that incorporates feedstock production, feedstock logistics, biofuel production and distribution. The supply chain model identifies the optimal type, size and location of biofuel refineries. The breakeven price of cellulosic ethanol was estimated at \$.074/liter (\$2.8/gallon). The breakeven price increases as the number of biorefineries in the region increased. Average breakeven price across plants for nine biorefineries was estimated to be \$0.77/liter (\$2.91/gallon). This difference is mainly due to increasing transportation cost. As the number of plants increased more biomass were needed and when nearby cropland and improved pasture land were under production required biomass was collected from the production regions that are far away from the refinery, which in turn raised the cost of transportation.

The final phase of the project involved the development of a community economic impact model that demonstrates the impact of biofuel production and biofuel refinery operation on rural communities. This model incorporated information on the optimal type, size and location and cost structure of biofuel refineries that were developed in the previous steps. The model estimated the direct, indirect and induced impacts on employment and economic activity associated with the development of a biofuel refinery in a rural community. Economic impact

was estimated for two scenarios: a 100% privately owned firm for which no profits were retained in the local community, and a cooperatively owned biorefinery.

In the case of the 100% privately owned scenario the combined industry output for switchgrass production and ethanol production was estimated at \$70 million, with a combined employment impact of 556 employees for the region. In the 100% cooperative owned scenario there is a combined industry output for switchgrass production and ethanol production of \$86.1 million, and a combined employment impact of 726 employees in the region. Because of the induced impacts that result from the cooperative membership model industry output is \$16.1 million higher than the privately owned and employment has 170 more jobs.

In addition to these specific estimates the project activities have created and documented a set of procedures that provide estimates of biofuel feed stock supply, harvesting and transportation costs, conversion cost, plant location and cost and economic impact. All of the components were designed so that they could be easily updated as additional data and technological advances become available.