AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

*The World's Largest Open Access Agricultural & Applied Economics Digital Library*

**This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.**

**Help ensure our sustainability.**

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

*No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.*

# Energy Sugar Beets to Biofuel: Field to Fuel Production System and Cost Estimates

Choolwe Haankuku, Francis M. Epplin and Gopal V. Kakani

Choolwe Haankuku is a graduate research assistant, Department of Agricultural Economics, Oklahoma State University, Stillwater, OK 74078, USA, Phone: 405-744-6156, email: choolwe.haankuku@okstate.edu; Francis M. Epplin is regents professor and Jean & Patsy Neustadt Chair, Department of Agricultural Economics, Oklahoma State University, Stillwater, OK 74078, USA, Phone: 405-744-6156, email: f.epplin@okstate.edu;Gopal V. Kakani is an associate professor, Department of Plant and Soil Sciences, Oklahoma State University, Stillwater, OK 74078, Phone: 405-744-4046, email: v.g.kakani@okstate.edu

The authors acknowledge the assistance of resources provided by the Oklahoma Agricultural Experiment Station. Additional funding was provided by the USDA-NIFA, USDA-DOE Biomass Research and Development Initiative, Grant No. 2009-10006-06070. The project was also supported by the USDA National Institute of Food and Agriculture, Hatch grant number H-2824, and by the Jean & Patsy Neustadt Chair. Support does not constitute an endorsement of the views expressed in the paper by the USDA**.**

Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Georgia, Atlanta, January 31- February 3, 2015.

*Copyright 2015 by Choolwe Haankuku, Francis M. Epplin and Gopal V. Kakani. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.*

**Abstract**

Energy beets (*Beta vulgaris* L.) meet the requirements for advanced biofuel feedstocks under the Energy Independence and Security Act of 2007. A mixed-integer programming model was constructed to determine the breakeven price of ethanol from energy beets, and to determine the optimal size and biorefinery location. The model, based on limited field data, evaluates Southern Plains beet production in a 3-year crop rotation, and beet harvest, transportation and processing. The optimal strategy depends critically on several assumptions including a just-in-time harvest and delivery system that remains to be tested in field trials. Based on a conversion rate of 26 gallons per wet ton and capital cost of $128 million for a 40,000,000 gallons per year biorefinery, the estimated breakeven ethanol price is $2.63 per gallon. The estimated beet delivered cost of $1.31 per gallon compares with the net corn feedstock cost ($1.17 to $1.74 per gallon in 2014). If for a mature industry, the cost to process beets was equal to the cost to process corn, the beet breakeven ethanol price would be $1.96 per gallon ($2.97 per gallon gasoline equivalent).

**Key words:** breakeven price, biorefinery, energy beets

**JEL classifications:** Q42, Q48

## Introduction

The USA Renewable Fuels Standard (RFS) mandates the use (if produced) of 36 billion gallons per year (BGY) of renewable fuels by 2022, of which 21 BGY would come from advanced biofuels. Under the Energy Independence and Security Act of 2007 (EISA), advanced biofuels are classified as non-grain based biofuels including ethanol derived from lignocellulosic biomass such as timber chips and perennial grasses, ethanol from sugar crops such as sugarcane and sugar beets, and ethanol derived from waste material including crop residues and urban waste (Congress, 2007). Most ethanol produced in the USA is corn based but a growing interest to diversify biofuel feedstock sources has prompted field trial research of energy beets (*Beta vulgaris* L.) across several geographical regions in the USA including the Southern Great Plains (Yacobucci et al., 2007; Panella, 2010; Kakani et al., 2012).

USA sugar beets are predominantly grown in the northern plains and some parts of the central plains and far west. The 11 sugar beet producing states include North Dakota, Minnesota, Michigan, Wyoming, Montana, Colorado, Nebraska, Idaho, Washington, Oregon, and California (USDA, 2011). Sugar beets perform well in temperate climate but due to genetic enhancement, the crop has proven to adapt to various soil and climatic conditions (Ali, 2004; USDA, 2011). Unlike conventional sugar beets, energy beets are specialized non-grade varieties bred for high sugar content but contain impurities which make them unsuitable for human consumption (Kakani et al., 2012). These non-food energy beets are under development for industrial use including bioenergy production.

In the USA, conventional sugar beets produced for processing into edible sugar are heavily regulated. The USA sugar program uses marketing allotments to restrict domestic production of sugar cane and sugar beets (USDA, 2014b). Federal law caps the volume of sugar that can be sold in the USA by domestic sugarcane and sugar beet processors for domestic human consumption. For fiscal year 2014, overall sugar beet and sugar cane allotments were set at 5.3 and 4.5 million tons, respectively (USDA, 2014a). If domestic production and the Commodity Credit Corporation (CCC) inventory falls short of these quotas, then reassignment could be made to imports. A provision under the 2014 farm bill feedstock flexibility program permits the CCC to sell excess sugar for use as a bioenergy feedstock (USDA, 2014b).

The eleven beet producing states are served by beet processors to which the marketing allotments are assigned. These are Amalgamated Sugar Co., American Crystal Sugar Co., Michigan Sugar Co., Southern Minnesota Beet Sugar Cooperative, Minnesota-Dakota Farmers' Cooperative, Western Sugar Company, and Wyoming Sugar Growers Association (USDA, 2014). It is not clear if the allotments for beet production and marketing under the sugar program are based on comparative advantage or are a result of public policy influenced by robust lobbying efforts by sugar producers (Anderson, 2009). Contrary to edible sugar beets, there is currently no federal restriction on the production and marketing of energy beets. As such, it is anticipated that energy beets could be legally grown and processed into biofuels in regions that do not have a sugar allotment such as the southern Great Plains.

Energy beets are being considered for biofuel production because they have high sugar content and could potentially double ethanol production per acre compared to other feedstocks (corn, cellulose) (Shapouri et al., 2006; Panella, 2010). In addition, the process to convert energy beets to biofuel is known and relatively less complex than conversion of other potential advanced biofuels such as corn stover to ethanol (Robb, 2007; Shapouri et al., 2006; Maung and Gustafson, 2011). However, to compete with other potential feedstocks at fulfilling the "advanced biofuels" mandate, the cost to produce biofuels from energy beets must be competitive. Cost estimates will be required to encompass the complete chain from the cost of bidding crop land from current use to the cost of marketing the biofuel. These cost estimates would be necessary to determine if an energy beet-to-biofuel system would be able to compete with other advanced biofuel alternatives as defined by EISA.

Several studies have evaluated the economic feasibility of the production of ethanol from energy beets (Shapouri et al. 2006; Yoder et al., 2009; Maung and Gustafson, 2011; Ripplinger, 2014). These studies have produced different conclusions depending on the geographic region and the assumptions made. In addition to feedstock yield and price assumptions, the number of days per year during which the biorefinery can operate at full capacity is critical to the overall economics. A plant with a shorter processing window would have relatively greater capital costs per unit processed.

Maung and Gustafson (2011) calibrated a stochastic simulation financial model using sugar beet yield data in North Dakota to examine the economic feasibility of producing ethanol from sugar beets. They used a conversion rate of about 26 gallons per wet ton for two plant sizes (20 MGY and 10 MGY) that they assumed could process 333 days per year. The reported breakeven ethanol price ranged from $1.52 and $1.71 per gallon for the larger and smaller sized plants, respectively.

Yoder et al. (2009) assessed the potential to develop a 20 MGY sugar beet based ethanol plant in Washington. Based on the assumed average yield, input prices, and beet prices, they found that the production of sugar beets failed to cover production costs and or transportation costs and concluded that the conversion of both raw beet juice and beet pulp to ethanol was not profitable under Washington agronomic and economic conditions. The estimated breakeven ethanol price was about $2.12 per gallon (beet acquisition and processing) when a more cost efficient conversion process was considered. Similarly, a study by the USDA (Shapouri et al., 2006) assessed the feasibility of producing ethanol from sugarcane, molasses, and sugar beets for a plant operating about 180 days per year. The study reported that ethanol production from sugar beets could only be profitable if the market price of ethanol was at least $4 per gallon.

Each of these prior studies produced estimates of costs for regions in which beets are currently grown to produce sugar. The expected cost to produce energy beets in nontraditional beet production regions such as the southern Great Plains is unknown. The objective of the current study is to determine the most economically efficient energy beet field-to-biofuel system that can be envisioned for conditions in Oklahoma. In particular, a model is developed to determine the most cost-efficient feedstock production system, to include description of crop rotations, location of production, location and size of the biorefinery, harvest timing and number of harvest machines, feedstock transportation flows and product sales. The model is designed to estimate specific costs along the entire value chain. The research presented in this study will contribute towards ongoing research in assessing the economic viability of ethanol production from a biorefinery that uses energy beets exclusively.

**Conceptual Framework**

Oklahoma has not had a sugar beet allotment and beets have not been grown in Oklahoma. A limited number of field trials have found that some specialized non-grade varieties of energy beets bred for high sugar content may produce reasonable yields in Oklahoma (Kakani et al., 2012). Further, since energy beets are a biennial crop, in Oklahoma, they may be seeded in the fall and may be harvested as early as June, or they may be left in the ground and harvested as late as March of the following year. This wide 10-month harvest window would enable a just-in-time harvest and deliver system for at least 300 days per year. The fixed costs of harvest and transportation machines could be spread over a substantial number of acres. Since the beets could be left in the field until required for processing, storage requirements and storage costs for harvested beets would be minimal.

A business plan for an energy beet biorefinery in the Southern Plains could be formulated similar to the closed-membership (also called "new generation") producer cooperative system used for food sugar beets in the Northern Plains. The closed-membership cooperative could build and manage the biorefinery as is the case with some corn ethanol plants in the U.S. Corn Belt. An Oklahoma energy beet new generation cooperative would require a predetermined amount of resources and pledges of feedstock from its members (Katz and Boland, 2002; Jansen et al. 2011). The cooperative could contract with farmers by selling delivery rights shares to potential energy beet growers. The contract between the grower and the cooperative would obligate farmers to grow and deliver beets from a specified number of acres over a specified number of years (Back et al., 1999). In northwest Oklahoma, a successful closed-membership producer cooperative to market frozen wheat dough was established in 1999. This member owned cooperative required its members to invest about $5,000 and provide at least 1,000 bushels of wheat per year (Bittner, 1999). However, since farmers in Oklahoma do not have a history of growing beets, a beet based biorefinery cooperative may still be a challenge to implement in Oklahoma. Prior to putting together a business plan that would be required to entice farmers to invest in a producer cooperative designed to produce advanced biofuels, it would be prudent to determine if an energy beet based biorefinery would be a viable enterprise.

Unlike perennial grasses, the production of energy beets would require rotational restrictions associated with energy beets. It is recommended that the beets be grown in a 3-5 year rotation with other crops such as grains to improve soil fertility, and manage diseases and nematodes (Ali, 2004). In Oklahoma, energy beets could be grown in a three year rotation with crops such as wheat, canola, and grain sorghum.

One option for a three year rotation would be to harvest wheat in June followed by seeding beets in October to be harvested in June to September after which either wheat or canola could be sown. However, some beets could be left in the ground beyond September until the following March and harvested as needed. Thus, wheat could be harvested in June and energy beets could be seeded in October and the harvest window could extend from June through to March of the following year. On those acres in which the presence of unharvested beets prevents the seeding of a fall crop, grain sorghum could be seeded in the spring and harvested in the summer enabling canola or wheat to be planted in the fall (Table 1). The 10-month harvest window would greatly reduce the cost to store harvested beets (Libsack, 2010). Additionally, some studies have found that delaying the harvest increases the quantity of harvestable yield as a result of the extended growing period for the biennial crop (Lauer, 1995; Lisback, 2010; Al-Sayed et al., 2012).

An extended harvest window does impose some potential challenges. The management team and producer members would have to agree on a harvest schedule that would both (a) enable the farmers to plan their subsequent crops and (b) appropriately compensate for the extended use of land on which harvest is delayed. Some of these details would have to be appropriately described and negotiated and specified in the closed-membership producer cooperative contracts.

## Methods

### Model

A multi-region multiple period mixed integer mathematical programming model is developed to determine the breakeven price of ethanol from energy beets (Tembo et al., 2003; Mapemba, 2005; Haque and Epplin, 2012). The objective function of the model is to maximize the net present value of producing and procuring energy beet feedstock for conversion to ethanol at the chosen biorefinery plant. The optimal location and size of the biorefinery are modelled as binary variables with the restriction that only one plant would be selected. The model is executed in GAMS (generalized algebraic modeling system) using the CPLEX solver. The breakeven price of ethanol at which the net present value of the production process is zero was determined by a grid search technique. The model was solved for three capital and three conversion rates combinations.

**Data and Assumptions**

**Feedstock Production and Harvest**

The study considers 35 Oklahoma counties as potential energy beet production regions. The counties were selected based on counties that have substantial acres of winter wheat (USDA-NASS, 2013) since it is expected that energy beets would be grown in rotation with wheat. Nine of these counties were considered as prospective locations for the biorefinery plant (Figure 1). The potential plant locations were selected based on availability of road infrastructure and energy beet yield potential of the producing regions (Mapemba, 2005).

The study used average beet yield produced from designed field experiments in Caddo, Grady, and Payne counties to synthesize yields for 32 other Oklahoma counties. A 30-year county level average of total annual precipitation data from the Oklahoma Mesonet website was obtained and used to compute the relative magnitude of annual precipitation of one county to another. The average yield from the three counties was then used to assign yields in each county based on the proportion of total precipitation received. Counties with a higher precipitation were assigned a higher yield compared to counties with a low long term annual precipitation. The implicit assumption was that moisture would be the most limiting factor. Given the paucity of available field trials and that fields across different counties could be expected to be subjected to various agronomic and edaphic conditions, a sensitivity analysis for 50% higher and 25% lower yields was included. The model was designed to consider a three year energy beet crop rotation activity which was modelled to require three land units. It was assumed that the proportion of acres that would be allocated to energy beet production rotation was limited to no more than 10 percent of the total county available cropland in each year. This assumption restricts energy beet production to be no more than 3.33% of the total cropland in any county in any year. The total available cropland in each county was based on the 2007 agriculture census (USDA, 2008).

It was assumed that energy beets would be seeded in October with harvest beginning in June and extending through March of the following year (Table 1). This is consistent with the conceptual framework that beets could be delivered just-in-time to the biorefinery for ten months each year. The beets would be left below ground until harvested as needed for processing. The opportunity cost charged for land use would include the cost of biding land from its current use. It was further assumed that $64 per acre which is double the land rental rate of cropland in Oklahoma (USDA-NASS, 2013) was required for beet production and an additional $64 per acre would have to be paid if land was tied to beets left in the ground beyond the normal crop year. A yield adjustment factor (YAD) which is the proportion of potential yield recovered in each harvest month was assumed to be one in the months of June and July. The value of YAD was assumed to decline by 0.05 per month from August until March (Kakani, 2014). For the months of April and May YAD was equal to zero implying that beets are not available for harvest in these months.

The tons of biomass and acres of land harvested depend on both the capacity of harvest machines and the available field days in that particular month. Harvest workdays were based on Hwang et al. (2009) who used historical weather data to estimate the number of suitable workdays for each month for Oklahoma counties. Beet harvesting requires soil conditions favorable for machine travel and for topping and lifting the beets. For the present study, a harvest unit was assumed to consist of a 600 horsepower self-propelled 12 row, 22 inch row-width, 28 ton tank beet harvester with a throughput of 7.4 acres per hour (Pates, 2013). The monthly capacity of the harvest machine was estimated in tons for each month in which harvest was permitted based on the available harvest work days for that month as computed by Hwang et al. (2009). The harvested beets are assumed to be offloaded from the harvester's tank to a delivery truck for direct transportation to the biorefinery. The total number of harvest machines required per year was modelled as an integer variable and was endogenously determined by the model. The harvest machines could either be owned by the cooperative or the entire harvest operation could be outsourced. In either case, a coordinated harvest schedule would be required to allocate the use of the harvest machines across acres for the duration of the 10 month harvest window and to insure a steady flow of beets to the processing unit. A crop budget for the production of energy beets in Oklahoma is presented in Table 2.

**Transportation Cost Assumptions**

The model is based on the assumption of a just-in-time delivery strategy in which the beets would be harvested and shipped as needed to the biorefinery. This strategy would require coordination by the cooperative management team and members. The transportation cost equation was based on Wang's (2009) model for transporting feedstock by road on trucks from the farm to the processing facility. The distances from the region of production to the candidate cooperative biorefinery location were based on mid-point cities in each potential production and processing county.

**Facility Related Assumptions**

The model considers three different sizes for the biorefinery based on processing capacity of 20, 40, or 80 million gallons per year (MGY). The corresponding daily feedstock requirement for each capacity of the biorefinery is 2,564, 5,128, and 10,256 wet tons per day for a plant that operates 300 days a year. The assumed base level conversion rate was 26 gallons per wet ton. A processing plant with capacity to process 40 MGY was assumed to be medium size. A factor of 0.5 was used to increase or decrease the processing facility capacities to other plant sizes. The capital costs associated with these facilities would vary by plant size. For a project in its feasibility stage, Dysert (2003) proposes a capacity factored estimate which uses a proration factor to define the nonlinear relationship between plant capacity and investment cost. The proration factor depends on the processing industry (Dysert, 2003; Gallagher et al., 2005). A proration factor of 0.73 for an ethanol plant (Dysert, 2003) was used for the present study. With a scaling exponent of 0.73, doubling the plant capacity would increase construction costs by about 66%.

Based on average capital cost estimates of energy beet ethanol plant reported by prior studies (Ripplinger, 2014; Maung and Gustafson, 2011; Yoder et al., 2009), the capital investment costs for 20, 40, and 80 MGY plant that operates for the assumed 10 months in a year was estimated to be $77, $128, and $212 million, respectively. Annual operating and maintenance costs were computed as a fixed proportion of total investment. The biorefinery was assumed to have an expected life of 20 years. The parameters used in the model are presented in Table 3. The analyses were repeated for half and double the investment cost and conversion rates. The model was also estimated for 25% lower and 50% greater beet yields and for lower and higher levels of land opportunity cost.

**Results**

**Breakeven Price of Ethanol**

Based on base model assumptions, the model determined that it would be optimal to establish a medium-sized (40 MGY) plant located in Grady County (Figure 2). The breakeven price of ethanol from energy beets for three conversion rates and three plant investment cost combinations are reported in Table 4. For a base level conversion rate of 26 gallons per ton and a plant investment cost of $128 million, the estimated breakeven price of ethanol for the 40 MGY plant is $2.63 per gallon. If the cost to establish the plant is reduced from $128 to $64 million, the breakeven ethanol price reduces by $0.26 per gallon to $2.37 per gallon. If the investment cost is increased from $128 to $256 million, the breakeven ethanol price increases by $0.52 per gallon to $3.15 per gallon. Doubling the ethanol yield per ton of feedstock reduces the breakeven ethanol price to $1.91 for a medium investment cost and to $1.65 for the low investment cost plant (Table 4). The reduced breakeven price when the conversion rate is increased from 26 to 52 gallons per ton is as a result of less land being contracted or harvested thereby decreasing production and delivery costs. The present findings are comparable to cost estimates reported by prior studies. Shapouri et al. (2006) reported a cost of $2.35 per gallon to convert energy beets into ethanol. Yoder et al. (2009) reported a slightly lower cost of $2.12 per gallon based on a more efficient conversion process. However, cost estimates from both studies excluded plant investment cost and any form of storage costs.

The cost components of the breakeven ethanol price from energy beets for three conversion rates and three plant investment cost combinations are reported in Table 5. The cost components include capital and processing cost, land opportunity cost, field production costs (seed, fertilizer and herbicides), field storage cost, harvest cost and hauling cost to produce a gallon of ethanol from energy beets. Plant capital and processing cost, energy beet field production cost and transportation cost were among the top three expenses for production of ethanol. The cost components of the breakeven ethanol price of $2.63 per gallon for the base level plant investment cost of $128 million and a conversion rate of 26 gallons per ton includes $0.15 (6 %) for land rental, $0.10 (4%) for grower compensation for delaying harvest beyond September, $0.57 (22%) for field production cost, $0.16 (6%) for harvest cost, $0.33 (13%) transportation cost, and $1.32 (50%) for plant investment and processing cost (Table 5).

**Cost of Delivered Feedstock**

Under the base scenario, the cost to deliver a continuous flow of beet feedstock to a biorefinery was $34.19 per ton ($1.32 per gallon) (Table 6 and Figure3). The cost to produce and deliver energy beet feedstock ranged from $32.36 per wet ton when the conversion rate was 52 gallons per ton to $36.46 per ton when the conversion rate was 13 gallons per ton. Field production cost ($0.57 per gallon) and transportation cost ($0.33 per gallon) accounted for a larger proportion (44% and 25% respectively) of total delivered energy beet cost of $1.32 per gallon (Figure 3).

For the base model, the medium sized biorefinery would process about 1.5 million wet tons of energy beets per year. The feedstock would be harvested from a total of 92,029 acres across 24 counties (Table 6 and Figure 2) over a ten month period from June through March. No harvested biomass would be obtained in April and May implying that the biorefinery would be idle for these two months. The model predicted that the biorefinery would operate at nearly full capacity during these ten months of the year, processing a constant feedstock quantity of 149,499 tons each month or about 5,000 wet tons per day.

When the conversion rate was decreased from the base level of 26 to 13 gallons per ton, the quantity of biomass required to meet the capacity of the plant was about 2.5 million tons from 154,926 acres of land (Table 6). By contrast, when the efficiency of the ethanol conversion rate increased from 26 to 52 gallons per ton, the biorefinery could process as few as 764,548 tons of energy beets per year (10 months) from only 44,054 acres of land. The land would be likely contracted from counties in close proximity to the biorefinery. This can be noted in the reduction of transportation cost from $8.64 per ton under the base scenario to $7.19 per ton when the conversion rate is improved and compared to $10.97 per ton when the conversion rate was 13gallons per ton (Table 6). Under the base model, the grower compensation for delaying harvest beyond September was $2.50 per wet ton and harvest cost was $4.20 per wet ton. The estimated grower compensation for delaying harvest beyond September would have to be sufficient to bid land from its alternate use and using it to maintain beets in the field until harvested.

**Sensitivity to Yield and Land Cost**

For most agricultural crops, yields could be expected to vary from year to year and or from county to county. When the biomass yield increased by 50%, the cost to produce and deliver biomass was $25.74 per wet ton and when the yield decreased by 25%, the cost to produce and deliver feedstock was $43.03 per wet ton (Table 6). The present study is based on limited field data. Further research would be required to identify locations suitable for beet production in Oklahoma and to examine yield consistency over time. Doubling the land rental cost from the base level of $64 to $128 per acre increased the cost to produce and deliver feedstock by 20% from $34.19 to $40.99 per wet ton. The development of a bio-based industry that depends on energy crops could easily be stalled by shifts in land value and rental rates. For the present study, land values would further be driven by the opportunity cost of using the land for delaying harvest beyond September as opposed to seeding it to other fall sown crops.

**Discussion**

The objective of the study was to estimate the breakeven price of ethanol for a biorefinery that is designed to use energy beet feedstock exclusively, and to determine the optimal size and plant location. The model considered energy beets in a 3-year rotation including a just-in-time ten month harvest strategy. Based on the assumptions of the study, the model determined that it was optimal to establish a medium sized plant in Grady County. For a conversion rate of 26 gallons per ton and an investment cost of $128 million, the breakeven price of ethanol was estimated to be $2.63 per gallon. At present, there is no established advanced biofuel biorefinery operating in Oklahoma. However, based on Abengoa, the only known operating advanced biofuel plant in the region, the cost to produce a gallon of ethanol from corn stover is approximately $2.62 per gallon. Haque and Epplin (2012) also report similar ethanol breakeven price values ($2.12 - $2.72 per gallon) produced from cellulosic feedstocks in the region.

For the base model, the estimated beet feedstock delivered cost is $1.31 per gallon of ethanol. This delivered beet feedstock cost is comparable to the net corn feedstock cost that in the last year ranged from $1.17 per gallon (Oct 2014) to $1.74 per gallon (April 2014). If the cost to process beets was equal to the cost to process corn (assuming a mature industry, and that beets could be harvested and delivered over a 10 month period, the expected cost to process beets into ethanol should be no more than the cost to process corn grain into ethanol), the breakeven cost would be $1.31 + $0.65 = $1.96 ($2.97 per gallon of gasoline equivalent). This suggests that under these circumstances, the cost to produce ethanol from energy beets may be comparable to the cost of ethanol production from corn grain ($1.50-$2.30 per gallon based on corn grain base price of $3.16-$6.32 per bushel) (Eidman, 2007; Hofstrand, 2012). This finding is consistent with Maung et al. (2011) who report that energy beets may be a viable feedstock for ethanol production in North Dakota.

One limitation for the beet based biorefinery is that energy beets require rotations with other crops (Ali, 2004). This implies that a closed cooperative biorefinery may have to include some members whose land is located at substantial distance from the processing plant and incur substantial shipping costs as indicated by high average shipping distance of 78 miles from the regions of production to the biorefinery under the base model. By comparison, Farahmand et al. (2013) estimated distances of only about 30 miles to transport energy beets from the field to the designated processing facility. The production of energy beets would be highly dependent on farmers and management of a cooperative for hundreds of producers in various production regions (counties) throughout the state. Implementing a closed-membership cooperative would be even more challenging as Oklahoma does not have a history of growing beets and cannot legally grow sugar beets for food consumption. Another challenge is that in some months harvested beets would be prone to spoil quickly due to inherent biological reactions if they are not processed in a timely manner.

For the base model, about 92,029 acres of land would be required to supply beets to the biorefinery for the 10 months processing window. Assuming that each member of the cooperative agreed to plant 80 acres of energy beets each year, the cooperative would need 1,150 members to supply the beets to the biorefinery. If the capital investment cost for a medium sized biorefinery is $128 million, and $7 million for harvest machines, and several more millions for trucks, an investment of $150 million may be required to establish the business. If 50% of the investment cost could be financed by borrowing, an investment of $65,000 would be required form each of 1,150 farmer members to form the cooperative. Given that none of the farmers have experience growing beets, and given the uncertainty of yields, revenue, and production costs, obtaining this level of investment from 1,150 potential members could be very difficult.

The optimal strategy presented herein depends critically on several assumptions including: (a) public policy would enable the production of energy beets in Oklahoma; (b) a closed-membership producer cooperative could be formed; (c) a scheme could be developed that would entice members to agree to permit the manager of the cooperative to schedule harvest over a 10 month harvest window; (d) members would agree to a differential payment system that would incentivize some producers in some cases to forgo crop production in a field in which beets from the previous growing season were awaiting harvest; (e) in years of excess production a system would be necessary to compensate members whose beets are not used; and (f) beet yields obtained in the limited field trials conducted in the region to-date are achievable across the region. These assumptions to facilitate the production of ethanol from energy beets in Oklahoma remain to be validated.

## References


Ali, M.B. *Characteristics and Production Costs of U.S. Sugarbeet Farms*. Washington, DC: U.S. Department of Agriculture, Economic Research Service, Statistical Bulletin No. 974-8. 2004.

Al-Sayed, M. H., A. A. El-Razek, M. H. Sarhan, and S. H. Fateh. “Effect of Harvest Dates on Yield and Quality of Sugar Beet Varieties.” *Australian Journal of Basic and Applied Sciences* 6 (2012): 525–529.

Anderson, S. “The Domestic Causes and International Consequences of the US Government’s Sugar Price Support Programs.” *Pepperdine Policy Review* 2(2009): 32-39.

Bittner, J.B. Co-Op Plans to Put Dough into Crops Of Wheat Farmers. 1999. Internet site: http://newsok.com/co-op-plans-to-put-dough-into-crops-of-wheat-farmers/article/2664488 (Accessed December 14, 2014).

Black, J.R., B.J. Barnett, and Y. Hu. “Cooperatives and Capital Markets: The Case of Minnesota-Dakota Sugar Cooperatives.” *American Journal of Agricultural Economics* 81(December 1999): 1240-1246.

Congress, U.S. *Renewable Fuels, Consumer Protection, and Energy Efficiency Act of 2007.* Section 111, Subtitle A, H.R. 6 (EAS), 2007.

Campbell, L.G. “Sugar Beet Quality Improvement.” *Journal of Crop Production,* 5(2002):395-413.

Doye, D., and R. Sahs. “Oklahoma Cropland Rental Rates: 2010.” Cooperative Extension Service Report CR-216, Oklahoma State University, 2010.

Dysert, L.R. “Sharpen your Cost Estimating Skills.” *Cost Engineering* 45(2003): 22-30.

Eidman, V.R. “Ethanol Economics of Dry Mill Plants.” Corn-Based Ethanol in Illinois and the U.S.: A Report. Department of Agriculture and Consumer Economics, University of Illinois, November 2007.

Epplin, F.M. “Cost to Produce and Deliver Switchgrass Biomass to an Ethanol-Conversion Facility in the Southern Plains of the United States.” *Biomass and Bioenergy* 11(July 1996):459-467

Epplin, F.M., and M. Haque. “Policies to Facilitate Conversion of Millions of Acres to the Production of Biofuel Feedstock.” *Journal of Agricultural and Applied Economics* 43 (August 2011):385-398.

Epplin, F.M., C.D. Clark, R.K. Roberts, and S. Hwang. “Challenges to the Development of a Dedicated Energy Crop.” *American Journal of Agricultural Economics* 89(2007):1296-1302.

Farahmand, K., N. Dharmadhikari, and V. Khiabani. “Analysis of Transportation Economics of Sugar-Beet Production in the Red River Valley of North Dakota and Minnesota using Geographical Information System.” *Journal of Renewable Agriculture* 7(2013):126-131.

Griffith, P.A. “Production Economics of Potential Perennial and Annual Biomass Feedstocks.” Ph.D. dissertation, Oklahoma State University, Stillwater, May 2012.

Haque, M., and F.M. Epplin. “Cost to Produce Switchgrass and Cost to Produce Ethanol from Switchgrass for Several Levels of Biorefinery Investment Cost and Biomass to Ethanol Conversion Rates.” *Biomass and Bioenergy* 46(November 2012):517-530.

Haque, M., and F.M. Epplin. Switchgrass to ethanol: a field to fuel approach. Paper presented at the annual meeting of the Agricultural and Applied Economics Association, Denver, CO, July 25-27, 2010.

Hofstrand, D. Tracking Ethanol Profitability. Ag Decision Maker Ethanol Profitability, D1-10. Ames, IA: Iowa State University. 2008. Internet site: http://www.extension.iastate.edu /agdm/energy/html/d1-10.html (Accessed December, 2014).

Hwang, S., F.M., Epplin, B.H. Lee, and R. Huhnke. “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 and Bioenergy* 33(August 2009):1037-1045.

Jensen, K.L., C.D. Clark, B.C. English, and R.J. Menard. “Preferences for Marketing Arrangements by Potential Switchgrass Growers.” *Journal of Cooperatives* 25(2011):16-43.

Kakani, G. Personal Communication. Department of Soil and Plant Sciences, Oklahoma State University, Stillwater, OK, March 2014.

Kakani, V.G., C.B. Godsey, P. Wagle, A.J. Foster, A. Kakani, R. Sripathi, and A. Pandey. “Energy Beets as a Bioenergy Feedstock in Southern Great Plains.” Paper presented at the National Conference of Science for Biomass Feedstock Production and Utilization, New Orleans, LA, October 2-5, 2012.

Katz, J.P. and M.A Boland. “One For All and All For One? A New Generation of Cooperatives Emerges.” *Long Range Planning* 35(2002): 73–89.

Kaylen, M., D.L. Van Dyne, Y. Choi, and M. Blase. “Economic Feasibility of Producing Ethanol from Lignocellulosic Feedstock.” *Bioresource Technology* 72(March 2000): 19-32.

Libsack, S. Energy Beets –Pipeline to Biofuel Feedstock. 2010. Internet site: http://biofuelsconnect.crowdvine.com/attachments/0003/9571/Libsack_Steve.pdf (Accessed April 4, 2014)

Mapemba, L.D. “Cost to Deliver Lignocellulosic Biomass to a Biorefinery.” Ph.D. dissertation, Oklahoma State University, Stillwater, July 2005.

Mapemba, L.D., F.M. Epplin, R.L. Huhnke, and C.M. Taliaferro. “Herbaceous Plant Biomass Harvest and Delivery Cost with Harvest Segmented by Month and Number of Harvest Machines Endogenously Determined.” *Biomass and Bioenergy* 32(November 2008):1016-1027.

Maung, T.A. and C.R. Gustafson. “The Economic Feasibility of Sugar Beet Biofuel Production in Central North Dakota.” *Biomass and Bioenergy* 35(October 2011): 3737-3747.

Panella, L. “Sugar Beet as an Energy Crop.” *Sugar Tech* 12(December 2010):288-293.

Panella, L. and S. R. Kaffka. “Sugar Beet (*Beta Vulgaris* L) as a Biofuel Feedstock in the United States.” *ACS 1058 symposium series*, 2010, pp.163-175.

Pates, M. Self-propelled beet harvesters showcased at sugar beet institute. March 2013. Internet site: http://www.agweek.com/event/article/id/20660/ (Accessed February 17, 2014).

Ripplinger, D. Personal communication. North Dakota State University, ND, May 2014.

Robb, T.W. 2007. “Biomass Derived Energy Southwest KS Project.” Paper presented at the Kansas Renewable Energy Conference, Topeka, Kansas, September 25-26, 2007.

Shapouri, H., M. Salassi, and J.N. Fairbanks. The Economic Feasibility of Ethanol Production from Sugar in the United States. 2006. Internet site: http://www.usda.gov/oce/reports/energy/EthanolSugarFeasibilityReport3.pdf. (Accessed March 23, 2014)

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

Turhollow, A. and F. Epplin. "Estimating Region Specific Costs to Produce and Deliver Switchgrass." Chapter 8 in Switchgrass: A Valuable Biomass Crop for Energy. ed. Andrea Monti. New York: Springer Publishing Co. 2012.

U.S. Department of Agriculture. Census of Agriculture. Geographic Area Series, vol. 1. Oklahoma State and County Data, part 51. 2009.

U.S. Department of Agriculture. Sugars and Sweetners. 2011. Internet site: http://www.ers.usda.gov/topics/crops/sugar-sweeteners/background.aspx (Accessed December 10, 2014).

U.S. Department of Agriculture. Oklahoma Cash Rents County Estimates. 2013. Internet site: http://nass.usda.gov/Statistics_by_State/Oklahoma/Publications/County_Estimates/2012/ok_cash_rents_co_est_12.pdf

U.S. Department of Agriculture. News release: USDA Reassigns Fiscal Year 2014 Sugar Allotments. News release no.0100.14. 2014a. Internet site: http://www.fsa.usda.gov/FSA/printapp?fileName=nr_20140530_rel_0100.html&newsType=newsrel (Accessed December 10, 2014).

U.S. Department of Agriculture. Sugar Loan Program, Sugar Marketing Allotments and Feedstock Flexibility Program. 2014 Farm Bill fact sheet. 2014b. Internet site: http://www.fsa.usda.gov/Internet/FSA_File/sugar_loan_2014.pdf (Accessed December 10, 2014).

Wang, C. "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. 2009.

Wright, M., and R.C. Brown. "Establishing the Optimal Sizes of Different Kinds of Biorefineries." *Biofuels, Bioproducts and Biorefining* 1(October 2007):191-200.

Yacobucci, B. D., R. Schnepf, and T. Capehart. Biofuels in the 2007 Energy and Farm Bills: A Side-by-Side Comparison. Congressional Research Service, Library of Congress, 2007.

Yoder, J., D. Young, K. Painter, J. Chen, J. Davenport, and S. Galinato. Potential for a Sugar Beet Ethanol Industry in Washington State. Report for the Washington State Department of Agriculture. 2009. Internet site: http://agr.wa.gov/fp/pubs/docs/EthanolfromWASugarBeetsWSUStudyMarch2009.pdf (Accessed February 9, 2014).

Table 1. Schedule for a potential energy beet-sorghum -wheat 3-year crop rotation in Oklahoma[a]

| Crop/Month | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year 1** | | | | | | | | | | | | |
| Beets | Seed beets | | | → | | | | | Harvest beets[b] | | | |
| **Year 2** | | | | | | | | | | | | |
| Beets | Harvest beets | | | | | | | | | | | |
| Sorghum | | | | | | | Seed Sorghum | | → | | Harvest Sorghum | |
| **Year 3** | | | | | | | | | | | | |
| Wheat | Seed Wheat | | | → | | | | | Harvest Wheat | | | |

[a] In year 1, energy beets would be seeded in October with harvest beginning in June and extending through to March of the second year. A summer sorghum crop would be produced in year 2 and in year 3, wheat would be seeded in October with harvest beginning June.

[b] If beets are harvested during the June through September period, the land could be seeded to a fall crop enabling a beet-canola-wheat rotation.

Table 2. No-till budget for producing roundup ready energy beet feedstock in Oklahoma (ac)

| Item | unit of measure | Price per unit | Quantity | Value |
|---|---|---|---|---|
| Land rental | ac | 64.00 | 1 | 64.00 |
| Energy beet seed | lb. | 34.80 | 4 | 139.71 |
| Herbicide (glyphosate 3x) | lb. | 3.68 | 4 | 14.70 |
| Urea (46-0-0) | lb. | 0.20 | 176 | 35.13 |
| DAP (18-46-0)[a] | lb. | 0.27 | 108 | 29.39 |
| Seeding no-till planter | ac | 14.64 | 1 | 14.64 |
| Fertilizer application | ac | 4.22 | 1 | 4.22 |
| Herbicide application | ac | 5.45 | 2 | 10.91 |
| Beet harvester | ac | 76.42 | 1 | 76.42 |
| Haulage to processing | ac | 73.98 | 1 | 16.19 |
| Annual operating capital | $ | 0.07 | 313 | 21.89 |
| Total cash costs | ac | | | 484.99 |

[a]DAP is diammonium phosphate. The budgeted cost of N represents the cost of 81 lb. N from urea and 19 lb. N from DAP to obtain 100 lb. of actual N per acre and 50 lb per acre of P applied.

Table 3. Assumptions to model a biorefinery plant based on energy beets in Oklahoma

| Item | Unit | Base | Source |
|---|---|---|---|
| Capacity adjustment factor[a] | | 0.5 | Haque, 2012 |
| Capital cost adjustment factor[b] | | 1.66 | Dysert, 2003 |
| Biorefinery capital investment | | | |
| 20 MGY processed in 300 days[c] | $ million | 77 | Ripplinger 2014 |
| 40 MGY processed in 300 days[d] | $ million | 128 | |
| 80 MGY processed in 300 days | $ million | 212 | |
| Operation and Maintenance cost (Processing) | $/gallon | 0.77 | Shapouri et al. 2006 |
| Project life | years | 20 | Haque, 2012 |
| Discount rate | % | 15 | Kaylen et al. 2000 |
| Conversion rate [e] | gallon/w ton | 26 | Maung and Gustafson, 2011 |
| Plant Operational Days per year[f] | no. | 300 | Ripplinger 2014 |
| Truckload | tons | 30 | Farahmand et al. 2013 |
| Harvest Machine[g] | $000 | 785 | Pates, 2013 |
| Harvest Machine throughput | acre/hr | 7.4 | Pates, 2013 |

[a] A factor of 0.5 is used to scale the processing facility capacities up/down to other plant sizes
[b]Following Dysert, 2003, it was assumed that doubling plant size will increase construction costs by about 66% based on a 0.73 proration factor
[c]Estimate by Ripplinger (2014) is $70 million for a 20 MGY plant for a processing window 330 days. Our energy beet plant would cost $77 million in capital investment cost for a 10 month processing window
[d]Computation based on the cost adjustment factor of 1.6586
[e]Implicitly, an average refined sugar recovery rate of 18% per ton of beets (Kakani, 2014) and 141 gallons per ton of refined sugar (Shapouri et al. 2006) was assumed
[f]A 10 month harvest window and 10 month processing season (just-in-time biomass delivery for processing)
[g]Agrifac (Holmer exxact HexxTraxx) 30-ton self-propelled 12-row model, 612 horse power

Table 4. Estimates of the breakeven price of ethanol from energy beets for three conversion rates and investment cost[a]

| Investment cost | Conversion rate (gallons per wet ton) | | |
|---|---|---|---|
| | 13 | 26 | 52 |
| $ million | | $/gallon | |
| 64 | 4.06 | 2.37 | 1.65 |
| 128 | 4.37 | 2.63 | 1.91 |
| 254 | 4.99 | 3.15 | 2.42 |

[a]Breakeven ethanol price was defined as the price at which the net present value of the production process is zero.

Table 5. Cost components of the breakeven price of ethanol from energy beets at three conversion rates and investment costs

| Investment cost ($ million) | Conversion rate (gallon per ton) | Land cost | | Compensation for delaying harvest beyond September | | Field cost | | Harvest cost | | Transportation cost | | Plant and processing cost[a] | | Total cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $/gallon | | | | | | | | | | | | |
| 64 | 13 | 0.30 | 7%[b] | 0.17 | 4% | 1.14 | 28% | 0.34 | 8% | 0.84 | 21% | 1.06 | 31% | 4.06 |
| 64 | 26 | 0.15 | 6% | 0.10 | 4% | 0.57 | 24% | 0.16 | 7% | 0.33 | 14% | 1.06 | 45% | 2.37 |
| 64 | 52 | 0.07 | 4% | 0.05 | 3% | 0.27 | 16% | 0.10 | 6% | 0.14 | 8% | 1.06 | 62% | 1.65 |
| 128 | 13 | 0.30 | 7% | 0.17 | 4% | 1.15 | 26% | 0.34 | 8% | 0.84 | 19% | 1.32 | 36% | 4.37 |
| 128 | 26 | 0.15 | 6% | 0.10 | 4% | 0.57 | 22% | 0.16 | 6% | 0.33 | 13% | 1.32 | 50% | 2.63 |
| 128 | 52 | 0.07 | 4% | 0.05 | 2% | 0.27 | 14% | 0.10 | 5% | 0.14 | 7% | 1.32 | 67% | 1.91 |
| 256 | 13 | 0.31 | 6% | 0.17 | 3% | 1.16 | 23% | 0.35 | 7% | 0.86 | 17% | 1.82 | 43% | 4.99 |
| 256 | 26 | 0.15 | 5% | 0.09 | 3% | 0.57 | 18% | 0.18 | 6% | 0.35 | 11% | 1.82 | 58% | 3.15 |
| 256 | 52 | 0.07 | 3% | 0.05 | 2% | 0.27 | 11% | 0.10 | 4% | 0.14 | 6% | 1.80 | 74% | 2.42 |

[a]Plant and processing cost includes cost of investment and an operating and maintenance cost of $0.77 per gallon
[b]Percentage of total cost per gallon of ethanol production

Table 6. Estimates of the cost to deliver a steady flow of biomass from energy beets at various conversion rates, land, fuel, and yield scenarios

| Item | Base | Half conversion | Double conversion | 25% Yield low | 50% Yield high | Double fuel price | Double land price |
|---|---|---|---|---|---|---|---|
| Land rent ($/ton) | 3.94 | 3.94 | 3.69 | 5.33 | 2.57 | 3.96 | 7.74 |
| Compensation for delaying harvest beyond September ($/ton) | 2.50 | 2.26 | 2.39 | 3.41 | 1.61 | 2.54 | 4.83 |
| Field production cost ($/ton) | 14.91 | 14.92 | 13.96 | 20.17 | 9.73 | 14.98 | 14.65 |
| Harvest cost ($/ton) | 4.20 | 4.37 | 5.13 | 4.20 | 4.66 | 4.20 | 4.66 |
| Transportation cost ($/ton) | 8.64 | 10.97 | 7.19 | 9.92 | 7.17 | 12.28 | 9.10 |
| Total cost of delivered feedstock ($/ton) | 34.19 | 36.46 | 32.36 | 43.03 | 25.74 | 37.96 | 40.99 |
| Harvested Area (acres) | 92,029 | 154,926 | 44,054 | 124,525 | 60,855 | 92,492 | 91,628 |
| Total harvested biomass (tons) | 1,494,987 | 2,515,169 | 764,548 | 1,494,987 | 1,514,647 | 1,494,987 | 1,490,056 |
| Plant location and size | Grady medium | Blaine medium | Grady medium | Grady medium | Grady medium | Blaine medium | Blaine medium |
| Harvest machines no. | 9 | 15 | 5 | 8 | 9 | 8 | 9 |

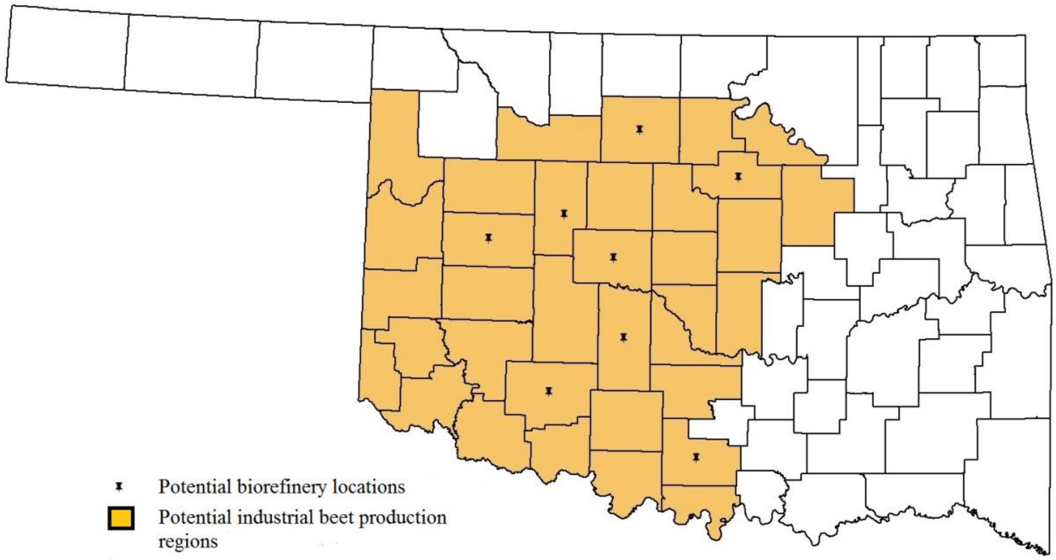


Figure 1. Potential production regions and biorefinery locations for energy beets in Oklahoma

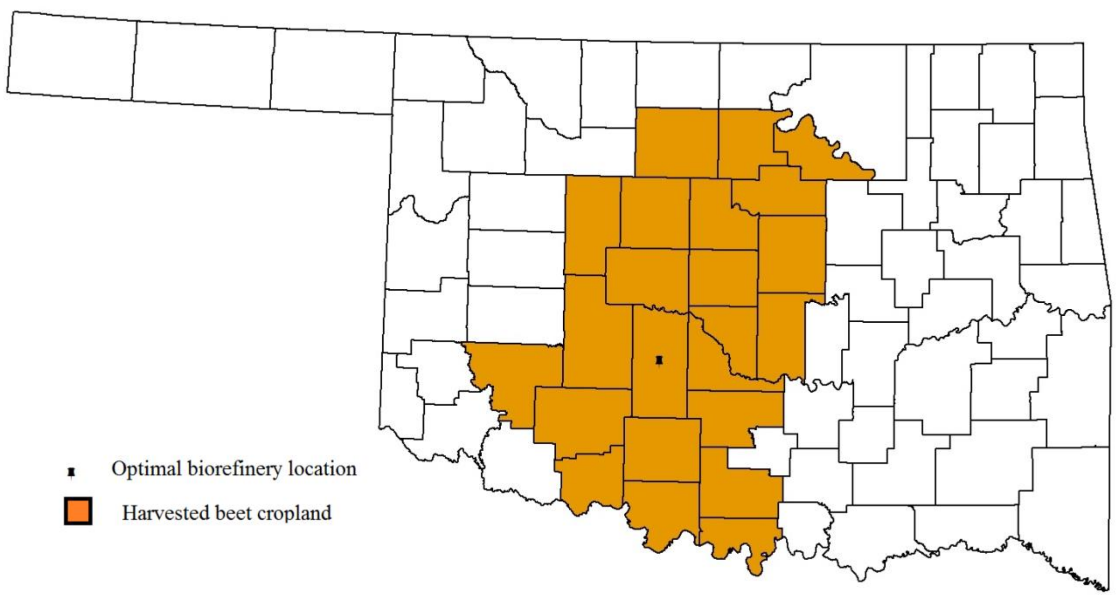


Figure 2. Optimal biorefinery location and counties in Oklahoma from which energy beets would be optimally produced for a plant capital cost of $128 million and a conversion rate of 26 gallons per wet ton.

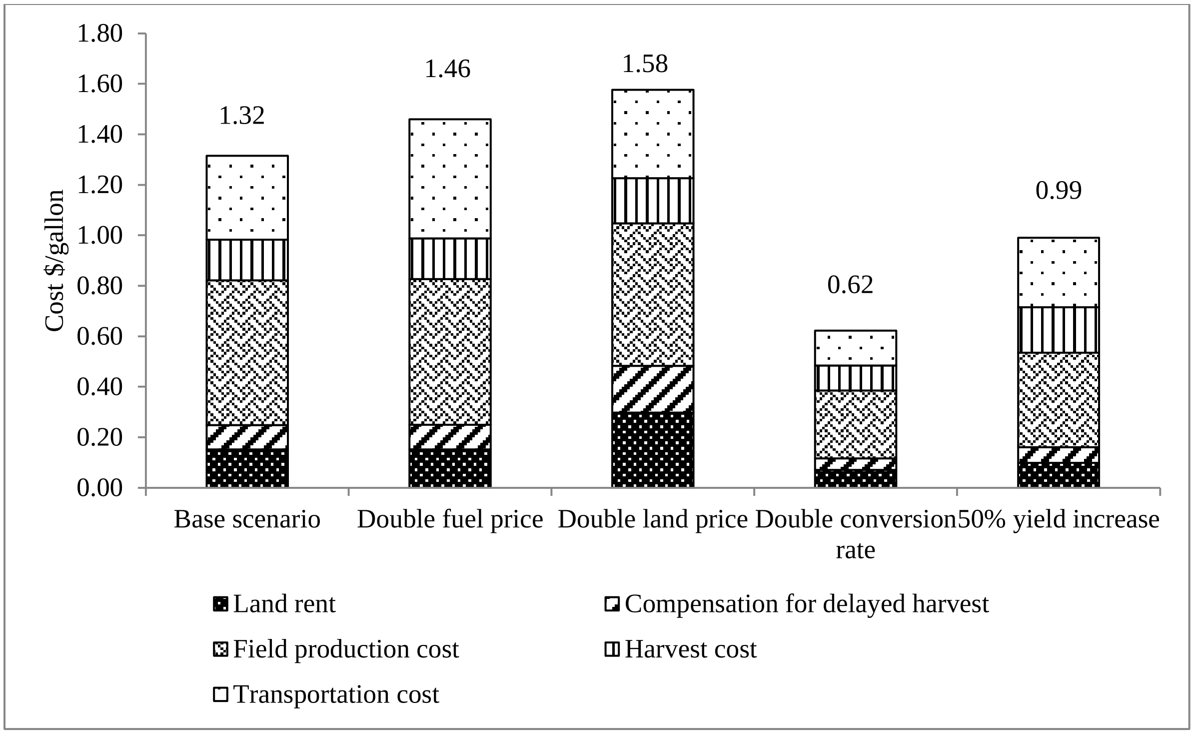

Figure 3. Estimated feedstock costs ($ per gallon) to provide a flow of feedstock to a biorefinery under different scenarios