Construction Cost Sensitivity of a Lignocellulosic Ethanol Biorefinery

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Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Dallas, Texas, February 2-5, 2008

Abstract

In recent years, technology has been developed to convert feedstocks with cellulose content into ethanol. However, ethanol produced from cellulosic feedstocks such as switchgrass, corn stover, wheat straw, and other sources is the same as the ethanol distilled from grain. The American Coalition for Ethanol (ACE) has identified ethanol as a cleaner fuel source than the currently used nonrenewable fuel sources. This could allow the land that is currently under conservation programs to be used to provide a feedstock for ethanol. In an interview with Brian Baldwin, switchgrass and giant miscanthus are identified as potential biomass feedstock based on the ease of production, cost of establishment, and yield. The objective of this research is to determine the price per gallon of ethanol needed so that producing lignocellulosic based ethanol become economically feasible.

Introduction

In the past few years, the increasing cost of crude oil along with America's movement to decrease the dependence on imported oil has lead to a boom of the biofuel industry. This boom has not only been fueled by the increasing cost of crude oil, but government tax incentives and environmental issues have played key roles. In the 2006 State of the Union Address, President Bush stated that ethanol provides a cleaner burning alternative fuel to gasoline. These actions like all actions cause reactions that ripple through other industries.

Ethanol is "ethyl alcohol," a 200 proof grain alcohol mainly produced from corn, however other feedstocks such as sugar cane, milo, barley, and wheat starch are used to create ethanol (RFA). The agricultural sector has seen direct effects of the booming ethanol industry with higher corn market prices. Westcott stated that in 2006 the ethanol industry's percentage in gasoline market was only 3.5 percent, while 14 percent of the corn produced in 2005 through 2006 was used to produce ethanol. The increase in market price of corn has rippled down to livestock industries that use corn as feed. Westcott points out that U.S. corn largest demand comes from of livestock feed accounting for 50 – 60 percent of total corn consumption. The production of corn based ethanol produces distillers' grains, a co-product, which can be utilized for feeding livestock. Even though distillers' grains will be able to displace some of the corn and soybean meal used in feed, hogs and poultry can only consume limited amounts, while cattle will have a larger benefit.

Market prices are vital in decision of what to plant for a farmer. The increased corn prices has shifted acres from other crops and could likewise cause the land currently idle in conservation programs to return to cultivation (Westcott). Another environmental issue that has risen from the ethanol industry boom is the effect the increase of production will have on the Northern Gulf of Mexico's hypoxic zone. A large portion of nitrogen fertilizer, which creates this hypoxic zone, found in the Mississippi River has been discovered to derive from agricultural lands (Ribaudo; Petrolia, *et al*.). According to the June 2007 NASS acreage report, production of principle crops went from 315.8 million acres in 2006 to 320.0 million acres in 2007. However the net change in the hypoxic zone from this increase in production is currently unknown.

LITERATURE REVIEW

Ethanol

Ethanol is predominately distilled from agriculture grains, corn in particular. There are 124 operating facilities with an annual capacity of 6.2 billion gallons of ethanol, with another 5.6 billion gallons annual capacity of ethanol from another 76 processing plants are under construction (ACE).

Ethanol technology, the pollution from the use of fossil fuels, increasing energy prices, and tax incentives have enticed automobile manufacturers to develop vehicles that use ethanol and gasoline blends as well as other alternative energy sources. According to the DOE, cities throughout the U.S. have been selling an ethanol blend, gasohol or E10, as fuel for automobiles. Gasohol is a blend of 10 percent ethanol and 90 percent gasoline. Ethanol adds to the overall fuel supply of the U.S. and helps to keep the fuel prices competitive and affordable. Even though a gallon of ethanol contains 38 percent less energy than a gallon of unleaded gasoline (125,000 Btu versus 78,000 Btu), other variables such as speed, air pressure, weather effects on driving conditions, and stop and go driving have a greater impact on fuel economy than the type of fuel used (ACE). ACE reported that the difference in mileage between regular 100 percent unleaded gasoline and E10 was only a 1.5 percent decrease.

Ethanol production has increased from 175 million gallons in 1980 to a capacity of 6.2 billion gallons in 2007 (Figure 2.2) (ACE). The ethanol industry is projected to more than double in size by 2012 to meet the renewable fuel production mandates set by state and federal legislation (Kenkel and Holcomb).

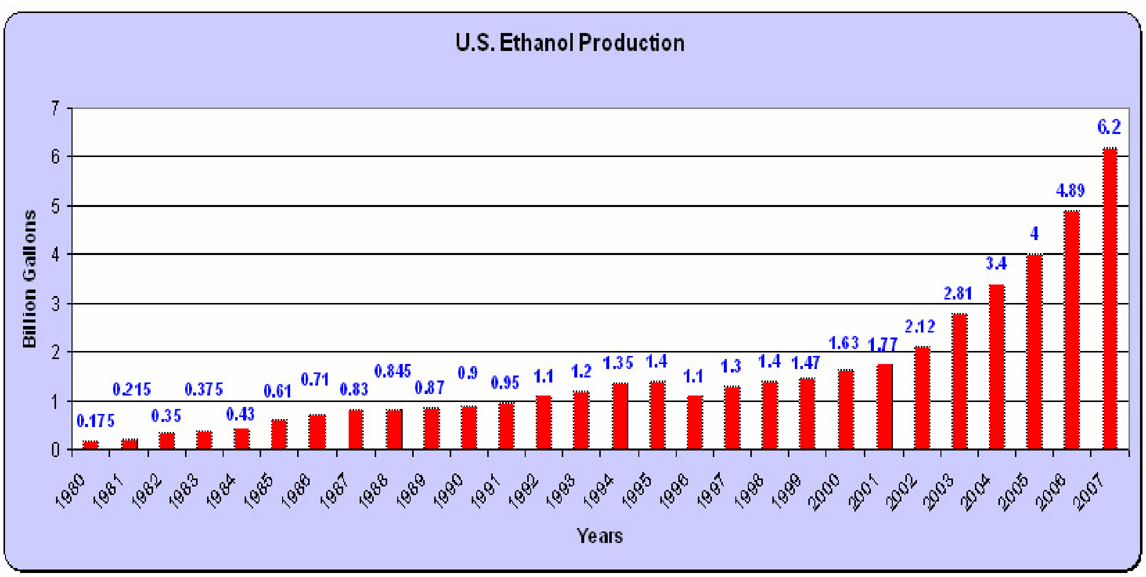

Figure 2.2 U.S. fuel ethanol production in billion of gallons.

Source: American Coalition for Ethanol (http://www.ethanol.org/index.php?id=37&parentid=8#header) (Last accessed April 18, 2007).

The Renewable Fuel Association (RFA) has outlined three federal tax incentives that benefit ethanol producers: (1) a $0.10 income tax credit per gallon of ethanol given to small producers (15 million gallons or less per year); (2) a $0.51 blender tax credit for each gallon of ethanol blended with gasoline; and, (3) a $0.054 tax exemption for alcohol based fuels. The RFA also includes the federal government's income tax deduction for consumers when purchasing of alcohol-fueled vehicles.

Lignocellulosic Biomass

Lignocellulose is a combination of lignin and cellulose. Several different types of LCB have been and are being evaluated as a feedstock used to produce ethanol, and if so, how much ethanol could be produced. Corn stover, switchgrass, giant miscanthus, wheat straw, rice straw, wood chips, and paper pulp are just a few examples of LCB.

Thorsell *et al.* estimated the optimal harvester unit to be ten laborers, nine tractors, three mowers, three rakes, three balers, and one bale transporter. The assumption was that there is a 1:1:1 ratio between the mower, rake, and baler in the field operations. Then Thorsell *et al*. assumed that a bale transporter, picking up and moving the bales to an all-weather road, could service the output of three balers. Tembo *et al.* created a model that estimated the optimal number of harvester units, as described in Thorsell *et al*., based on the window of harvest and the number of field days (number of days that field work could be conducted) subject to the tons of biomass needed to operate a specific size gasification-fermentation biorefinery.

Mapemba *et al.* (2004) determined that cost ranged from $38.22 to $58.24 per metric ton (MT) to deliver a flow feedstock based on the size of the biorefinery and the length of the harvest window. In addition, only 25 percent of the enrolled CRP acres were harvested and the transportation distance from the field to the plant was between 60 to 105 miles. The transportation cost of feedstock was estimated from $8.27 to $13.06 per MT. Mapemba *et al*. (2004) concluded that the 120 day harvest window restriction more than doubled the expected harvest and field storage cost. The harvest restriction increased the delivery cost from $13.65 to $15.47 per MT.

Gasification-Fermentation

Gasification-fermentation is a process where grasses or other types of LCB are gasified into carbon monoxide, carbon dioxide, hydrogen and other components. Then, the gases are bubbled through a bioreactor where microorganisms convert the gases into ethanol and other value-added products, such as butanol and acetic acid. Gasification can convert essentially the entire biomass, even the lignin, into syngas with the use of bacteria to ferment the LCB (Rajagopalan *et al.*) Syngas is a mixture of H_2 and CO that is produced by biomass gasification (Thameur and Halouani).

One major advantage of using a gasification-fermentation process to convert LCB to ethanol over conventional grain fermentation is that a single biorefinery can process a range of different LCB feedstocks such as agricultural residue like corn stover and wheat straw, and perennial grasses like switchgrass, fescue, and bermudagrass (Tembo *et al.*).

Tembo *et al.* explain that one significant challenge is that LCB feedstock is bulky and difficult to transport. Also, unlike grain feedstocks, LCB does not currently have markets in place, while a grain-to-ethanol biorefinery can post competitive market prices and use futures markets to manage price risk.

Epplin (1996) estimated that to achieve economies of size, a biorefinery must process between 1,800 and 9,000 MT per day. This study assumed that the biorefinery would operate 350 days a year, a 1,800 MT/day plant would need 630,000 MT per year while a 9,000 MT/day plant would need 3.15 million MT per year. Epplin (1996) concluded that a 1,800 MT per day plant would require 70,000 hectares (ha) (150,000 acres) and a 9,000 MT per day plant would require 350,000 ha (875,000 acres).

Cost of Operations

Soldatos *et al.* point out that perennial energy crops tend to have high costs in the establishment year, with lower annual costs for the remainder of the productive life. Soldatos *et al.* studied different ways to calculate costs for perennial energy crops by estimating the individual year cost, a typical year's cost once the crop reaches maturity, or the overall approach is to estimate the average cost over the entire life of the crop. The results of Soldatos *et al.*'s first approach are not useful and are difficult to use for comparison between plantations, the second approach does not take into account the establishment year, and the third approach includes the initial investment cost and the time value of money and is able to compare directly to different crops.

Soldatos *et al.* used BEE (Biomass Economic Evaluation http://www.bee.aua.gr) to estimate the cost of producing *Arundo donax* L. (Giant Reed) and *Miscanthus x* *gigantheus* (Giant Miscanthus). Based on the third approach that Soldatos *et al.* explained, the total cost of growing and harvesting Giant Reed is $1,518.91 per cultivated ha or $88.58 per dry MT while the total cost of growing and harvesting Giant Miscanthus is $1,517.64 per cultivated ha or $105.03 per dry MT. The cost of Giant Reed and Giant Miscanthus reflect the cost of planting, irrigation, fertilization, weed control, harvesting, other field operations, land, and overhead.

Bransby *et al.* (2005) built at interactive budget model for producing and delivering switchgrass to a biorefinery. The assumptions were made that hauling distance was set at 80 km (~50 miles), 10-year stand life, and the crop was established on cultivated land. Harvesting cost for baling and pelletizing the biomass was reported to be 22 – 44% more expensive than loose chop and modulizing where cost per unit started to level off at 16 MT dry matter per ha. At this level of production the cost per MT is approximately $45 for chopped and modulated; while round bales and pelleted is approximately $60 per MT. Cost of transportation increased linearly with distance but decreased on a per unit basis as hauling capacity increased, leveling off above 20 MT. Transporting 20 MT of chopped and modulated per load the cost approximately $40 per MT; round bales and pelleted transported for at a cost of approximately $60 and $65 per MT, respectively. However, the baling option had a lower relative impact due to higher handling and processing cost. Bransby *et al.* (2005) also reported that nearly half of total costs were due to production and harvesting, while processing, handling, and transportation made up the remaining half. Of the four harvest methods analyzed studied, modulated switchgrass had the lowest total cost to deliver to the biorefinery.

Walsh summarized several production cost studies that exist showing a range from $22 per dry MT to more than $110 per dry MT depending on type of production practices, different kinds of biomass, and expected yields. Comparing production and production costs of different studies was difficult due to the fact that assumptions such as yields, input levels, and expected prices vary between studies. The rest of the variation was explained by the differences in the framework and research methods used to estimate production costs (Walsh).

Lowenberg-Deboer and Cherney estimated that the cost to produce switchgrass was $37 per MT in Indiana. However, the cost of land, labor, and transportation were not taken into account. In Virginia, Cundiff and Harris estimated production costs to range from $51-$60 per MT. Cundiff and Harris estimated these costs assuming that cropland could be rented for $49 per ha, yields were 9 dry MT per ha, and by using current farming operations and economies of size to decrease average fixed machinery cost.

De La Torre Ugarte *et al.* estimated that at a price of $40 per dry ton for switchgrass, up to 42 million acres could be profitably switched to generate bioenergy crops. This level of production would make bioenergy crops the fourth largest crop grown in the U.S. based on total acres, following wheat, corn, and soybeans. It was also stated that CRP acres could become a significant source of biomass crops, but that criteria would have to be developed to determine appropriate CRP acres and the proper management practices for bioenergy crop production.

Tembo *et al.* note that many problems with previous studies on the harvest and transportation cost is that harvest windows, storage location, transportation, and storage losses are fundamentally overlooked. Several different articles have looked at the cost of transporting LCB to an ethanol plant, all assuming that the biomass would be trucked to the plant or storage facility (Walsh; Epplin;1996). Key differences in the studies were the size of the truck and trailer combination and the distance from pickup to delivery. Cost ranged between $5.50 - $12 per dry MT (Walsh) and $8.80 per MT (Epplin; 1996). Thorsell *et al.*, Walsh, and Epplin (1996) have looked at estimates for harvest windows and transportation. Tembo *et al.* do not provide cost estimates when considering storage location and storage losses.

Methods and Procedures

Since the construction cost per annual gallon of ethanol produced for a lignocellulosic biorefinery has not been published, this study displays how sensitive this cost is to a lignocellulosic biorefinery. The biorefinery biomass feedstock, operating, and construction costs are used to estimate the price per gallon of ethanol needed for the biorefinery to breakeven. While these cost are not all of the components to a biorefinery's total cost of production, other costs such as feedstock storage or any post production cost associated with ethanol production are assumed to be zero in this study. Two different cost scenarios were used to provide a range from a lower to a higher cost scenario. The lower cost scenario took advantage of less expensive biomass feedstock and operating costs, while the higher cost scenario utilized the more expensive feedstock and operating costs.

Using the following equation

$$P_E = \frac{\mathrm{B}}{\delta} + \mathrm{X} + \Phi$$

P_E is the breakeven price per gallon of ethanol. B represents the price of the delivered stock. The production costs were estimated by using the establishment cost, maintenance cost, harvesting cost, and moving the LCB to a convenient location in the field for the transport vehicle. The transportation costs are estimated by assuming that the feedstock would be loaded on a semi-truck in the field and hauled to the biorefinery. The cost of loading and transporting is divided by the assumed weight of the truck load, to calculate the transportation cost per ton. The production data used, was agronomic data collected at Mississippi State University and Oklahoma State University through the Biomass-Based Energy research project. Transportation cost data, from the field to the plant, was collected from survey data conducted on trucking companies in Mississippi. δ represents the gallons produced per ton of feedstock. X is the construction cost per annual gallon. Φ is the operating cost per gallon. Some biorefineries will be eligible for a tax incentive to produce ethanol. This tax incentive per gallon has been subtracted from the cost per gallon produced in the first two charts.

Results

Gallon/ton	Construction Cost per Annual Gallon								
	$1.00	$1.50	$2.00	$2.50	$3.00	$3.50	$4.00	$4.50	$5.00
	Price per gallon of Ethanol Needed (In Dollars)								
150	2.80	3.30	3.80	4.30	4.80	5.30	5.80	6.30	6.80
140	2.85	3.35	3.85	4.35	4.85	5.35	5.85	6.35	6.85
130	2.91	3.41	3.91	4.41	4.91	5.41	5.91	6.41	6.91
120	2.98	3.48	3.98	4.48	4.98	5.48	5.98	6.48	6.98
110	3.06	3.56	4.06	4.56	5.06	5.56	6.06	6.56	7.06
100	3.16	3.66	4.16	4.66	5.16	5.66	6.16	6.66	7.16
90	3.28	3.78	4.28	4.78	5.28	5.78	6.28	6.78	7.28
80	3.43	3.93	4.43	4.93	5.43	5.93	6.43	6.93	7.43
70	3.62	4.12	4.62	5.12	5.62	6.12	6.62	7.12	7.62
60	3.87	4.37	4.87	5.37	5.87	6.37	6.87	7.37	7.87
50	4.23	4.73	5.23	5.73	6.23	6.73	7.23	7.73	8.23
40	4.76	5.26	5.76	6.26	6.76	7.26	7.76	8.26	8.76
30	5.66	6.16	6.66	7.16	7.66	8.16	8.66	9.16	9.66
20	7.44	7.94	8.44	8.94	9.44	9.94	10.44	10.94	11.44

This chart explains the upper bound incentives needed to breakeven. The prices were calculated by using a price of delivered feedstock of $107.15, and a per gallon operating cost of $1.75. These results include the tax incentive package of $.66. Currently, the average facility produces about 30 gallons of ethanol per ton of feedstock. If construction costs are at $3.00 per annual gallon, then the price per gallon of ethanol needed to breakeven is $7.66.

Gallon/ton	Construction Cost per Annual Gallon								
	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
	Price per gallon of Ethanol Needed (In Dollars)								
150	1.07	1.57	2.07	2.57	3.07	3.57	4.07	4.57	5.07
140	1.08	1.58	2.08	2.58	3.08	3.58	4.08	4.58	5.08
130	1.10	1.60	2.10	2.60	3.10	3.60	4.10	4.60	5.10
120	1.12	1.62	2.12	2.62	3.12	3.62	4.12	4.62	5.12
110	1.15	1.65	2.15	2.65	3.15	3.65	4.15	4.65	5.15
100	1.18	1.68	2.18	2.68	3.18	3.68	4.18	4.68	5.18
90	1.22	1.72	2.22	2.72	3.22	3.72	4.22	4.72	5.22
80	1.27	1.77	2.27	2.77	3.27	3.77	4.27	4.77	5.27
70	1.33	1.83	2.33	2.83	3.33	3.83	4.33	4.83	5.33
60	1.41	1.91	2.41	2.91	3.41	3.91	4.41	4.91	5.41
50	1.53	2.03	2.53	3.03	3.53	4.03	4.53	5.03	5.53
40	1.70	2.20	2.70	3.20	3.70	4.20	4.70	5.20	5.70
30	1.99	2.49	2.99	3.49	3.99	4.49	4.99	5.49	5.99
20	2.57	3.07	3.57	4.07	4.57	5.07	5.57	6.07	6.57

This chart shows the lower bound incentives needed to breakeven. The prices were calculated by using a price of delivered feedstock of $34.61 and a per gallon operating cost of $.50 It also includes the tax incentives package of $.66. If the plant produces 30 gallons of ethanol per ton of feedstock, and assumes a $3.00 construction cost per annual gallon, the plant needs a price of $3.99 to breakeven.

Gallon/ton	Construction Cost per Annual Gallon								
	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
	Price per gallon of Ethanol Needed (In Dollars)								
150	3.46	3.96	4.46	4.96	5.46	5.96	6.46	6.96	7.46
140	3.52	4.02	4.52	5.02	5.52	6.02	6.52	7.02	7.52
130	3.57	4.07	4.57	5.07	5.57	6.07	6.57	7.07	7.57
120	3.64	4.14	4.64	5.14	5.64	6.14	6.64	7.14	7.64
110	3.72	4.22	4.72	5.22	5.72	6.22	6.72	7.22	7.72
100	3.82	4.32	4.82	5.32	5.82	6.32	6.82	7.32	7.82
90	3.94	4.44	4.94	5.44	5.94	6.44	6.94	7.44	7.94
80	4.09	4.59	5.09	5.59	6.09	6.59	7.09	7.59	8.09
70	4.28	4.78	5.28	5.78	6.28	6.78	7.28	7.78	8.28
60	4.54	5.04	5.54	6.04	6.54	7.04	7.54	8.04	8.54
50	4.89	5.39	5.89	6.39	6.89	7.39	7.89	8.39	8.89
40	5.43	5.93	6.43	6.93	7.43	7.93	8.43	8.93	9.43
30	6.32	6.82	7.32	7.82	8.32	8.82	9.32	9.82	10.32
20	8.11	8.61	9.11	9.61	10.11	10.61	11.11	11.61	12.11

This chart shows the upper bound incentives needed to breakeven. It does not include a tax incentive package. The prices were calculated using a price of delivered feedstock of $107.15, and a per gallon operating cost of $1.75. If the plant produces 30 gallons of ethanol per ton of feedstock, and assumes a $3.00 construction cost per annual gallon, the plant needs a price of $8.32 to breakeven.

Gallon/ton	Construction Cost per Annual Gallon								
	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
	Price per gallon of Ethanol Needed (In Dollars)								
150	1.73	2.23	2.73	3.23	3.73	4.23	4.73	5.23	5.73
140	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75
130	1.77	2.27	2.77	3.27	3.77	4.27	4.77	5.27	5.77
120	1.79	2.29	2.79	3.29	3.79	4.29	4.79	5.29	5.79
110	1.81	2.31	2.81	3.31	3.81	4.31	4.81	5.31	5.81
100	1.85	2.35	2.85	3.35	3.85	4.35	4.85	5.35	5.85
90	1.88	2.38	2.88	3.38	3.88	4.38	4.88	5.38	5.88
80	1.93	2.43	2.93	3.43	3.93	4.43	4.93	5.43	5.93
70	1.99	2.49	2.99	3.49	3.99	4.49	4.99	5.49	5.99
60	2.08	2.58	3.08	3.58	4.08	4.58	5.08	5.58	6.08
50	2.19	2.69	3.19	3.69	4.19	4.69	5.19	5.69	6.19
40	2.37	2.87	3.37	3.87	4.37	4.87	5.37	5.87	6.37
30	2.65	3.15	3.65	4.15	4.65	5.15	5.65	6.15	6.65
20	3.23	3.73	4.23	4.73	5.23	5.73	6.23	6.73	7.23

This chart shows the lower bound incentives needed to breakeven. It does not include a tax incentive package. The prices were calculated by using a price of delivered feedstock of $34.61, and a per gallon operating cost of $.50. If the plant produces 30 gallons of ethanol per ton of feedstock, and assumes a $3.00 construction cost per annual gallon, the plant needs a price of $4.65 to breakeven.

Discussion

This research shows that the higher the conversion rate (gallons per ton) and lower construction cost provides the lower ethanol prices needed to breakeven on the construction and delivered lignocellulosic biomass costs. Table 1 represents the price per gallon of ethanol needed for a lignocellulosic biorefinery to breakeven. At 150 gallons of ethanol per ton and a construction cost per annual gallon of $1.00, a biorefinery will need transportation, and operating costs, but does not include feedstock storage or any post production transactions. Biorefineries must achieve economies of size in order to make ethanol a feasible alternative fuel. The current conversion rate of feedstock to ethanol is poor and must dramatically increase to become feasible. The construction cost for biorefineries are currently large and must be cut, in order to produce ethanol more efficiently. The production of ethanol from feedstock is in its infancy stage and must mature as the demand for ethanol matures to be a feasible source of ethanol.

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