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Energy cane usage for cellulosic ethanol: estimation of feedstock costs and comparison to corn ethanol

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ABSTRACT

To reach the US 2022 mandate of 136.3 billion litres of annual biofuel production, multiple sources must be integrated into the renewable biofuels supply chain. Energy cane appears well suited to help meet this mandate, particularly in Louisiana. Although not traditionally grown, production similarities to sugarcane make it an attractive option for Louisiana farmers if they are offered the 'right price.' If farmers are to switch hectares from sugarcane to energy cane, cellulosic ethanol processors must provide farmers an additional $2.84/MT[5] and $3.41/MT on a third and fourth stubbling above breakeven to make the net revenue on a per tonne basis from energy cane equal to that of sugarcane.

Providing farmers with the right monetary incentive is only part of the equation for ethanol processors, as they also need to determine if cellulosic ethanol from energy cane is competitive with corn ethanol. A breakeven analysis is utilized to determine the monetary incentive needed to cover the cost of production. An additional equation is used to evaluate the cost of cellulosic ethanol so that comparisons may be drawn between cellulosic costs and traditional corn ethanol costs. Our results indicate that this occurs at enzyme prices of $0.04/l (projected enzyme costs), irrespective of energy cane yields, stubbling length, and/or corn prices. Since 2007, enzyme costs for the lignocellulosic ethanol process have fallen by $0.07/l, which have increased the competitiveness of cellulosic ethanol relative to corn ethanol.

KEYWORDS: Biofuels; Production Incentives; Cellulosic Ethanol; Breakeven Analysis

1. Introduction

The use of ethanol as an alternative energy source has received significant publicity in recent years because of increasing oil prices and worries about future oil supply shortages. Moreover, US energy policies have also influenced the expansion of the ethanol industry; these policies include the banning of Methyl Tertiary Butyl Ether (MTBE), the 2005 Energy Policy Act, and the 2007 Energy Independence and Security Act (EISA). The phasing out of MTBE in 2000 created an opportunity for ethanol to become the primary oxygenate used in the production of gasoline (Energy Information Association, 2005). The 2005 Energy Policy Act established a Renewable Fuel Standard (RFS), which mandated 15.1 billion litres of biofuels be produced annually by 2006 and 28.4 billion litres annually by 2012 (Tyner, 2007). Since both of these mandated levels were surpassed before their deadline, a new RFS was passed in 2007 with a ratification of the 2007 EISA. This ratification mandated that fuel producers use at least 136.3 billion litres of biofuels by 2022. In addition, it placed an emphasis on the production of cellulosic ethanol (Office of the Press Secretary, 2007). The combination of these factors and others influence whether cellulosic ethanol becomes a significant contributor in the US energy market.

If this does occur, how does production agriculture respond? In 2009, 335.8 million tonnes (metric tons) of corn were produced on 32.2 million agricultural hectares in the US (USDA, 2011). If all of this corn were converted into ethanol, it would produce enough fuel to last approximately 64 days, based upon average US daily gasoline consumption (Energy Information Association, 2007).[6] Moreover, if corn were the only source of ethanol available for meeting the 2022 136.3 billion litre biofuel mandate, the US would have to allocate approximately 98% of its corn production to biofuels. Usage of corn at this level for ethanol is not sustainable given other demands for corn (i.e. feed grain in the livestock industry and consumer food products). The development of a cellulosic ethanol industry depends on usage crops that have less impact on the food supply (Coyle, 2010). Consequently, alternative

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[5] In mid-December 2013, US$1 was approximately equivalent to £0.61 and €0.73 (www.xe.com).

[6] A conversion ratio of 11 liters of ethanol per 25.4 kg is assumed (Schnitkey *et al.*, 2007).

crop sources will have to be utilized to meet this ethanol mandate.

Each geographic/production area within the US should produce the energy crop for which it has a comparative advantage. For example, in the Midwest, corn will probably continue to be the crop of choice, while for the Southern US, other biomass crops may be a more suitable energy crop choice. Energy cane could be that crop in Florida, Louisiana, and Texas. While energy cane and sugarcane are the same genus, *saccharum*, energy cane is bred for its high fibre and low sugar content, while sugarcane is bred for the opposite characteristics.

Unlike corn, ethanol from energy cane comes from two sources: 1) the sugar from the energy can be converted to ethanol and 2) the cellulosic material (fibre) from the energy cane can be processed into ethanol. Cellulosic technology is still in the developmental phase, and only a handful of companies (e.g. Abengoa, POET LLC, Koir's, and Fiberight LLC) are currently experimenting with producing ethanol from cellulosic materials (e.g. forestry by-products, wheat, corn stover and perennial grasses such as switchgrass and energy cane). The reason for the emphasis on cellulosic material is that the Renewable Fuels Association (2008) estimates that the 1.2 billion tonnes of sustainable cellulosic material available in the US on an annual basis could produce an estimated 227.1 billion litres of ethanol each year. Additionally, the majority of this biomass would be harvested from second-generation feedstocks (e.g. perennial grasses and forestry by-products), which are not used for human consumption (Biomass Research and Development, 2008).

Limitations and risks still exist with the usage of these second-generation feedstocks. For example, corn stover a potential biomass feedstock in the Midwest is constrained by both soil moisture availability and water/wind erosion (Kadem and McMillan 2003; Graham *et al.*, 2007). Additional limitations exist with the adoption of feedstocks such as energy cane and miscanthus, as well as other feedstocks. The markets for these crops are thin and secondary market options for these crops are just being developed. Jorgensen (2011), Bocqueho and Jacquet (2010) and Stone *et al.* (2010) discuss the risks associated with the production of various biomass crops. They note that with biomass feedstocks such as miscanthus there is an increased water need, susceptibility to diseases, and liquidity constraints that can arise from a producer switching to biomass production. Liquidity is a major concern for producers growing perennial crops, such as energy cane, as these crops have both significant upfront establishment costs and typically do not realize revenues in the first year of production (Ericsson *et al.*, 2009)

Given the limitations and risks associated with the production of biomass feedstocks, it is important to investigate all aspects of biomass production. The production of non-traditional crops such as energy cane creates a situation wherein producers are uncertain about whether and how these new crops will allow them to maintain future farm income at current levels. According to Beierlein *et al.* (1995), breakeven analysis can be used effectively as a 'first screening procedure' or 'ballpark technique' for a top-level examination. Khanna *et al.* (2008) employ a Net Present Value (NPV) framework to determine the breakeven price required to cover the cost of production for both switchgrass (10-year time horizon) and miscanthus (20-year time horizon). Hallam *et al.* (2001) also use a breakeven analysis to determine the required price needed to cover the total production costs for reed, canarygrass, switchgrass, big bluestem, alfalfa, sweet sorghum, forage sorghum, and maize. However, no such analysis exists for energy cane.

Consequently, this paper has two objectives: 1) to determine the breakeven price producers must receive to cover energy cane's cost of production and 2) to determine how increasing energy cane yield (mt/ha) and the price of corn impacts cellulosic ethanol's competitiveness with traditional corn ethanol. Energy cane production costs are significantly influenced by the cost of seed cane, which is the initial plant material that is purchased to start the energy cane crop. One of the key costs that influence the competitiveness of cellulosic ethanol with traditional ethanol is enzyme costs. In the last decade, enzyme costs have dropped by 80 percent (Advanced Ethanol Council, 2013). Taken together, these objectives will help better define the current economic feasibility of the production of energy cane.

2. Method

For the energy cane industry to take current production hectares away from sugarcane in Louisiana, energy cane production must generate expected net returns per hectare that are at least equal to the net returns for sugarcane. One way to evaluate this is through a comparison of expected net returns per hectare for the two crops. Given the lack of data on energy cane production, we examine breakeven prices for a variety of yields and two of the most common stubbling lengths. For a producer, these two variables are key drivers in crop choice decision. As the tonnes of energy cane harvested per hectare increases, the breakeven price required by the producer to grow energy cane declines. With respect to length of stubbling, the breakeven price required to cover production costs decreases as stubbling length increases. This occurs because fixed planting costs are spread across more years of production and a smaller percentage of the producer's land is devoted to energy cane seed production.

Comparison between Characteristics of Energy Cane and Sugarcane

Louisiana is the largest producer of sugarcane in the U. S. with approximately 172,000 hectares (425,000 acres) in 2009 (USDA, 2011), which means it has an established sugarcane production, harvest, transportation, and processing infrastructure. In addition, energy cane and sugarcane are also similar in how they are grown, where they are grown, and in their growing cycles. These characteristics, especially from a producer's standpoint, make energy cane a good candidate and viable alternative crop for farmers already producing sugarcane. In addition, energy cane's ability to produce substantial amounts of biomass per hectare and to grow under marginal conditions are reasons why this feedstock is an excellent candidate for cellulosic ethanol in Louisiana (Alexander, 1985).

Table 1: Brix and fibre comparison of a standard sugarcane variety and two energy cane varieties

Variety	Gross Cane (MT/ha)	Brix (% Cane)	Fiber (% Cane)
LCP 85-384 (a)	70.56	18.2	13.0
Ho 00-961 (b)	77.50	17.7	15.9
HoCP 91-552 (b)	87.14	16.8	15.2

a. Dominant Louisiana Sugarcane Variety. b. High-fiber energy cane variety.
Source: Tew et al., 2007.

While they share the aforementioned similarities, the cane varieties have vastly different end uses, i.e. energy cane has little value in the sugar market and sugarcane has reduced value in the cellulosic ethanol market. Table 1 contains the tonnes of cane harvested per hectare, the percentage of sugar by mass (i.e. brix), and the percentage of insoluble material delivered for processing (i.e. fibre) for two energy cane varieties grown in Louisiana (Ho 00-961 and HoCP 91-552) compared with a traditional sugarcane variety (LCP 85-384) (Tew *et al.*, 2007, Rein, 2006). An additional energy cane variety, L 79-1002, has also been released. Initial reports suggest that this variety generates yields of over 224 MT/ha, which is significantly higher than the 78 MT/ha current varieties are yielding (Tew *et al.*, 2007).

Another factor that could cause sugarcane producers to make the shift into energy cane is the recent increase in input costs, which have driven down the profitability in sugarcane. Although market returns at average yields have more than covered variable production costs, they do not cover total production costs (variable costs plus fixed costs).[7] From 2005 to 2009 net returns per hectare for the average Louisiana sugarcane producer were approximately -$77.5 (Breaux and Salassi, 2005; Salassi and Breaux, 2006; Salassi and Deliberto, 2007, 2008a, 2009). Production of sugarcane has continued because average returns above variable cost are positive ($305 per hectare), allowing producers to cover their costs in the short-run (Breaux and Salassi 2005; Salassi and Breaux 2006; Salassi and Deliberto, 2007; 2008a; 2009). This situation was reversed for 2010, when net return per hectare averaged $150 because of the significant rise in sugarcane price and decline in input costs (Salassi and Deliberto, 2010).

To determine if farmers would be willing to produce energy cane in place of sugar cane, data on both costs of production and output prices is needed. Because the energy cane market is in its infancy, there is inadequate production cost and output price data available for analysis. To address this issue we utilize the *2010 Sugarcane Production in Louisiana* costs and returns report that provides the budget data used for determining sugarcane production costs, since energy cane requires similar production practices as sugarcane and the two crops have a comparable growth cycle (Salassi and Deliberto, 2010). Revenue adjustments reflect the assumption that growers will no longer be paid on the sugar content of the crop, but rather on the total biomass delivered to the processor.

Grower Breakeven Costs

To induce production of energy cane, a biofuel facility/biomass processor would need to pay energy cane growers, at a minimum, a price that on average would cover variable, fixed, overhead, land rental, and transportation costs (i.e. the breakeven price). Breakeven price is determined using equation 1,

$$BE = (fixed + variable + overhead) / \left(\frac{harvested}{100}\right) * tonsperha, \quad (1)$$

where BE is the breakeven price in \$/MT, *fixed* is the fixed cost \$/ha, *variable* is the variable cost \$/ha, *overhead* is the overhead costs in \$/ha, *harvested* is the hectares harvested, and *tonsperha* is the average MT/ha harvested on the operation. Given the similarities between energy cane and sugarcane (production methods and growth), it is expected that the production cost of energy cane will be similar to sugarcane.

Additional assumptions for the model are a one-sixth crop share land rental charge paid by growers to property owners and a payment from the processor to the producer of an average value of $3.85 per tonne for transportation credit from farm to mill (Salassi and Deliberto, 2010). We assume that the producers utilize the typical land rental arrangement of a Louisiana sugarcane producer, and hauling distances represent the average observed in the sugarcane industry (the same data currently utilized in enterprise production cost sugarcane budgets for Louisiana) (Salassi and Deliberto, 2010).

The true yield potential of energy cane is currently unknown, because research and development of energy cane varieties is in its infancy. Consequently, for this analysis we examine yield ranges from 67.2 tonnes (30 short tons) to 156.8 tonnes (70 short tons) per hectare, to allow breakeven price analysis to account for this uncertainty. Uncertainty in energy cane production is not limited to yields, as it is also present in harvesting costs. To reflect the unknown nature of the harvesting cost, we conduct the breakeven analysis over a range of harvesting costs (Tew *et al.*, 2007).[8]

Given that energy cane is a perennial crop, a grower's flexibility is limited by stubbling length, which is the length of the crop cycle (the number of annual harvests possible before replanting is necessary). While stubbling length may be adjusted, the amount it can be adjusted is dependent upon the energy cane variety planted. Since optimal stubbling length varies with variety, we examine both 3rd and 4th stubble, the two most common lengths.[9] For example, if an operation harvests through 3rd stubble, a five-year production cycle is being used.

[7] Appendix A contains the specific variable and fixed costs considered.

[8] Harvesting costs are based on the assumption of 40.5 metric tons per hour can be harvested (Barker, 2007).

[9] For a complete explanation of the stubbling process, please see Mark (2010).

Table 2: Breakeven prices of biomass required to cover energy cane production costs in a five-year crop cycle at various energy cane yields

3rd Stubble		
Yield/Harvested MT/ha	**Breakeven Price (Processer Paying Hauling Costs) ($)**	**Breakeven Price (Producer Paying Hauling Costs) ($)**
67.2	34.60	38.46
78.4	29.52	33.38
89.6	25.74	29.60
100.8	22.82	26.68
112.0	20.48	24.34
123.2	18.57	22.43
134.4	17.21	21.06
145.6	15.69	19.54
156.8	14.54	18.40

Comparison Between Cellulosic and Corn Ethanol

There are two main reasons why corn is currently the major agricultural crop used for US ethanol production: 1) its abundance (supply availability) and 2) the cost of producing ethanol from corn, which is substantially lower than that of cellulosic ethanol. Recent developments have narrowed the production cost gap between corn ethanol and cellulosic ethanol (decreasing enzyme and pre-processing costs) (Aden, *et al.*, 2002; Collins, 2007; Bullis, 2009). For example, in 2007 production costs per litre for cellulosic ethanol were estimated to be $0.70 (Collins, 2007). By 2010, it was expected to decrease to between $0.28 and $0.29 (Aden *et al.* 2002; Collins, 2007). This did not occur as cellulosic ethanol costs are still above $0.52 per litre (POET, 2012). Collins (2007) found that on a percentage basis, capital and enzyme costs were significantly larger portions of the production costs for cellulosic ethanol when compared to corn ethanol.

Ethanol production per ton of biomass varies with the pre-treatment process and the enzyme technology used. For this research, a lignocellulosic ethanol process with an alkaline pre-treatment is assumed for the cellulosic portion of the process, while the juice from the energy cane is fermented using traditional ethanol methods. For these production technologies, it is assumed that each tonne of energy cane produces 94.6 litres of ethanol. Ethanol yield per tonne of biomass can be broken down into sucrose juice ethanol (44 L/MT) and cellulosic ethanol (41 L/MT) (Day, 2010). The total cost for cellulosic ethanol production for the processor is determined using equation 2,

$$TC = FC - BP + EC + OC + CC \tag{2}$$

where TC is total costs, FC is feedstock costs, BP is by-product revenue, EC is enzyme costs, OC is other costs, and CC is capital costs.

Feedstock procurement accounts for over 70% of the cost of production for a corn ethanol plant. Since this cost is a majority of total costs, and because corn costs have experienced tremendous variation in recent years, two different corn prices are utilized in this analysis. The first price is $145.66 per tonne, which is the average price of corn in the United States for 2009 (USDA 2011). The second price investigated is $275.57 per tonne, which is representative of the high corn prices observed in 2007 and 2011 (USDA, 2011). Collins (2007) and Aden, *et al.* (2002) at the National Renewable Energy Laboratory provide the base by-product, enzyme, capital, and other cost assumptions used in the analysis for the two-ethanol production processes.

3. Results and Discussion

Producer Breakeven

Producer Breakeven for 3rd Stubbling

Table 2 contains the breakeven prices for farmers who grow energy cane on a five-year cycle (harvest through the3rd stubble). At the current yields for energy cane varieties being produced (78.4 MT/ha), growers need to secure a production contract of at least $33.38/MT (column 3, in Table 2). This amount would allow growers to cover costs of production including land rent and transportation. If processors decided to cover the cost of shipment from the farm to the plant, the price required by producers to grow energy cane would fall to $29.52/MT (column 2, in Table 2). It is important to note that Iogen Corporation considered the use of a third party custom hauler for the transportation of biomass from farm to processor (Altman, *et al.*, 2007).[10] Thus, producers under this set of contractual arrangements would only be responsible for planting, growing, and harvesting the crop. As expected, increases in energy cane yield decreases the breakeven price ($/MT) required by producers. Examination of the table shows that the decrease in breakeven cost occurs at a decreasing rate; total cost per tonne is approaching average variable costs as fixed costs are spread out across more tonnes of energy cane. The ability to increase the tonnes per acre to the levels evaluated in this table is possible, and there are reports of these higher yield levels (Somerville *et al.*, 2010)

As observed in table 2, increasing energy cane yields substantially lowers breakeven prices, but this provides only part of the story; we also need to know if the breakeven prices presented in table 2 are sufficient to

[10] Iogen Corporation is a biotechnology firm specializing in cellulosic ethanol. Their corporate headquarters is located in Ottawa, Ontario, Canada. They are considering expansion into the United States in the Pacific Northwest and use wheat straw in their cellulosic ethanol process.

Table 3: Breakeven prices of biomass required to cover energy cane production costs in a six-year crop cycle at various energy cane yields

4th Stubble		
Yield/Harvested MT/ha	**Breakeven Price (Processer Paying Hauling Costs) ($)**	**Breakeven Price (Producer Paying Hauling Costs) ($)**
67.2	31.57	35.43
78.4	26.72	30.58
89.6	23.52	27.38
100.8	20.87	24.72
112.0	18.75	22.61
123.2	17.11	20.97
134.4	15.59	19.44
145.6	14.37	18.23
156.8	13.32	17.17

Table 4: Decline in breakeven prices when farmers grow energy cane on a 4th stubble as opposed to a 3rd stubble basis for various energy cane yields

Yield/Harvested MT/ha	Decline in Breakeven Price (Processer Paying Hauling Costs) ($)	Decline in Processor Costs ($/ha)
67.2	(3.03)	(203.70)
78.4	(2.57)	(201.36)
89.6	(2.20)	(197.53)
100.8	(1.94)	(195.56)
112.0	(1.73)	(193.83)
123.2	(1.57)	(192.84)
134.4	(1.43)	(192.59)
145.6	(1.31)	(190.99)
156.8	(1.23)	(193.58)

attract farmers away from producing sugar cane to producing energy cane. This requires that cellulosic ethanol processors pay a price that would generate at least as much profit as sugar cane. At current sugar prices ($0.10/kg) and expected yields (78.4 MT/ha), sugarcane producers are earning a profit of approximately $2.34/MT. This means that cellulosic ethanol producers would need to pay farmers breakeven plus $2.34 on a per tonne basis. For example, a farmer whose energy cane yield is 100.8 MT/A and works with a processor who pays hauling expense would need to receive $25.16/MT ($22.82/MT+$2.34M/T) for energy cane.

Producer Breakeven for 4th Stubbling

Table 3 shows the breakeven prices required for producers to cover production costs including rent and transportation for a six-year crop cycle (harvest through 4th stubble). As with the shorter crop cycle (Table 2), when yield increases, producers require a lower biomass price per tonne. One of the advantages for producers to switch to a longer stubbling variety is that they are able to spread fixed costs of planting over more years. This reduces the breakeven price for 4th stubble to levels below those observed for harvest through the 3rd stubble at corresponding yields. A second advantage to longer stubbling lengths is that growers harvest more energy cane. Shorter stubbling lengths require farmers to have to replant their cane fields more often, and for both the year the energy cane is planted and the subsequent year no cane is harvested. For example, changing from 3rd stubble to 4th stubble results in an additional 13.8 hectares harvested annually, for the 404.7-hectare (1,000 acre) representative Louisiana farm. As with the harvest through the 3rd stubble, cellulosic ethanol processors would need to pay energy cane producers a premium above breakeven ($2.80/MT) to make the farmers just as well off as if they had produced sugarcane.

Differences in Producer Breakeven Between 3rd and 4th Stubbling

Table 4 illustrates the decrease in breakeven prices if energy cane growers are able to increase the stubbling length from 3rd to 4th stubble. On a per tonne basis, the most significant decrease in price occurs at 67.2 MT/ha. On a per hectare basis, this would save processors $74.82 per hectare. This increase in stubbling length would save processors operating a 37.9 million litre cellulosic ethanol plant approximately $1.1 million a year.[11] The ability to increase the stubbling length is variety dependent (Brown, 2012). As more varieties with greater yields are developed the lower the breakeven price will go. As shown in Appendix A, there is a significant amount of upfront costs to establish energy cane. In Appendix A, we have provided the cost estimates utilized in this estimation. For a more accurate representation, each producer should utilize his or her own costs in equation 1 to estimate a breakeven price for his or her farm. As stubbling length increases in this equation, a larger and larger proportion of the 404.7

[11] This is assuming 67.2 mt/h and 85.8 liters of ethanol per metric ton.

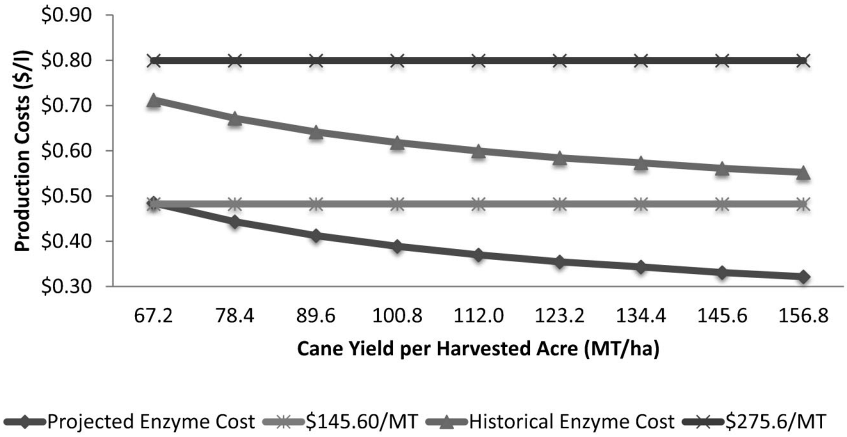

Figure 1: Comparison of ethanol production costs using corn and energy cane (harvest through 3rd stubble) feedstocks for both historical and projected enzyme costs

hectare farm will be harvested on an annual basis, because fewer acres are being left in fallow.

Corn Ethanol Production Costs vs. Cellulosic Ethanol Production Costs

While the previous results provide information on the breakeven prices required by farmers to cover various production costs given energy cane yield and stubble lengths, it is also essential that we examine the choice of ethanol feedstocks from the processors point of view. For cellulosic ethanol to be a viable ethanol production process, the cost to processors must be less than or equal to the costs of manufacturing corn ethanol. The major areas of difference between the two production processes are found in the costs of enzymes and feedstock. In particular, many of the enzymes currently being used in the cellulosic ethanol process are relatively new, and the costs of these enzymes are high. As mentioned previously, it is expected that enzyme costs will fall as more work is done in the cellulosic ethanol arena and enzyme standards are adopted. Consequently we examine both a high enzyme cost of $0.11/l (historical enzyme cost) and a low enzyme cost $0.04/l (projected enzyme cost). Figure 1 shows how cellulosic ethanol production costs compare to the production costs of traditional ethanol when corn is priced at $145.66/MT or $275.57/MT, for both historical and projected enzyme costs. Please note that in figure 1, we are assuming cellulosic ethanol uses energy cane feedstock harvested through the third stubble. Figure 2, contains a similar comparison, except here cellulosic ethanol uses energy cane feedstock harvested through the fourth stubble.

4. Conclusions

For the renewable fuels supply chain to fulfil the mandated 136.3 billion litres of annual biofuel production by 2022, feedstock sources besides corn must be integrated into the supply chain. While corn has historically dominated the ethanol industry, other demands placed on corn stocks for feed grains and human consumption when combined with limited acreage prohibits corn from meeting this mandate alone. Cellulosic ethanol, a biofuel endorsed by EISA to meet this mandate, can be made from a wide variety of feedstocks. For the Southeastern US and in particular

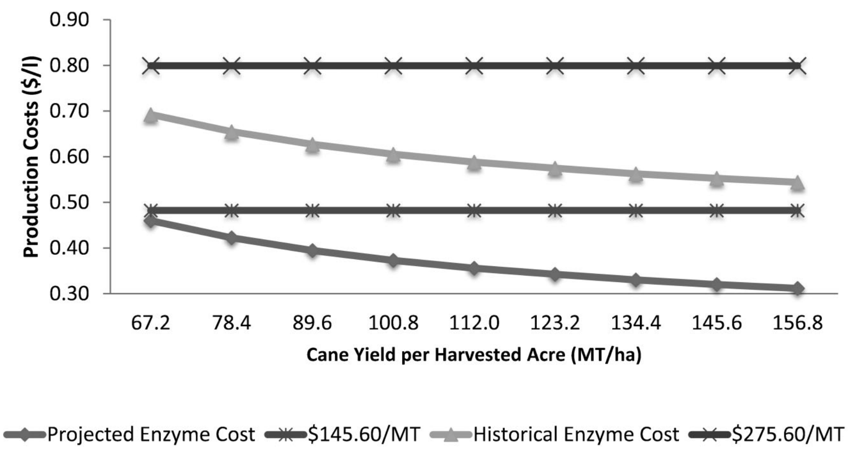

Figure 2: Comparison of ethanol production costs using corn and energy cane (harvest through 4th stubble) feedstocks for both historical and projected enzyme costs

Louisiana, energy cane is a feedstock that appears well suited to help meet this mandate.

Although farmers in Louisiana have not traditionally grown energy cane, its production similarities to sugarcane combined with farmer familiarity with sugarcane make it an attractive option for Louisiana farmers, if they are offered the 'right price' from cellulosic ethanol producers. To find this 'right price' a breakeven analysis was conducted in an effort to provide farmers and ethanol producers with economic information concerning the viability of energy cane as an alternative to sugarcane and as a source of ethanol. The results indicate that both farmers and cellulosic ethanol producers would like to have high yielding varieties with long stubbling lengths. By working with agricultural scientists to develop energy cane varieties that have longer stubbling lengths, farmers would be able to spread out the initial establishment costs of the crop.

While breakeven analysis provides the first economic screen, the breakeven amount is likely an insufficient amount of return for farmers to switch hectares from sugarcane to energy cane. Indeed, the results show that at current sugar prices ($0.10/kg) and yields (78.4 MT/ha) cellulosic ethanol producers must provide farmers an additional $2.34/MT and $2.80/MT on a 3rd and 4th stubbling, respectively if they want farmers to grow energy cane. This premium makes the net revenue on a per hectare basis from energy cane equal to what would be obtained from sugarcane production. Thus, if farmers could have only secured energy cane contracts at breakeven prices, then they would have preferred to stay with sugarcane. We would expect at high yield levels, cellulosic ethanol processors would be more inclined to offer the premium because of decreasing breakeven costs and the constant nature of the price premium.

This result more than any other indicates the need for cellulosic ethanol processors to work with agricultural scientists in developing high yielding varieties. Not only does this decrease the price paid to farmers, it also decreases the number of hectares of energy cane a potential cellulosic ethanol facility needs to operate at a minimum efficient scale (MES). Moreover, this also reduces the biomass transportation costs because there would be a large amount produced in a smaller transportation radius.

Although beyond the scope of this study, we hypothesize that once yields reach a certain threshold, processors will be able to pay the premium for any yields that exceed the threshold. This occurs because as yield increases the breakeven price declines but the premium does not change, and at the threshold yield level, breakeven plus the premium is less than the maximum amount the processor can pay and still make a profit. This model does not incorporate a risk premium for growing energy cane for biomass. The production of energy cane is risky because the market is still in its infancy, which means the market is thin. The risk for growing energy cane as a biomass feedstock is lessened relative to other feedstocks because it can be processed for sugar. Consequently, if the biomass market in the region collapses, the producer would have an alternative market for energy cane. It should be noted that it would not provide the level returns as the traditional sugarcane varieties, because the sugar content is lower than that of sugarcane.

Finally, the competitiveness of cellulosic ethanol with corn ethanol is also investigated in this study. Cellulosic ethanol production is competitive with corn ethanol utilizing projected enzyme prices, irrespective of energy cane yields, stubbling length, and/or corn prices. However, when using historical enzyme costs ($0.11/l), cellulosic ethanol is unable to compete with corn ethanol when corn prices are $145.66/MT, irrespective of energy cane yield or stubbling length. When corn reaches $275.57/MT as it did in 2007 and 2011, the production costs per litre for traditional ethanol exceed $0.79, which is more than the cost of cellulosic ethanol produced from energy cane regardless of energy cane yields or stubbling length.

As enzyme costs continue to decrease, production costs per litre for cellulosic ethanol will decline, which would improve cellulosic ethanol relative to corn ethanol as a profit centre. NREL (2007), Collins (2007), and Day (2010) find that the cost of enzymes and amount of enzymes used will continue to decrease and allow cellulosic ethanol to become more competitive. However, it should be noted that this decrease in enzyme costs would be feedstock and pre-treatment process dependent. Since 2007, enzyme costs for the lignocellulosic ethanol process have fallen by $0.06/l, which has increased the competitiveness of cellulosic ethanol. These results suggest that cellulosic ethanol derived from energy cane should be produced if sufficient biomass exists in an area to operate a MES ethanol plant.

In summary, cellulosic ethanol derived from energy cane could be a source of biofuels in Southeastern US that would help meet the 2022 RFS mandate. Varietal enhancements with respect to yield and stubbling length likely provide the quickest and easiest ways to increase the competitiveness of cellulosic ethanol. As production costs continue to fall over time, as they have done in the corn ethanol industry, cellulosic ethanol could play a pivotal role in the renewable fuel supply chain. Additional research would seek to examine the yield levels of energy cane that would allow cellulosic ethanol producers to pay energy cane farmers the premium above breakeven. The results of this research demonstrate the need for additional work that would investigate ways to increase the competitiveness of the cellulosic ethanol industry.

About the authors

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Appendix A: Variable and Fixed Cost Components for a Representative 404.7 ha Farm[1]

Field Operation	Variable Costs ($/ha)	Fixed Costs ($/ha)[1]	Total Costs ($/ha)	% of ha in each phase
Fallow Field & Seedbed Prep	$356	$219	$576	20.00%
Cultured Seed Cane	$1,290	$34	$1,325	0.06%
Hand Planting Wholestalk Seed Cane	$639	$187	$826	0.06%
Whole Stalk See Cane Harvest	$169	$128	$297	1.88%
Mechanical Planting Wholestalk Seed Cane	$560	$141	$701	18.12%
Plant Cane Field Harvest	$655	$115	$770	20.00%
1st Stubble Field Operations	$805	$129	$935	20.00%
2nd Stubble Field Operations	$791	$122	$913	20.00%
3rd Stubble Field Operations	$791	$122	$913	20.00%
Harvest for Biomass	$352	$231	$583	78.06%
Overhead	$74	$0	$74	

[1]Assumptions: 78.4 MT/ha, One-sixth land share rent, 3rd Stubbling, Hauling costs not included.