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Research article

Economic Potential for Energy Cane Production as a Cellulosic Biofuel Feedstock in the Southeastern United States

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Abstract: The Energy Independence and Security Act of 2007 established the Renewable Fuels Standard which set forth goals for domestic renewable fuel production of cellulosic and advanced biofuels in the United States. A major issue confronting the achievement of these biofuel utilization goals is the probability that the eventual expansion of advanced cellulosic biofuel production would be sufficient to meet the stated goals. Current long range projections of cellulosic biofuel production are expected to remain significantly below statutory targets due to the limited supply and expected development of cellulosic biofuel production. The production capacity expansion of advanced cellulosic biofuel has been identified as a major challenge in meeting the Renewable Fuels Standard. Energy cane has been identified as a crop with having significant potential to be developed as a biofuel feedstock crop. The greatest challenge currently facing the production of energy cane is the ability to expand production of the crop outside temperate zones. Within the six-state study area, approximately 1.15 million hectares were identified as idle cropland having the greatest potential for energy cane production. With a low seed cane expansion planting ratio and harvest through a fourth stubble crop, total energy cane production costs were estimated to be $113 per dry metric ton of feedstock. At higher planting ratios, projected total energy cane production costs were below $70 per metric ton.

Keywords: cellulosic biofuel; energy cane; biofuel feedstock production cost

1. Introduction

The Energy Independence and Security Act of 2007 (EISA) contained provisions for increasing the availability of renewable fuel production in the United States. In this legislation, the Renewable Fuels Standard set forth goals for domestic renewable fuel production: 9.0 billion gallons of renewable fuel production in 2008, rising to 36 billion gallons by 2022, with 21 billion gallons required to be produced from cellulosic ethanol and other advanced biofuels [1]. In the EISA legislation, advanced biofuel is defined as renewable fuel other than ethanol derived from corn starch that have reduced greenhouse gas emissions [2]. Cellulosic ethanol refers to ethanol derived from cellulose, hemicellulose or lignin that is derived from biomass sources. Other advanced biofuels would include ethanol derived from waste material, biomass-based diesel, biogas, and butanol and other alcohols produced through conversion of organic matter from renewable biomass. As cellulosic ethanol can be produced from a wide variety of biomass sources, agricultural crops with high biomass yields per acre, such as energy cane, represent ideal potential sources of feedstock material. With the projected expansion in the development and production of cellulosic biofuels, several issues or concerns arose related to the impacts on agricultural commodity markets and the resulting impacts on food prices of potential large-scale shifts in agricultural production related to cellulosic biofuel demand [3]. As a result, much of the focus of cellulosic biofuel research has been on developing and utilizing alternative agricultural feedstock sources which would not compete with food crops for currently utilized agricultural land.

A joint U.S. Department of Energy and U.S. Department of Agriculture study, published in 2005, estimated the potential for biomass as a feedstock for the development of a bioenergy industry in the United States [4]. This study projected that the U.S. could produce nearly one billion dry tons of biomass annually and still continue to meet food, feed and export demands. A later update to this study attempted to assess the relative economic competitiveness of energy crop production by evaluating a range of alternative biomass sources including forest biomass and wood waste products, agricultural biomass and waste resources and biomass energy crops [5]. One biomass energy crop identified with having significant potential to develop as a biofuel feedstock crop is energy cane, a type of sugarcane with high fiber content. The greatest challenge currently facing the production of energy cane as a biofuel feedstock is the ability to expand production of the crop outside temperate zones through conventional plant breeding techniques to develop varieties which are more stress and cold tolerant.

Since the Renewable Fuels Standards were established, several concerns have been raised related to such issues as the feasibility of complying with the standards, the potential impact on food and transportation fuel prices and whether achievement of production goals will actually lead to greenhouse gas emissions. In addition, one of the major issues confronting the achievement of the Renewable Fuels Standard is the probability that the expansion of advanced cellulosic biofuel production will be great enough to meet the stated goals. Commercial production of cellulosic biofuel has begun, but the levels of production are relatively minor compared to the statutory targets [6]. As a result, the U.S. Environmental Protection Agency (EPA) has had to significantly lower the renewable fuel standards for specific years due to the unavailability of sufficient biofuel volumes. For 2014, EPA proposed a cellulosic biofuel standard of only 17 million gallons, significantly lower than the original target goal of 1.75 billion gallons [7]. Current long range projections of cellulosic biofuel production are expected to remain significantly below targets due to the limited supply and expected development of cellulosic biofuel production [8]. A Congressional Budget Office report has identified the production capacity expansion of advanced cellulosic biofuel as a major challenge in meeting the Renewable Fuels Standard, highlighting the higher capital costs associated with the production and harvest of bulky cellulosic feedstock crops [9].

The general objective of this study explored the economic feasibility of using energy cane as a feedstock to supply a cellulosic biofuel industry in the southeastern United States. More specifically, the study's objective was to estimate the potential production area in the southeastern United States which might eventually produce energy cane, to estimate the total cost of producing energy cane as a biofuel feedstock and to estimate the required crop yields necessary to bring per unit production costs down to economically feasible levels. With potentially greater cold tolerance traits than commercial sugarcane varieties currently produced, energy cane has the potential to be grown in areas outside, and further north, than the current sugarcane production regions of the United States. The agronomic practices and mechanical field operations associated with energy cane production would be expected to be very similar to existing practices for sugarcane. However, because energy cane has not been traditionally produced, projected production costs and potential required yields will need to be estimated in order to determine its potential as a biomass feedstock. In the development of an eventual biomass feedstock market, prices paid by biofuel producers for energy cane feedstock would need to cover total production costs in order for energy cane to be an economically viable feedstock over the long run.

2. Methodology

2.1. Energy cane production area potential

Estimation of the potential future expanded production area of energy cane was performed by first specifying a study region where energy cane could most likely be produced and then estimating what farm acreage classification types might be feasible for energy cane production. The Agricultural Census of 2012 [10] was utilized to identify various land classification types on which energy cane could be grown, either land which currently has no existing crop production utilization as well as crop land currently being utilized by other crops on which energy cane might potentially compete for production area over the long run should production and economic conditions favor expansion of biofuel feedstock production.

For purposes of this study, six states in the southeastern region of the United States were chosen as the study area. Those six states included Alabama, Arkansas, Florida, Georgia, Louisiana and Mississippi. Energy cane could possibly be produced in other states in the southern region of the United States. However, this southeastern region comprised by these six states have similar land types and more homogenous crop production systems, allowing for a more equitable comparison and tabulation of energy cane production land potential across the entire study region. Land area estimated to have varying degrees of potential for energy cane production were aggregated into three land classifications: (1) cropland with existing agricultural crop production, (2) other cropland not being utilized including idle land, failed crop land, and land in summer fallow and (3) permanent pasture.

2.2. Required acres for planting and succeeding harvest acres

Production of energy cane as a biofuel feedstock would be expected to be produced in a manner similar to sugarcane. The crop would be planted vegetatively, with a seed cane expansion process analogous to that conducted in sugarcane production. Being a perennial crop, several years of harvest would be expected from one initial planting. The first crop harvested after planting, commonly referred to as the "plantcane crop", would be harvested in the year following the initial planting. Succeeding crop harvests are referred to as "stubble crops". The second harvest after planting is referred to as the "first stubble crop," the succeeding harvest is the "second stubble crop," and so on. In the analysis presented here, energy cane feedstock production costs are estimated for two assumed potential crop cycle lengths: a nine-year crop cycle with biomass harvest through fourth stubble and an eleven-year crop cycle with biomass harvest through sixth stubble. The first few years of each crop cycle are devoted to seed cane expansion followed by the specified years of biomass harvest. The primary purpose of analyzing these two different potential crop cycle lengths is to evaluate the impact of greater energy cane crop stubbling ability on the resulting crop production costs per feedstock unit.

Seed cane expansion in energy cane production, as in sugarcane production, would likely involve a two-step process of expanding an initial purchased quantity of seed cane into a larger volume to be planted for biomass harvest. Each step of this expansion process involves the harvest of seed cane and then using this harvested quantity to plant an expanded land area. Planting ratio (PR) is the relationship between land area units of cane planted from the harvest of one land area unit of seed cane. For example, a planting ratio of 6:1 would indicate that the volume of cane harvested from one land area unit of seed cane would be sufficient to plant 6 land area units. Planting ratios are a function of harvested cane tonnage yield per land area. Higher cane tonnage yields would result in higher planting ratios, as the planting rate volume of cane planted per land area remains relatively constant.

A mathematical model relating the initial planting of energy cane to the seed cane expansion process and to the eventual land area of cane planted for biomass harvest over an entire crop cycle from the initial planting of one land area unit is presented below. Land area units in the seed cane expansion process can be presented in terms of either acres or hectares. Initiation of energy cane production harvest as a biofuel feedstock would begin with an initial planting of cultured seed cane purchased from a commercial seed cane provider. Equation 1 below represents the planting of one land area unit (acre or hectare) of purchased energy cane seed cane where CSP_1 is the land area planted in cultured seed cane in year 1.

Initial cultured seed cane planting:

$$CSP_1 = 1.0 \tag{1}$$

Equations 2−5 depict the two-stage seed cane expansion process from harvest of the cultured seed cane plantcane crop initially planted in year 1. Land area of cultured seed cane planted in year 1 (CSP_1) are harvested in year 2 and replanted as propagated seed cane using a planting ratio expansion factor of PR1:1. The following year, the propagated seed cane is harvested and replanted as biomass cane using a planting ratio expansion factor of PR2:1.

Plantcane seed cane expansion:

$$CSH_2 = CSP_1 \tag{2}$$

$$PSP_2 = CSH_2 * PR1 \tag{3}$$

$$PSH_3 = PSP_2 \tag{4}$$

$$BP_3 = PSH_3 * PR2 \tag{5}$$

where CSH_2 = area of cultured seed cane harvested in year 2, PSP_2 = area of propagated seed cane planted in year 2, PR1 = planting ratio of the first seed cane expansion, PSH_3 = area of propagated seed cane harvested in year 3, BP_3 = area of energy cane for biomass harvest planted in year 3 and PR2 = planting ratio of the second seed cane expansion.

Equations 6−9 depict the two-stage seed cane expansion process from harvest of the cultured seed cane first stubble crop initially planted in year 1. Area of cultured seed cane planted in year 1 (CSP_1) are harvested in year 3 and replanted as propagated seed cane using a planting ratio expansion factor of PR1:1. The following year, the propagated seed cane is harvested and replanted as biomass cane using a planting ratio expansion factor of PR2:1.

First stubble seed cane expansion:

$$CSH_3 = CSP_1 \tag{6}$$

$$PSP_3 = CSH_3 * PR1 \tag{7}$$

$$PSH_4 = PSP_3 \tag{8}$$

$$BP_4 = PSH_4 * PR2 \quad (9)$$

where CSH_3 = area of cultured seed cane harvested in year 3, PSP_3 = area of propagated seed cane planted in year 3, PR1 = planting ratio of the first seed cane expansion, PSH_4 = area of propagated seed cane harvested in year 4, BP_4 = area of energy cane for biomass harvest planted in year 4 and PR2 = planting ratio of the second seed cane expansion. The complete energy cane seed cane expansion process and planted area for biomass harvest, illustrated using one initial land area unit of seed cane planting, is depicted in Table 1. Total land area required for planting of seed cane for one complete crop cycle through the full seed cane expansion process can be stated as follows:

$$TBP = CSP_1 + PSP_2 + BP_3 + PSP_3 + BP_4 \quad (10)$$

where TBP represents the total seed cane area required for energy planting for one complete crop cycle.

Table 1. Energy cane for biomass seed cane expansion and planted area.

Seed Cane Expansion Operation	Year 1	Year 2	Year 3	Year 4
	(land area unit)			
(a.) Plant initial seed cane	1			
(b.) Harvest initial seed cane		1	1	
(c.) Plant first seed cane expansion[1]		6	6	
(d.) Harvest first seed cane expansion			6	6
(e.) Plant second seed cane expansion[1]			36	36
(f.) Total area of energy cane planted[2]	1	6	42	36

[1] Planting ratio of 6:1—one seed cane acre harvested will provide sufficient seed cane to plant six acres.
[2] Beginning with one initial acre of seed cane planted, total area required for planting would equal 85.0 acres (34.4 hectares).

From the initial multi-year crop establishment planting phase, land area of planted energy cane would then be available for harvest as biofuel feedstock. Plantcane crops would be harvested in the year following planting. First stubble through fourth stubble crops would be harvested in the second through fifth years following planting. Total area harvested over one crop cycle through fourth stubble (nine-year total crop cycle) is specified below.

Biomass area harvested:

$$BPCH = BP_3 + BP_4 \quad (11)$$

$$B1SH = PSP_2 + PSP_3 + BP_3 + BP_4 \quad (12)$$

$$B2SH = CSP_1 + PSP_2 + PSP_3 + BP_3 + BP_4 \quad (13)$$

$$B3SH = CSP_1 + PSP_2 + PSP_3 + BP_3 + BP_4 \quad (14)$$

$$B4SH = CSP_1 + PSP_2 + PSP_3 + BP_3 + BP_4 \quad (15)$$

$$TBH = BPCH + B1SH + B2SH + B3SH + B4SH \quad (16)$$

where BPCH = total area of plantcane harvested for biomass over the crop cycle, B1SH = total area of first stubble harvested for biomass over the crop cycle, B2SH = total area of second stubble harvested for biomass over the crop cycle, B3SH = total area of third stubble harvested for biomass over the crop cycle, and B4SH = total area of fourth stubble harvested for biomass over the crop cycle.

2.3. Energy cane feedstock production costs

Total costs associated with the production of energy cane include variable production costs, fixed and overhead production costs and land rent. Variable energy cane production costs were estimated as the sum of crop establishment costs and biomass cultivation and harvest costs. In the cost estimation results presented in this analysis, costs of transporting harvested energy cane from the field to a processing facility were excluded, as this cost would be expected to be paid by the biofuel processor analogous to transportation cost arrangements in the sugarcane industry. In the Louisiana sugarcane production industry for example, transportation costs of hauling the harvested sugarcane from farms to mills are paid by the mills processing the sugarcane, either to the producer or an independent trucker, whoever hauls the cane. Using the seed cane expansion process outlined above, the total variable cost of crop establishment was estimated as the sum of area devoted to specific seed cane planting or harvesting operations multiplied by their respective variable cost per land area. Published production cost estimates for sugarcane for 2014 were utilized in this estimation [11]. The net present value of these total variable costs were estimated, over an example nine-year and eleven-year crop cycle, using an 8% discount rate and then were annualized using the annuity formula $A = PV\ [0.08/(1-(1.08)^{-n})]$. This annualized value was then divided by the average area per year devoted to crop establishment to result in an annualized crop establishment cost per hectare.

Fixed and general farm overhead expenses published in sugarcane commodity budget reports typically include depreciation and interest on equipment and are commonly allocated per land area unit on an hourly basis and therefore, they do not take into account a specific farm size. General farm overhead costs includes expense charges for such items as interest, accounting services, farm shop expenses and other charges. In order to calculate total energy cane production costs in this study, a fixed and overhead cost value of $445 ha^{-1} was assumed, similar to corresponding cost values on commercial sugarcane farms [11]. In addition, given the fact that the majority of energy cane would likely be produced on leased farm land, land rent must also be included as a production expense. This study assumed that land rent for energy cane production would be charged at a rate of 16.7% (one-sixth crop share) of the total biomass production value. Since biofuel feedstock prices are not readily available, due in part to the lack of an established feedstock commodity market, the value of land rent as a production cost was determined by estimating the breakeven price required to cover total specified production costs and then estimating a percentage crop share value as the land rent expense.

$$BBP = (TVC + TFC + TOC) / (TPRD * GRSH) \quad (17)$$

$$LDRT = TPRD * BBP * LDSH \quad (18)$$

The variable BBP is the estimated breakeven biomass farm level market price in dollars per ton, TPRD is the total production of biomass in tons over one crop cycle, TVC, TFC, and TOC represent total farm variable, fixed and overhead costs, GRSH is the grower's share of crop value, LDSH is the landowner's share of crop value and LDRT is the total land rent charge for the whole farm. In traditional sugarcane production, the mill's share (charge) for processing the sugarcane into raw sugar is taken out of the yield. The mill, grower and landlord each receive the same raw sugar market price for their respective shares of production. In the analysis presented here for energy cane feedstock production, the processor's charge (share) for converting the biomass into biofuel is assumed to be taken out of the biomass price paid. Land rent charges are assumed to be a percentage crop share lease with the landlord receiving a share of the biomass production valued at the net price paid by the processor.

3. Results

Tabulations of potential agricultural land available for the establishment of energy cane production is shown in Table 2 for three categories of farm land across the six-state study region. Land area classifications tabulated included existing cropland in production of various agricultural crops, existing idle cropland and other cropland not currently in production, and permanent pasture which would have potential to be converted to cropland. The expected potential degree to which energy cane production could be established would vary significantly across these three land types. Feedstock crop production could be most easily established on idle cropland and other cropland currently not utilized in crop production. This land area category contains 1.15 million hectares over the six-state region with no existing agricultural crops in production which would compete for planted area with energy cane. Several factors would be expected to have a significant influence on the development of energy cane production on these land tracts in a given locality including the yield potential of energy cane on marginal lands as well as the ability to concentrate a sufficient quantity of energy cane production in close proximity to a biofuel processing facility which would transport the harvested biomass to the facility for conversion to biofuels and other bio-based products.

Approximately 5.67 million hectares of permanent pasture are available in the region. There would be some expense involved in converting pastureland to cropland and it would be expected that a relatively small percentage of permanent pasture might be converted for energy cane production. The largest land category is total cropland currently in agricultural production, totaling 10.92 million hectares. Energy cane, and any other potential biofuel feedstock crop, would have to compete with existing crops for planted area on this cropland category. As the cellulosic biofuel industry in the United States develops over the next several years, how the biofuel feedstock commodity market and price discovery process evolves will have a significant influence on the likelihood of feedstock crops competing with traditional agricultural crops for planted area in various regions.

Table 2. Potential agricultural land available for energy cane feedstock production.

State	Total Cropland *(hectares)*	Other Cropland[1] *(hectares)*	Permanent Pasture *(hectares)*
Alabama	1,116,335	179,279	918,360
Arkansas	3,209,610	175,539	1,264,094
Florida	1,110,484	113,987	1,517,430
Georgia	1,696,006	182,338	555,972
Louisiana	1,730,290	247,213	703,614
Mississippi	2,054,016	252,101	708,820
Total	10,916,741	1,150,457	5,668,291

[1] Includes idle cropland, summer fallow, and failed or abandoned cropland.

Source: 2012 Agricultural Census, National Agricultural Statistics Service, USDA.

Projected variable feedstock production costs for a nine-year energy cane crop cycle is shown in Table 3. This production scenario represents a crop cycle with harvest through a fourth stubble crop (five years of harvest following initial crop establishment). Estimates of area required for planting and harvest, as well as projected crop establishment, cultivation and harvest costs, are shown for a range of potential energy cane planting ratios. Total required acres for seed cane planting was determined using equation 10 while total area harvested for biomass was determined using equation 16. Higher planting ratios, which are a function of energy cane tonnage production yields, greatly enhance the ability of establishing and expanding energy cane production as rapidly as possible. With a 6:1 planting ratio, expanded seed cane area would result in a total of 166.3 hectares of energy cane biomass available for harvest over the crop cycle compared with a planting ratio of 14:1 which would yield an estimated 839.7 total hectares of energy cane production available for harvest as biomass. As expected, estimated variable production costs per land area unit did not vary greatly over the range of alternative planting ratios, with annualized total variable cost over the entire crop cycle of approximately $1,080 per hectare.

Total production area of energy cane could be increased quicker if, for example, only one seed cane expansion would performed. Assuming a 67.2 Mg/ha energy cane harvest yield and a 6:1 planting ratio, eliminating first stubble seed cane expansion and performing only one seed cane expansion, annualized total variable costs would be estimated to be approximately $1218 per hectare. In this situation, only 5.5 hectares of seed cane area, rather than 34.4 hectares, would be required to yield the same total area of harvested biomass over the crop cycle (166.3 hectares). With a higher average harvest yield, resulting from less area devoted to seed cane expansion, annualized variable cost per wet ton of energy cane harvested would be approximately $19.31 per wet ton, compared with an estimate of $21.91 per ton with the two stage seed cane expansion. This cost reduction from a shortened seed cane expansion process would only be realistically possible in a commercial farm production situation if there were a significantly reduced threat of plant disease occurrence. The primary purpose of the extended seed cane expansion process is to reduce the threat of plant disease spread which reduces yield, particularly in the stubble crops.

Table 3. Projected variable feedstock production costs for a 9-year crop cycle through harvest of 4th stubble crop[1].

Planting Ratio	Total Required Area for Seed Cane[2] *(hectares)*	Total Area Harvested for Biomass[3] *(hectares)*	Annualized Crop Establishment Costs *($/hectare)*	Annualized Cultivation and Harvest Costs *($/hectare)*	Annualized Total Variable Costs *($/hectare)*
6:1	34.4	166.3	$211	$872	$1,083
8:1	58.7	286.1	$202	$878	$1,080
10:1	89.4	438.3	$197	$881	$1,078
12:1	126.7	622.8	$194	$883	$1,077
14:1	170.4	839.7	$191	$885	$1,076

[1] Harvest through 4th stubble includes five years of harvest from initial planting.
[2] From one initial acre (0.4 hectares) of cultured seed cane planted in year 1.
[3] Total biomass harvested acreage over entire crop cycle.

Similar production area and variable cost estimates are shown for an eleven-year crop cycle through harvest of a sixth stubble crop in Table 4 to illustrate the impact of extension of the crop cycle which would be expected with increases in harvested energy cane yields. In this scenario, planted energy cane area is kept in production for an additional two years of harvest. Total area required for seed cane planting remains unchanged, however, extension of the crop cycle for two additional years increases the total area harvested for biomass over the entire crop cycle. Extension of the crop harvest cycle length by two years in this example increased the projected total area available for biomass harvest by approximately 41% over the scenario in Table 3 through harvest of a fourth stubble crop. In addition, although the projected total variable production cost per area remained relatively unchanged in Table 4, crop establishment cost per hectare is lower and cultivation and harvest cost per hectare is higher due to the fact that in a longer crop cycle a lower percentage of total land area is devoted to seed cane expansion and a higher percentage of land area is devoted to biomass harvest.

Table 4. Projected variable feedstock production costs for an 11-year crop cycle through harvest of 6th stubble crop[1].

Planting Ratio	Total Required Area for Seed Cane[2] *(hectares)*	Total Area Harvested for Biomass[3] *(hectares)*	Annualized Crop Establishment Costs *($/hectare)*	Annualized Cultivation and Harvest Costs *($/hectare)*	Annualized Total Variable Costs *($/hectare)*
6:1	34.4	235.1	$169	$927	$1,096
8:1	58.7	403.5	$162	$930	$1,092
10:1	89.4	617.1	$158	$932	$1,090
12:1	126.7	876.1	$155	$934	$1,089
14:1	170.4	1,180.5	$153	$935	$1,088

[1] Harvest through 6th stubble includes seven years of harvest from initial planting.
[2] From one initial acre (0.4 hectares) of cultured seed cane planted in year 1.
[3] Total biomass harvested acreage over entire crop cycle.

In Table 5, projected values for variable and total energy cane feedstock production costs per ton of dry matter is shown for alternative planting ratios and projected energy cane yields for the nine-year crop cycle. Required energy cane yields were estimated utilizing the specific planting ratios listed and then determining the harvested yield necessary to achieve that planting ratio while playing a constant quantity of seed cane per land area (11.21 Mg/ha). Field biomass yields for energy cane generally decline with the age of stubble crops. In the analysis presented here, required energy cane field yield represents the average harvested biomass yield over all area harvested, including plant cane and stubble crops harvested on the farm in a given year. A farming operation would be harvesting plant cane and stubble crops in a given year, utilizing a small percentage of harvested energy cane as seed cane. As a result, average yield over all harvested area is the relevant yield factor to use when estimating required area for seed cane and biomass. With a 6:1 planting ratio and a projected required energy cane yield of 67.2 Mg/ha, total energy cane production costs were estimated to be $113.75 per dry ton of feedstock. These total estimated production costs include charges for variable costs, fixed costs, general farm overhead expenses and land rent. In order to reduce this projected feedstock cost, higher energy cane yields would be required. With a 12:1 and 14:1 planting ratio, projected crop yields would need to exceed 130 Mg/ha in order to reduce projected total production costs below $70 per metric ton.

The impact of extending the crop production cycle, in this case by two additional years with harvest through a sixth stubble crop, on projected total feedstock costs are shown in Table 6. With average projected energy cane harvest yields remaining the same and only extending the energy cane harvest by two more years from an initial planting, projected total feedstock production costs per dry ton of biomass material was estimated to be reduced by approximately 11%. The primary cause of this reduction in production cost per land area from an extended crop cycle is the reduction in total planting costs attributed to each hectare of biomass harvested. Therefore, higher biomass harvest yields, by increasing the planting ratio and extending the production crop cycle, are the primary factor which can have the greatest impact in lowering biofuel feedstock production costs per unit.

Table 5. Projected variable and total production costs per dry ton of biomass feedstock for a 9-year crop cycle through harvest of 4th stubble crop[1].

Planting Ratio	Required Energy Cane Field Yield[2] *(Mg/ha)*	Total Quantity of Biomass Produced Over Crop Cycle *(Mg)*	Annualized Variable Costs per Wet Ton of Feedstock *($/Mg)*	Annualized Variable Costs per Dry Ton of Feedstock[3] *($/Mg)*	Annualized Total Costs per Dry Ton of Feedstock[4] *($/Mg)*
6:1	67.2	10,206	$21.91	$99.60	$113.75
8:1	89.7	23,333	$17.79	$80.88	$91.68
10:1	112.1	44,588	$15.37	$69.88	$78.69
12:1	134.5	75,931	$13.78	$62.63	$70.12
14:1	156.9	119,322	$12.65	$57.50	$64.05

[1] Harvest through 4th stubble includes five years of harvest from initial planting.
[2] Estimated yield required to achieve specified planting ratio at current seed cane planting rates (app. 11.2 MG/ha).
[3] Cost per dry ton estimated using a fiber content factor of 22%.
[4] Total production costs include variable costs as well as charges for fixed costs, general farm overhead and land rent.

4. Discussion

In regard to the potential location of energy cane production for use as a biofuel feedstock, two issues are worth further discussion. The first issue is related to suitable soil types on which energy cane, or any other biofuel feedstock crop, could be produced while achieving crop yields that are agronomically and economically feasible. A great deal of current agronomic research is directed toward the production of feedstock crops on marginal soils, such that the production of these crops would not compete for land with food crop production. Production of feedstock crops on marginal or idle land is intuitive given the ready availability of that land for crop production. However, feedstock crops such as energy cane have nutrient requirements just like other crops do and would be expected to achieve higher crop yields on better soils. The agronomic challenge will be to develop new varieties of feedstock crops which can achieve acceptable levels of crop yields on marginal soils.

Table 6. Projected variable and total production costs per dry ton of biomass feedstock for an 11-year crop cycle through harvest of 6th stubble crop[1].

Planting Ratio	Required Energy Cane Field Yield[2] *(Mg/ha)*	Total Quantity of Biomass Produced Over Crop Cycle *(Mg)*	Annualized Variable Costs per Wet Ton of Feedstock *($/Mg)*	Annualized Variable Costs per Dry Ton of Feedstock[3] *($/Mg)*	Annualized Total Costs per Dry Ton of Feedstock[4] *($/Mg)*
6:1	67.2	13,499	$19.46	$88.45	$100.95
8:1	89.7	30,917	$15.81	$71.84	$81.37
10:1	112.1	59,148	$13.66	$62.10	$69.87
12:1	134.5	100,806	$12.25	$55.69	$62.30
14:1	156.9	158,503	$11.25	$51.15	$56.93

[1] Harvest through 6th stubble includes seven years of harvest from initial planting.

[2] Estimated yield required to achieve specified planting ratio at current seed cane planting rates (app. 11.2 MG/ha).

[3] Cost per dry ton estimated using a fiber content factor of 22%.

[4] Total production costs include variable costs as well as charges for fixed costs, general farm overhead and land rent.

The second issue regarding the location of feedstock crop production is directly related to the location and processing capacity of potential biofuel plants which would utilize these feedstock crops as input. Heavy tonnage feedstock crops such as energy cane are comprised of mostly water. The dry matter content of these crops is relatively low. Transportation costs of these crops, as harvested in the field, will be a major limitation on the distances harvested feedstock crops can be economically transported to a processing facility. This will eventually have a direct impact on potential locations at which processing facilities could be constructed. As is the case with sugarcane processing, biofuel feedstock processing facilities will be a relatively high fixed cost enterprise, requiring large volumes of feedstock transported to the facility for processing on an annual basis at relatively low cost.

In terms of whether the production of energy cane as a biofuel feedstock crop will be able to expand to commercially feasible operational size and scale, the development of higher yielding varieties of feedstock crops is of primary importance. Higher harvested tonnage yields of energy cane, for example, will allow for greater planting ratios as well as longer crop cycles. In the analysis presented here, projected (required) energy cane yields were estimated which would achieve the desired increased levels of planting ratios. These required harvest yields were estimated assuming that the planting rate of energy cane remained at current assumed levels of approximately 11.2 Mg/ha. Lower planting rates would permit higher planting ratios. However, there is limited research available regarding the range of production area where lower planting rates would result in acceptable stands of energy cane production. Current agronomic research to date suggests that currently expected crop yields are not sufficient to achieve desired reductions in feedstock crop production costs per dry matter unit [12,13,14]. For the five energy cane varieties evaluated at the Sugar Research Station in St. Gabriel, Louisiana from 2009 to 2013, the estimated energy cane field yield for the plant cane through fourth stubble crops averaged only 92.0 Mg/ha, including a high average yield of 138.0 Mg/ha for second stubble and a low average yield of 77.3 Mg/ha for fourth stubble [12]. The highest yielding energy cane variety included the study only averaged 113.9 Mg/ha over the plant cane through fourth stubble crops, reaching an average yield plateau of 162.3 Mg/ha on the second stubble crop and declining thereafter.

Finally, the establishment of a sufficient volume of feedstock production which would supply a processing facility in a given area will depend upon the formation of an average feedstock market price level which would be high enough to cover total feedstock crop production costs over the long run. Given the uncertainty regarding expected crop yields and production costs at the present time, biofuel processing facilities may need to acquire adequate supplies of feedstock material through some contractual means, whereby the input prices paid for feedstock would be a function of the production costs incurred to produce and transport the crop. These contractual acquisitions of feedstock material will probably need to remain the primary means of feedstock acquisition until a large enough area is under production whereby a feedstock commodity market can be established providing market price discovery for both producers and processors.

5. Conclusions

In this study, the economic potential of the production of energy cane as a cellulosic biofuel feedstock was evaluated for processing facilities which would be located in a six-state region of the southeastern United States. Specific objectives of the study included the identification of the scale of production areas which might be suitable for energy cane production across various land use categories as well as the estimation of total feedstock production costs per dry matter unit over a range of potential harvest yields and seed cane expansion planting ratios.

According to 2012 Agricultural Census data, the six-state region currently contains a total of 1.15 million hectares of idle or otherwise unused cropland. Energy cane could potentially be produced on this area without competing with existing food crops for land production area. In addition, approximately 5.67 million hectares of permanent pasture currently exist in the region. Portions of this area could potentially be converted to energy cane production without competing with food crop production. However, conversion of pasture land to crop land for feedstock production would require additional expenses for land conversion in addition to production costs for the feedstock crop itself. Any future utilization of alternative land classification types for feedstock crop production would be directly related to having an average feedstock material market price paid to producers which would be sufficient to cover total production costs and provide a return above costs to feedstock producers over the long run.

Projected total feedstock production costs were estimated over a range of alternative potential crop harvest yields and seed cane planting ratios. Annualized total production costs of producing energy cane as a biofuel feedstock where found to decline significantly as expected harvest yield increased. Energy cane harvest yields of over 134.5 Mg/ha were required to bring total production costs below approximately $70 per ton of dry matter for a five-harvest crop cycle and below approximately $60 per ton for a seven-harvest crop cycle. As agronomic research on energy cane production continues and is expanded to more areas of the country, the accuracy of the level of expected yields and associated production costs per unit will improve. The ultimate ability of advanced cellulosic biofuels to compete in the market place with existing fuels will depend greatly on the eventual level of cellulosic feedstock production costs per unit of dry matter as well as the feedstock to biofuel conversion costs.

Conflict of Interest

All authors declare no conflicts of interest in this paper.

References

1. Congressional Research Service (2007) Energy Independence and Security Act of 2007: A Summary of Major Provisions. RL34294.
2. Energy Independence and Security Act of 2007, Public Law 110–140, U.S. Government Printing Office, Dec. 19, 2007.
3. Yacobucci BD, Capehart T (2009) Selected Issues Related to an Expansion of the Renewable Fuel Standard. Congressional Research Service. R40155.
4. Perlack RD, Wright LL, Turhollow AF, et al. (2005) Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Available from: http://www1.eere.energy.gov/bioenergy/pdfs/final_billionton_vision_report2.pdf.
5. U.S. Department of Energy (2011) U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. Available from: http://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf.
6. Energy Information Administration (2013) Cellulosic Biofuels Begin to Flow but in Lower Volumes than Statutory Targets. Today in Energy. U.S. Department of Energy, February 2013. Available from: http://www.eia.gov/todayinenergy/detail.cfm?id=10131#.

7. Environmental Protection Agency (2013) EPA Proposes 2014 Renewable Fuel Standards, 2015 Biomass-Based Diesel Volume. Available from: http://www.epa.gov/otaq/fuels/renewablefuels/documents/420f13048.pdf
8. Energy Information Administration (2014) Annual Energy Outlook 2014, With Projections to 2040. U.S. Department of Energy. Available from: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.
9. Congressional Budget Office (2014) The Renewable Fuel Standard: Issues for 2014 and Beyond. Available from: https://www.cbo.gov/publication/45477.
10. U.S. Department of Agriculture (2014) 2012 Census of Agriculture. United States Summary and State Data, Volume 1 Geographic Area Series—Part 51, AC-12-A-51. Available from: http://www.nj.gov/agriculture/news/hottopics/approved/topics071218.html
11. Salassi ME, Deliberto M, Hilbun BM (2014) Projected Costs and Returns—Sugarcane, Louisiana, 2 014. LSU Agricultural Center, Dept. of Agricultural Economics and Agribusiness, A.E.A. Informati on Series No. 295 January 2014. Available from: http://www.lsuagcenter.com/NR/rdonlyres/4B534 BE5-00EF-47E5-852B-955FAB2B31CF/97408/2014SugarBudgets .pdf
12. Gravois K, Fontenot D, Kimbeng C, et al. (2013) Yield and Fiber Content of High-Fiber Sugarcane Clones. Sugarcane Research Annual Progress Report. Sugar Research Station, Louisiana State University Agricultural Center.
13. Lemus R, Baldwin B, Lang D (2011) Agronomic Suitability of Bioenergy Crops in Mississippi. Mississippi State University Extension Service, Pub. No. 2713. Available form: http://msucares.com/pubs/publications/p2713.pdf
14. Viator RP, Richard Jr EP (2012) Sugar and Energy Cane Date of Planting Effects on Cane, Sucrose and Fiber Yields. *Biomass Bioenerg* 40: 82−85.