Economic Feasibility of Ethanol Production from Sweet Sorghum Juice in Texas

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Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meetings, Atlanta, Georgia, January31-February 3, 2009

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Abstract

The economic feasibility of producing ethanol from sweet sorghum juice is projected using Monte Carlo simulation models to estimate the price ethanol plants will likely have to pay for sweet sorghum and the uncertain returns for ethanol plants. Ethanol plants in high yielding regions will likely generate returns on assets of 11%-12% and in low yield areas the returns on assets will be less than 10%.

Ethanol first gained popularity as an energy source in response to the oil embargos of the 1970's and the resulting oil and gasoline price increases. Government support fueled industry growth through the mid 1980's until oil and gasoline prices retreated, collapsing the market for ethanol. Much like then, increasing oil and gasoline prices, and the topic of energy security, were instrumental mechanisms in the revival of the ethanol industry over the last few years. As of January 2009, there are 172 ethanol plants in the U.S. with a combined capacity of over 10 billion gallons (Renewable Fuels Association 2009).

Corn is currently the feedstock of choice for U.S. ethanol producers. Increasing ethanol production led to higher domestic corn utilization, as it is also widely used in the food and livestock sectors. This, coupled with other factors such as the value of the dollar and investment markets, has contributed to corn prices rising to some of the highest levels in U.S. history. Farmers responded to high corn prices by shifting planted acres to corn, which has caused ripple effects across other crops, contributing to higher price levels of competing crops. As a result, public and political interest has escalated for the production of ethanol from sources other than corn.

Economic research has explored various alternative ethanol production technologies. Progress has been made with respect to biochemical and thermochemical technologies for cellulosic ethanol, yet the ability to reach commercial viability continues to elude the industry. Herbst (2003), Shapouri, Salassi, and Fairbanks (2006), Ribera et al. (2007a), Salassi (2007), and Outlaw et al. (2007) have examined the economic feasibility of ethanol production from grain sorghum and corn, sugar, sugarcane juice and molasses, sugar, and sugarcane juice, respectively. Studies by Epplin (1996), Graham, English, and Noon (2000), and Mapemba et al. (2007) have explored transportation, harvest, and delivered feedstock cost components of biomass used for cellulosic ethanol. Outlaw et al. (2007) conclude ethanol production from sugarcane juice, a predominant production method in Brazil, would be economically feasible in certain regions of the United States. However, sugar policy has left little opportunity for this method to gain traction in the United States.

Sweet sorghum, grown as an alternative to sugarcane, has been identified as a potential dedicated energy crop that can be grown as far north and south as latitude 45° (Rooney et al. 2007). During very dry periods, sweet sorghum can go into dormancy, with growth resuming when sufficient moisture levels return (Gnansounou, Dauriat, and Wyman 2005). Several varieties of sweet sorghum have been developed ranging in size, yield, and intended use. The Mississippi Agricultural and Forestry Experiment Station and the United States Department of Agriculture developed several sweet sorghum varieties (2008). The four varieties that were developed, Dale (1970), Theis (1974), M81-E (1981), and Topper 76-6 (1994), have different maturity lengths, seed weights, and juice and dry matter yields. Rooney et al. (1998; 2007), at Texas A&M University, has developed and is testing hybrid sweet sorghums for biomass and energy production. Additionally, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is developing sorghum varieties specifically for ethanol production (2007).

Sweet sorghum is a variety of sorghum that has a high concentration of soluble sugars in the juice. Characteristics of high fermentable sugars, low fertilizer requirement, high water use efficiency (1/3 of sugarcane and 1/2 of corn), short growing period, and the ability to adapt well to diverse climate and soil conditions make sweet sorghum a potential feedstock for ethanol production (Wu et al. 2008). While single-cut yields may be low, an increased growing season increases cumulative yields due to the ratoon potential of the crop (Rooney et al. 2007). As shown in Table 1, this disparity is evident when comparing yields across climatic zones in Texas. See Figure 1 for a map showing the locations referenced in Table 1.

Table 1: Annual Average Sweet Sorghum Yields, Frost Free Days, Growing Days, and Yield Disparity Across Study Areas.

	Willacy	Wharton	Hill	Moore
Average Sweet Sorghum Yield (tons/ac	137	47	33	24
Average Days without a Freeze				
Minimum	232	205	192	129
Mean	303	243	225	171
Maximum	365	293	286	194
Average Growing Days Between Harvests				
Between Planting and First Cut	105	107	123	135
Between First Cut and Second Cut	60	77	90	90
Between Second Cut and Third Cut	60	77	90	90
Average Yield Disparity Between Harvests				
Second Cut Fraction of First Cut	0.7	0.7	0.7	0.7
Third Cut Fraction of First Cut	0.5	0.5	0.5	0.5

Research has suggested sweet sorghum juice as a potential feedstock for ethanol production (Gibbons et al. 1986; Venturi and Venturi 2003; ICRISAT 2007; Prasad et al.

2007; Rooney et al. 2007). Worley, Vaughan, and Cundiff (1992) estimated the energy costs for producing sweet sorghum as a potential feedstock for ethanol production in Virginia. Research at Oklahoma State University's Food and Agricultural Products Center (2006) has estimated the feasibility of ethanol production from sweet sorghum juice using an experimental, in-field ethanol production process. Additionally, research has shown that sweet sorghum bagasse can be utilized as a fuel source for electricity generation (Blottnitz and Curran 2007; Gnansounou, Dauriat, and Wyman 2005; Monti and Venturi 2003).

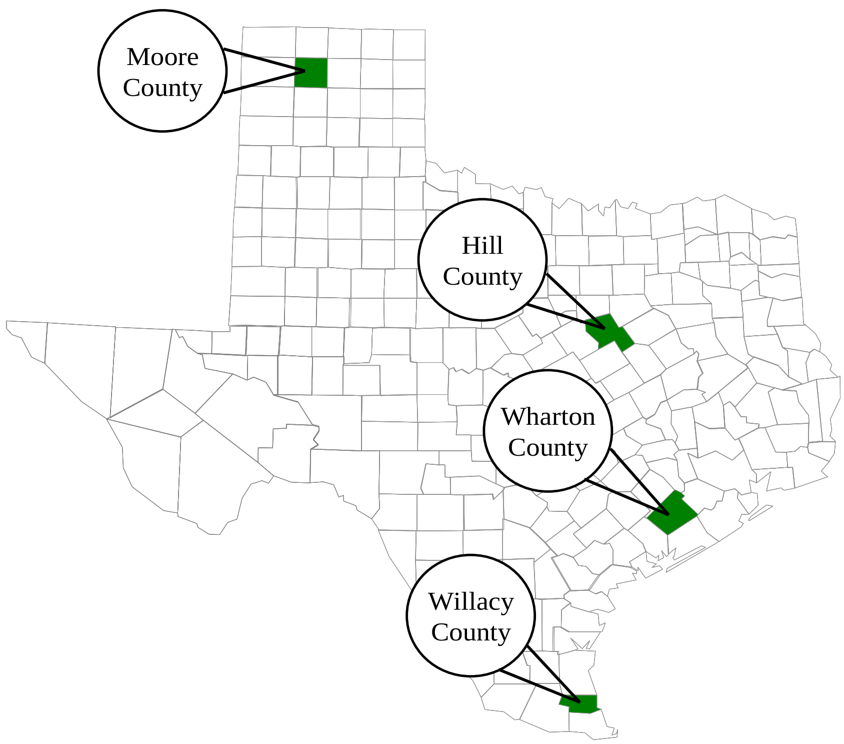


Figure 1: Regions in Texas Selected to Analyze Sweet Sorghum Production.

No published studies are currently available that evaluate the economic feasibility of ethanol production from sweet sorghum juice using commercially available large-scale technologies. The objective of this research is to assess the economic feasibility of a large scale ethanol firm using sweet sorghum juice in three growing regions of Texas.

This study examines multiple feedstock scenarios: (1) sweet sorghum and molasses, (2) sweet sorghum with corn, and (3) corn. Feedstock production, harvest, and transportation costs were modeled for each region to account for regionally specific conditions. Producing ethanol from sweet sorghum juice is limited to the duration of the harvest period, as research has shown that as much as 20 percent of the fermentable sugars can be lost in three days after harvest under typical (room temperature) storage conditions (Wu et al. 2008).

Study Areas

Three regions in Texas were selected to analyze sweet sorghum ethanol production across variable climatic conditions: Willacy County, Wharton County, and Hill County (Figure 1). A fourth region, Moore County, was also considered, but eliminated because the shorter growing season did not provide even a small probability of economic success. Current crop production alternatives in each region were compared to growing sweet sorghum to estimate the minimum price a plant must pay producers to grow sweet sorghum. These cropping alternatives are: irrigated cotton and grain sorghum in Willacy County, rice in Wharton County, and dryland corn, grain sorghum, and wheat in Hill County. Enterprise budgets from the Agricultural and Food Policy Center (AFPC) and Texas AgriLife Extension Service were used to estimate production costs and returns for competing crops in each study area. Budgets for producing sweet sorghum were developed based on grain sorghum budgets and results from Texas AgriLife Research and Extension field trials for hybrid sweet sorghum varieties (Rooney 2007; Blumenthal 2007).

Model Description and Parameters

Two models were developed for each region to estimate the economic feasibility of ethanol production from sweet sorghum juice in Texas: a farm level sweet sorghum production model and an ethanol firm model. Both models employ Monte Carlo simulation to account for inherent risk in each business. Monte Carlo simulation has been used extensively for bio-fuel feasibility studies (Outlaw et al. 2007; Ribera et al. 2007a; Ribera et al. 2007b; Richardson et al. 2007a; Richardson et al. 2007b; Lau 2004; Herbst 2003; Gill 2002). Richardson et al. (2007a) further demonstrated the benefits of using Monte Carlo probabilistic simulation over the limitations of deterministic simulation in economic analyses.

Sweet Sorghum Production Model

The farm level sweet sorghum production model calculated the minimum sweet sorghum price that could be offered to sweet sorghum producers by the ethanol firm to attract producers away from growing their next best alternative. Farmers are assumed to be rational and risk averse decision makers. Given available resources, farmers are assumed to produce the crop mix with the highest expected utility to get sweet sorghum produced, the plant will have to pay more than next best crop.

Annual sweet sorghum contract prices to farmers were assumed to have two components: a guaranteed payment based on a fraction of the sweet sorghum cost of production, and a fixed contract price based on sweet sorghum yield. The first component provided a payment equal to 90 percent of the sweet sorghum production cost per acre. The second component consisted of a fixed rate ($/ton) paid on realized production. The production payment price per ton was changed systematically to discover the price that would make risk averse farmers prefer sweet sorghum over their next best alternative in a stochastic efficient context.

A farm level crop model was used to simulate risky net returns realized by farmers who included sweet sorghum in their crop mix. The probability distributions of net returns for the crops currently produced were compared to the risky net returns for growing sweet sorghum with alternative contract prices. Stochastic efficiency with respect to a function (SERF) (Hardaker et al 2004) was used to rank the alternative risky net returns distributions. The lowest contract price for growing sweet sorghum which dominated the most preferred current crop, in a stochastic efficiency context, was used as the contract price offered by the ethanol plant.

Input and output variables for the farm model include prices, yields, fixed costs, planting and soil preparation, equipment, seed, fertilizer, labor, repairs, irrigation, and storage costs. Stochastic variables for the model are crop yields and crop prices for alternative crops and yields for sweet sorghum. A CroPMan simulation for 47 years of actual weather data in each region provided yield histories to estimate the parameters for the multivariate yield distributions in each region (Harman 2007). Average yields, as reported by AFPC farm panels, were used to calibrate the CroPMan yields to ensure stochastic yields were consistent with the crop budgets. Sweet sorghum mean yields from field trials (Rooney 2007; Blumenthal 2007) were used to calibrate CroPMan. A MVE distribution for crop yields was estimated using the procedures described by

Richardson et al. (2000) to ensure past correlation among crops is reflected in the simulated values.

Annual mean crop prices for the farm model come from the Food and Agricultural Policy Research Institute's (FAPRI) January Baseline (FAPRI 2008). Price wedges were calculated to localize FAPRI's stochastic national prices to Texas crop prices (Table 2). Total costs per acre were combined with stochastic yields and prices to simulate net returns for the crops. Alternative sweet sorghum contract prices were combined with stochastic yield and costs of production to simulate sweet sorghum net returns.

Table 2: Average Annual Prices, 2008-2017.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Ethanol ($/gal)	2.42	1.75	1.69	1.80	1.87	1.93	1.97	2.17	2.38	2.58
Electricity Used ($/kwh)	0.073	0.074	0.075	0.076	0.077	0.078	0.079	0.080	0.081	0.082
Green Electricity Sold ($/kwh)	0.053	0.054	0.055	0.056	0.057	0.058	0.059	0.060	0.061	0.062
Gasoline/Denaturant ($/gal)	2.04	2.09	2.12	2.16	2.20	2.24	2.28	2.32	2.36	2.40
Natural Gas ($/Mcf)	6.79	6.77	6.77	6.78	6.80	6.79	6.81	6.81	6.81	6.83
Corn ($/bu)	4.02	4.03	3.97	4.05	4.00	4.03	4.07	4.07	4.07	4.08
Cotton ($/lb)	0.60	0.58	0.57	0.57	0.57	0.56	0.57	0.57	0.57	0.57
Sorghum ($/bu)	6.01	6.20	6.05	6.20	6.14	6.22	6.29	6.33	6.36	6.43
Rice ($/cwt)	11.12	11.66	11.53	12.08	12.07	12.61	12.63	12.81	12.99	12.87
Wheat ($/bu)	5.36	5.29	5.28	5.38	5.43	5.50	5.54	5.60	5.66	5.71
Cotton Seed ($/ton)	188	168	174	175	178	178	181	184	185	187
DDGs ($/ton)	126	127	125	127	126	127	128	128	128	128
Hay ($/ton)	115	113	113	115	117	117	117	117	117	117
Potash ($/ton)	247	247	247	247	247	247	246	247	247	247
Molasses ($/ton)	62	62	62	62	62	62	62	62	62	62

Ethanol Firm Model

A firm level ethanol production model was developed to analyze the feasibility of ethanol production in each study area across three feedstock scenarios. Net present value (NPV) and annual ending cash (EC) were key output variables (KOVs) simulated to evaluate the economic success of the ethanol firm. Standard accounting relationships in pro forma financial statements were used to simulate annual net income, ending cash, and net worth over a 10 year planning horizon (Richardson et al. 2007b). Technical coefficients for the ethanol firm, such as productive capacity and sweet sorghum yields, differ by study area based on historical production characteristics (Table 3).

Ethanol plant capacity was limited by the sweet sorghum growing season and throughput capacity in each study area for the first feedstock scenario (SSM). To fully utilize the ethanol plant, molasses can be purchased and processed into ethanol. The second feedstock scenarioin Hill County supplements sweet sorghum juice with corn (SS + Corn) outside the sweet sorghum harvest period to extend ethanol production to 12

Table 3: Assumptions for Sweet Sorghum (SSM), Sweet Sorghum and Corn (SS+Corn) and Corn Only (Corn) Ethanol Firms in Three Study Areas of Texas.

	Willacy County		Wharton County		Hill County		
	SS	Corn	SS	Corn	SS	SS + Corn	Corn
Ethanol Plant Capacity (MMGY)	28	28	27	27	23	23	23
Sweet Sorghum Ethanol (MMGY)	28	-	22	-	8	8	-
Molasses Ethanol (MMGY)	0	-	5	-	15	-	-
Corn Ethanol (MMGY)	-	28	-	27	-	15	23
Average SS Harvesting Days	175	-	136	-	102	102	-
Fraction of Syrup to Storage	0.5	-	0.4	-	0.4	0.4	-
Average Operating Days from Storage	175	-	150	-	62	62	-
Average Molasses Operating Days	0	-	64	-	186	-	-
Average Corn Operating Days	-	330	-	330	-	186	330
Annual Scheduled Operating Days Down	15	15	15	15	15	15	15
Denaturant Fraction of Ethanol	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Grain Ethanol Plant Cost ($/gal)	-	2.25	-	2.25	-	-	2.25
Grain Ethanol Yield (gal/bu)	-	2.73	-	2.73	-	2.73	2.73
SS Ethanol Yield (gal/ton)	15.8	-	15.8	-	15.8	15.8	-
Molasses Ethanol yield (gal/ton)	56	-	56	-	56	-	-
DDGS Yield (lbs/bu)	-	18	-	18	-	18	18
Vinasse Yield (gal/gal SS alcohol)	1	-	1	-	1	1	-
Electricity Use - Corn (kWh/gal)	-	0.80	-	0.80	-	0.80	0.80
Electricity Use - SS (kWh/ton SS)	15.50	-	15.50	-	15.50	15.50	-
Electricity Produced - SS (kWh/ton SS)	70.00	-	70.00	-	70.00	70.00	-

Note: Sweet Sorghum (SS); Million Gallons Per Year (MMGY) months. The third feedstock scenario (Corn) uses only corn and serves as a base for comparing the sweet sorghum scenarios. In the first two scenarios, sweet sorghum ethanol production received an added benefit from the generation and sale of excess green electricity from bagasse and the sale of potassium fertilizer, derived from the vinasse. Vinasse was assumed to accumulate at a rate of one gallon (9 pounds) per gallon of ethanol produced (or 4½ pounds of potassium). Sweet sorghum alcohol production was estimated to generate 70 kWh of electricity per ton of bagasse, based on the electricity production from sugarcane bagasse (Brandao 2008). Processing sweet sorghum into ethanol is estimated to consume 15.5 kWh per ton, leaving a surplus of green electricity for sale in the SSM scenario and reducing the energy cost in the SS + Corn scenario.

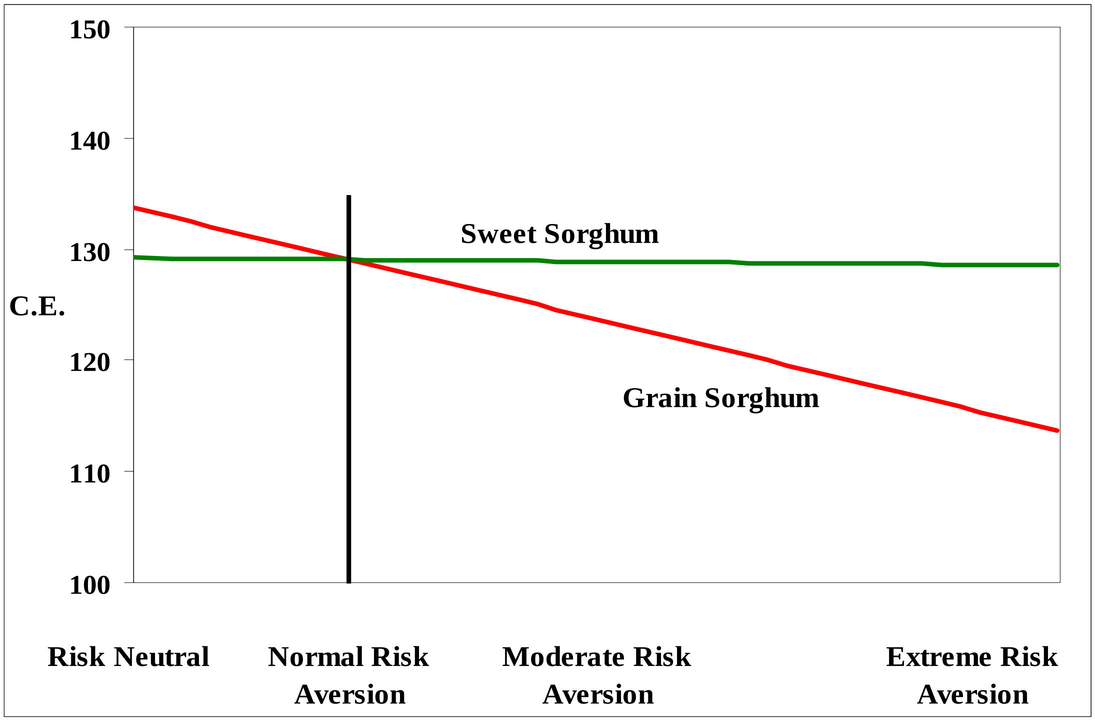
Estimated capital and per unit variable costs for producing ethanol from sweet sorghum juice were obtained from Brazilian ethanol industry experts (Campos 2006; Chaves 2006; Fernandes 2003) and Louisiana Green Fuels (2008). Capital costs for the corn feedstock scenario were estimated at $2.25 per gallon of ethanol capacity, while per unit non-corn variable costs were estimated by inflating 2004 costs reported by Bryan and Bryan International (2004). Capital costs in each scenario are fully amortized over a 20 year period at 7 percent fixed interest. Processing inputs include enzymes, labor, administrative costs, maintenance, water, denaturant, electricity, and natural gas.

Sweet sorghum available to the ethanol plant is a stochastic variable that is the product of stochastic yield and contracted acres. Sweet sorghum juice yield and content efficiency were obtained from field trials (Rooney 2007). Stochastic variables include prices for corn, electricity, gasoline, natural gas, potassium, distillers grains, molasses, and ethanol, as well as sweet sorghum yields and sugar content (Table 2). All variable costs were inflated to the current time period, and in each year 2008-2017, input costs were inflated using the January 2008 FAPRI baseline inflation rate projections (FAPRI 2008). Water costs were based on the price set by the water district in each study area (Hillsboro 2008; Raymondville 2008; Wharton 2008).

Results for Farm Level Model

The stochastic net return distributions for alternative crops and sweet sorghum with alternative contract prices were ranked using stochastic efficiency with respect to a function (SERF) (Hardaker et al. 2004). The lowest feasible contract price was determined as the certainty equivalent (CE) for sweet sorghum that equaled the CE for the best alternative crop at a relative risk aversion coefficient (RRAC) of one. A RRAC of one was chosen to reflect the risk aversion level for a normal person. The selection process is depicted in Figure 2 for Hill County where a SERF chart shows the intersection of the sweet sorghum CE and the grain sorghum CE at the RRAC equal to a normal risk aversion of one.

Figure 2: Stochastic Efficiency with Respect to a Function (SERF) Results for Crop Returns per Acre in Hill County.



Contract prices included a payment to producers at a rate of 90 percent of the simulated total cost of producing sweet sorghum, plus a fixed contract price paid on production (Table 4). The SERF analysis was done annually based on expected prices and costs to insure that the sweet sorghum contract price was sufficient to attract land from the next best alternative crop

Table 4: Contract Price for Sweet Sorghum Production in each Study Area over the 10 Year Planning Horizon ($/wet ton).

$/ton	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Willacy	5.99	6.02	5.80	5.87	5.81	5.84	5.87	5.90	5.92	5.97
Wharton	9.73	9.56	9.31	9.34	9.34	9.31	9.37	9.47	9.56	9.66
Hill	16.71	17.16	16.57	16.94	16.73	16.86	16.99	17.09	17.07	17.17

Fifty percent of the farmable land in each study area was assumed to be available for sweet sorghum production to allow for a two year otation.. The plant's contracted acres are a function of average yield per acre and the average number of days sweet sorghum can be harvested for juice, based on historical frost free days for each study area, and the grinding capacity of the plant. Ethanol firms were assumed to contract enough acres each year to produce ethanol at full capacity trough the harvest season. Estimated days for the first and subsequent cuttings of sweet sorghum to grow and mature were based on field trail results, whereas, the probability of multiple harvests each year was a function of the number of frost free days and the total number of days required for sweet sorghum to reach maturity in each study area. Field trial results indicated ratoon yields averaging 70 percent and 50 percent of the first cutting for the second and third cuts, respectively (Rooney 2007; Blumenthal 2007). National Oceanic and Atmospheric Administration (NOAA) weather data was used to estimate the parameters for a truncated normal distribution, which was used to simulate the number of growing days without a freeze in each study area (NOAA 2007).

For the ethanol plant, harvest and transportation costs per ton mile were estimated based on information obtained from Louisiana Green Fuels (2008), and inflated to the current time period. The plant’s transportation costs were calculated using French's (1960) transportation cost formula. Stochastic dried distillers grains with solubles (DDGS) prices were simulated by using a regression of DDGS prices as a function of corn prices and adding an empirical distribution of the residuals.

Ethanol Plant Results

In the SSM scenario, sweet sorghum juice serves as the primary feedstock for the firm. A fraction of the syrup processed each day is stored which allows the plant to extend the ethanol production period beyond the growing season and install a smaller (cheaper) ethanol plant. In areas where ethanol capacity exceeded the combined production from the harvest period and juice storage, molasses was used as a feedstock to further extend ethanol production. The SS + Corn scenario in Hill County analyzes the use of corn instead of molasses to fill the remaining capacity after the combined harvest and juice storage is processed into ethanol. The Corn scenario serves as a base for comparison.

The net present value (NPV) distribution was estimated from the simulated results to determine the probability of economic success for ethanol firms in each study area and production scenario. In each region, ethanol production from all feedstock scenarios returned a positive average NPV (Table 5). For sweet sorghum ethanol production, Willacy County is the most profitable (economically feasible) production area, with the representative ethanol firm returning an average NPV of $39 million and a 100 percent chance of a positive NPV or economic success. Hill County was the only study area that returned a probability of economic success below 90 percent, occurring in both SSM and SS + Corn scenarios. Subsequent analysis concluded that to achieve a 90 percent probability of economic success in each of these scenarios, the total sweet sorghum contract payment to the producer would have to be discounted to 73 and 75 percent of the contract prices in Table 4, respectively.

Table 5: Average Net Present Value, Average Annual Return on Assets, Ending Cash, and the Probability of a Positive Net Present Value and Ending Cash in 2017 Ethanol Firms in Each Study Area.

	Willacy County		Wharton County		Hill County		
	SSM	Corn	SSM	Corn	SSM	SS + Corn	Corn
NPV (M $s)	39	33	27	32	1	2	27
P(NPV>0)	1.00	1.00	0.99	1.00	0.54	0.60	1.00
CP Fraction, P(NPV>0)=0.90[1]	-	-	-	-	0.73	0.75	-
Avg. Annual ROA	0.12	0.33	0.11	0.34	0.07	0.07	0.34
EC1 (M $s)	8	23	6	22	-2	-2	19
EC3 (M $s)	-6	36	-16	36	-39	-38	30
EC5 (M $s)	-15	53	-35	53	-78	-76	45
EC10 (M $s)	-7	141	-55	139	-168	-165	118
P(EC10>0)	0.43	1.00	0.13	1.00	0.00	0.00	1.00

(1) Fraction of total contract payment (CP) to attain 90 percent probability of economic success

Discussion

This study indicates that producing ethanol from sweet sorghum juice is a feasible option in at least regions of Texas. While ending cash is adversely impacted by the high initial cost of the facility, average annual return on assets remains favorable for sweet sorghum ethanol production. The Corn only feedstock scenarios outperformed the sweet sorghum juice ethanol scenarios meaning that investors wanting to produce ethanol would be better off to invest in corn only plant then in a sweet sorghum juice ethanol plant.

Length of growing season, yield, and competing crops are key factors influencing the feasibility of sweet sorghum ethanol production across the study areas. Regions with a long growing season and a high probability of ratoon crops will generate greater returns from sweet sorghum ethanol than areas with shorter growing seasons (Willacy County vs. Hill County). As illustrated in the results for Willacy County vs. Hill County, higher yields effectively decrease the average per unit contract price to the ethanol firm, increasing the probability of economic success for the firm. Areas with higher returns for competing crops will have to offer a higher contract price for sweet sorghum, which lowers the chance of earning reasonable returns for the ethanol firm, as indicated in the results for Hill County vs. Wharton County.

Recent downward pressure on crop prices is expected to continue to improve the profitability of sweet sorghum ethanol relative to corn ethanol. Continued research and advances in efficient harvest and transportation technologies would also be expected to benefit ethanol production from sweet sorghum. As public and political interests continue to identify sustainable ethanol production from sources other than corn, ethanol production from sweet sorghum juice may provide an avenue through which to achieve this goal.

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