Economic Analysis of Utilization of Corn Stover for Bioenergy Production: Towards Diversifying Income Opportunities for Small Farmers

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Abstract: Bioenergy production from plant wastes such as corn stover has the potential to improve energy security and mitigate climate change in the United States. However, there is a limited understanding of its utilization and economic potentials for bioenergy production. The overall objective of the study was to estimate the economic profitability of utilizing corn stover for different ventures after harvesting corn, which includes: 1) corn stover production, 2) ethanol production, and 3) electricity generation through on-farm gasifiers. The data for this study was based on secondary data from various sources. The benefit-cost model was applied for the analysis. Investment evaluation criteria include annualized net return from corn stover, ethanol, and electricity generation. Results show that under current conversion rate, the net return from marketing corn stover ranges from $80.61/kg to $394.11/kg, while the net return from ethanol production ranges from $-104.91/ha to $848.96/ha of corn stover under varying price and yield scenarios. Also, under the government subsidy scheme that covers 25% of equipment costs, there is an investment opportunity for on-farm gasifier with an NPV of $4,329.29. The findings of the study show the potential for using corn stover for bioenergy production since it showed a positive net return. Also, the production of ethanol from corn stover is not only economically feasible but also socially acceptable since it does not compete with food production, and serves as a means of income diversification for corn farmers.

Keywords: Corn stover, plant waste, biofuel, ethanol, benefit-cost, gasifier.

INTRODUCTION

Today, more than ever before, the world is increasingly exploring the potential of utilizing agricultural residues for bioenergy production. Agricultural residues such as corn (*Zea mays*) could reduce the current dependence on fossil fuels [1,2], mitigate the release of greenhouse gases [3], and help stabilize the price of energy fuels in international markets [4].

Biofuels are increasingly used as transportation fuels and have been touted by many to replace fossil fuel in the future [5,6]. Currently, most transportation fuels in the US contain at least 10% of ethanol, which is primarily derived from corn [7]. However, many studies have suggested that biofuels from food crops are competing with food production [8-10]. Harvey and Pilgrim [11], concluded that increased biofuel production in the US, Brazil, and Europe has led to an increase in food price, as well as straining of land resources. Therefore, for food prices to reduce, ethanol producers need to shift to cellulosic (non-food) feedstock [12]. However, for this to happen, ethanol producers need information regarding the profitability of using cellulosic feedstock (i.e., corn stover) for bioenergy production, since ethanol production from cellulosic feedstock is at relatively early stages, and relatively few studies have explored the feasibility of producing cellulosic feedstock [13,14]. Specifically, it is important to have reliable information on the benefit-cost estimation of cellulosic feedstock production, to attract farmers to grow cellulosic feedstocks [14]. Moreover, because small farmers are relatively poor and are looking to improve their profit while not incurring too much cost, there is a need to find a means of income diversification [15]. This is extremely difficult because most 'profit-improving' ventures require some form of start-off capital. However, corn farmers may be able to escape such start-off capital, while at the same time improving profit, since corn stover is an agricultural residue that comes at little to no cost to corn farmers [13].

Besides, corn stover can be converted to electrical energy through gasification [16]. However, biomass gasification plants are still in the early commercial stage of development [17], and farmers need information with regards to investment cost and benefits of setting up a small-scale on-farm gasifier.

In light of the importance given to the commercial production of cellulosic feedstocks, and the various

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information gaps associated with its profitability, it is imperative to study the economic feasibility of producing corn stover (a type of cellulosic feedstock) from which ethanol and electricity can be generated [16,18]. This study considers options available for farmers, such as marketing of corn stover to ethanol biorefineries and utilization of corn stover for on-farm electricity generation using gasifiers. These options serve as a means of income diversification and/or energy security to corn farmers.

The overall objective of the study is to estimate the economic profitability of utilizing corn stover for different ventures after harvesting corn. The more specific objectives of the study are to, a) estimate economic returns from marketing corn stover to ethanol biorefineries; b) evaluate the profitability of utilization of corn stover by ethanol producers; c) evaluate investment opportunities for on-farm gasifiers for electricity generation from corn stover.

METHODOLOGY

Benefit-cost Analysis for Corn Stover and Ethanol

The benefit-cost analysis was applied for the proposed study. From an economic point of view, the overall approach was to estimate annual costs and revenues of corn stover [19]. To calculate costs and revenues in annual equivalent terms, the present values of all costs and revenues over the useful life of the crop were transformed into an equivalent annuity. The following procedure was adopted in estimating annual equivalent cost and revenue [20].

To estimate present value of benefits and costs:

$$PVC_i = \sum_{t=1}^{n} \frac{TCP_i}{(1+r^n)} \tag{1}$$

$$PVB_i = \sum_{t=1}^{n} \frac{GR_i}{(1+r)^n} \tag{2}$$

Where:

PVC_i = Present value of production cost of i th crop ($/ha).

TCP_i = Total cost of production of i th crop ($/ha).

PVB_i = Present value of benefits of i th crop ($/ha).

GR_i = Gross revenue of i th crop ($/ha).

r = Average discount rate during the last decade.

n = Project duration (years).

Accordingly, annual equivalent cost and revenues:

$$AEC_i = \frac{PVC_i \times d}{1-(1+d)^{-n}} \tag{3}$$

$$AER_i = \frac{PVB_i \times d}{1-(1+d)^{-n}} \tag{4}$$

Where:

AEC_i = Annual equivalent cost of i th crop ($/ha yr^{-1}).

AER_i = Annual equivalent revenue of i th crop ($/ha yr^{-1}).

d = Discount rate. In this analysis, r = 2.19 %.

n = Project duration (years). In this analysis, n was assumed equal to 10 years.

To calculate stover yield, we adapted Lang's formula [21] to reflect a corn stover/corn proportion of 0.8:1; assuming that the grain contains a moisture content of 25%.

$$Stover\ Yield\ (kg/ha) = \frac{Corn\ yield\ (bu/ha) \times 56\ lb/bu \times 0.8}{2.205\ lb/kg} \tag{5}$$

The procedure for estimating the feedstock cost of ethanol was adopted from National Renewable Energy Laboratory's [22] model:

$$Ethanol\ Cost\ (\$/l) = \frac{Corn\ stover\ cost\ (\$/kg)}{Ethanol\ Conversion\ rate\ (l/kg)} \tag{6}$$

MESP (minimum ethanol selling price) = Feedstock cost + other processing costs (7)

Other processing cost = $0.37/l (Adopted from NREL [16])

Ethanol yield (l/ha) = Ethanol Conversion rate (l/kg) x Avg. Corn Stover yield (kg/ha) (8)

Total Cost ($/ha) = MESP ($/l) X Ethanol Yield (l/ha) (9)

Investment Analysis Criteria for Gasifier (Electricity Generation)

The second part of the study evaluates the costs and benefits of establishing a gasifier for electricity generation on a farmer's field, to help potential growers determine the economic feasibility of generating on-farm electricity. It considers the internal rate of return (IRR), net present value (NPV), net return (NR) and

payback period for establishing a gasifier. Full cost analysis was used to evaluate investment for the on-farm gasifier. The unit cost of production per kWh of electricity from corn stover was estimated.

The same procedure used in estimating annual equivalent costs and revenues for corn stover production was adopted [14]:

$$AEC_i = \frac{PVC_i \times d}{1-(1+d)^{-n}} \tag{10}$$

$$AER_i = \frac{PVB_i \times d}{1-(1+d)^{-n}} \tag{11}$$

Where:

AEC_i = Annual equivalent cost of i th gasifier ($/yr).

AER_i = Annual equivalent revenue of i th gasifier ($/yr).

PVC = Present value of production cost per kWh of electricity ($/ha),

PVB = Present value of benefits per kWh of electricity ($/ha).

d = Discount rate. In this analysis, r = 2.19 %.

n = Project duration (years). In this analysis, n was assumed equal to 10 years.

To estimate the quantity of stover needed to power a 15KWh capacity gasifier for a year:

Qty of stover needed for a year (kg/yr) = Qty of Stover for 15kWh (kg/hr) X Number of hr/yr   (12)

To estimate the acreage of land needed by a farmer to meet this stover requirement:

$$Land\ acreage\ (ha/yr) = \frac{Qty\ of\ stover/year\ (kg/yr)}{Qty\ of\ stover\ produced\ (kg/ha)} \tag{13}$$

To estimate the cost of producing the required stover:

Stover Harvesting Cost ($/yr) = Land acreage (ha/yr) X Cost of Bailing ($/ha)   (14)

Data Source

The data for this study was based on secondary data from various sources. Data for corn yield in Tennessee and other three southern states (Louisiana, Mississippi, and South Carolina) were based on data from the 2015 USDA National Agricultural Statistics Services [23]. The production cost for corn for the United States was based on data from enterprise budget from various sources (University of Tennessee Extension, Clemson extension, Louisiana agricultural experiment station, and Mississippi agricultural and forestry experiment station). Ethanol conversion rates and input costs were based on sources such as the National Renewable Energy Laboratory design report [22]. The 'Power Pallet PP20' gasifier manufactured by 'All Power Labs' located in Berkeley California, USA, was used for this study [24]. The investment costs for gasifier were based on manufacturer's selling costs for small-scale gasifier units [24]. Itemized operation was estimated for electricity generation. The cost was updated to reflect current market prices. The prices of electricity consumed by consumers were based on data from the U.S. Energy Information Administration. All price data represents either current market prices or an average of current and previous prices.

RESULTS

Profitability of Corn Stover

The profitability of corn stover production is expressed in terms of net return from the marketing of corn stover. The net return from corn stover production for a representative farm of 1 hectare over a project life of 10 years was calculated. To do this, the annual

Table 1: Annual Equivalent Cost of Corn Stover Production

Cost of Feedstock	Average Cost ($/ha)	Annual Equivalent Cost ($/ha)
Fertilizer Removed	$36.43	$40.13
Windrowing	$25.56	$28.16
Baling	$104.91	$115.56
Collecting Bales	$31.83	$35.06
Hauling Bales (25 miles)	$56.04	$61.74
Total Cost	$254.77	$280.62

equivalent cost of corn stover production was calculated (Table **1**) and subtracted from the annual equivalent revenue (Table **2**).

Table 2:   Corn Stover Yield and Price Scenarios

Scenarios	Stover Yield (kg/ha)	Stover Price ($/kg)
High	9253.05	$0.07
Average	7910.85	$0.06
Low	6263.60	$0.05

Annual Equivalent Cost (AEC) of Corn Stover

Table **1** shows that the AEC of corn stover production, which is approximately $280.62/ha, includes the cost of nutrients removed from the soil as a result of harvesting and removing corn stover. This shows that corn stover is not a free product, although it is considered as a farm waste. However, the exclusion of nutrient loss would result in a lower annual equivalence cost of $240.49/ha.

Annual Equivalent Revenue (AER) from Corn Stover

The Annual Equivalent Return (AER) from corn stover depends upon the price and quantity of corn

stover. As shown in Table **2**. The price of corn stover ranges from $0.05/kg to $0.07/kg, while corn stover yield ranges from 6263.60 kg/ha to 9253.05 kg/ha.

Table **3** shows that the AER from corn stover production ranges from $361.23/kg to $674.73/kg. This is due to the variations in the price and quantity of corn stover.

Net Return (NR) from Corn Stover

It could be seen from Figure **1** that the net return was positive for the yield and price scenarios considered for the analysis, ranging from $80.61/kg to $394.11/kg.

The Profitability of Utilization of Corn Stover For Ethanol Production

The profitability of utilizing corn stover for ethanol production is expressed in terms of net return. To calculate the net return from ethanol production, the annual equivalent cost (AEC) of ethanol production over a project life of 10 years was subtracted from the annual equivalent revenue (AER).

Table 3:   Annual Equivalent Revenue of Corn Stover Production

		Yield (kg/ha)		
		High	Average	Low
Price ($/kg)	High	$674.73	$576.05	$456.28
	Average	$604.45	$516.04	$408.75
	Low	$534.17	$456.03	$361.23

	High	Average	Low
High Price	$394.11	$295.43	$175.66
Avg. Price	$323.84	$235.42	$128.14
Low Price	$253.56	$175.41	$80.61
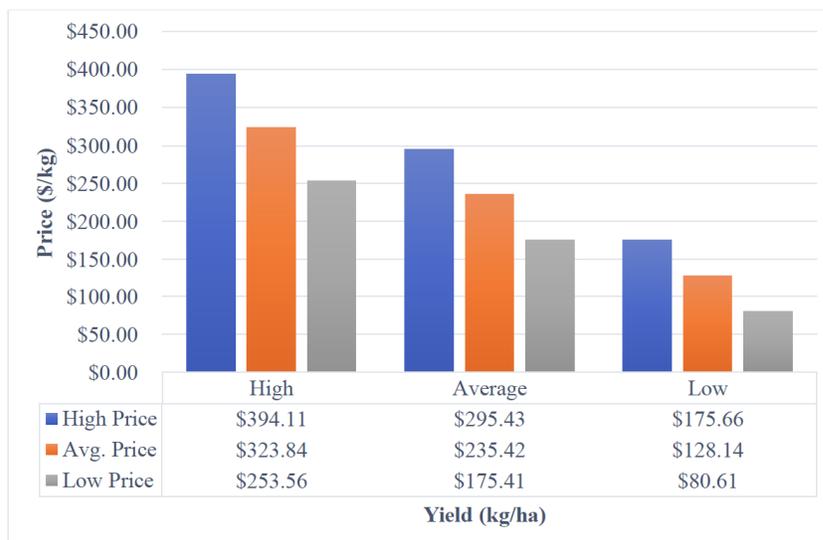
Figure 1: Net return from corn stover production under various yield and price scenarios.

Table 4: Minimum Ethanol Selling Price under Different Stover Cost and Ethanol Conversion Scenarios

Feedstock (Stover) Cost ($/kg)	Ethanol Conversion Rate (l/kg)	Ethanol Cost ($/l)	Processing Cost($/l)	MESP ($/l)
$0.07	0.38	$0.18	$0.37	$0.55
$0.07	0.33	$0.20	$0.37	$0.58
$0.07	0.29	$0.23	$0.37	$0.60
$0.06	0.38	$0.16	$0.37	$0.53
$0.06	0.33	$0.18	$0.37	$0.55
$0.06	0.29	$0.20	$0.37	$0.58
$0.05	0.38	$0.14	$0.37	$0.51
$0.05	0.33	$0.16	$0.37	$0.53
$0.05	0.29	$0.18	$0.37	$0.55

Table 5: Annual Equivalent Cost of Ethanol Production under Various Yield and Price Scenarios

Scenario	Feedstock/Stover Cost ($/kg)	MESP ($/l)	Ethanol yield (l/ha)	Total Processing Cost ($/ha)	AEC ($/ha)
High Stover Cost	$0.07	$0.55	2,970.54	$1632.42	$1,650.33
		$0.58	2,574.47	$1,482.79	$1,499.05
		$0.60	2,310.42	$1,385.64	$1,400.84
Avg. Stover Cost	$0.06	$0.53	2,970.54	$1,577.49	$1,594.79
		$0.55	2,574.47	$1,428.37	$1,444.03
		$0.58	2,310.42	$1,330.71	$1,345.30
Low Stover Cost	$0.05	$0.51	2,970.54	$1,522.55	$1,539.25
		$0.53	2,574.47	$1,373.96	$1,389.02
		$0.55	2,310.42	$1,275.77	$1,289.76

Annual Equivalent Cost (AEC) of Ethanol

To calculate the AEC of ethanol production, the total cost (TC) of producing ethanol per hectare of corn stover was calculated. To calculate the TC of producing ethanol, the minimum ethanol selling price of ethanol and ethanol yield per hectare of corn stover were calculated (see equation 7 & 8). The minimum ethanol selling price ranges from $0.51/l to $0.60/l (Table **4**).

Also, ethanol yield per hectare ranges from 2,310.42l/ha to 2,970.54l/ha (Table **5**). Accordingly, AEC ranges from $1289.76/ha to $1650.33/ha of corn stover (Table **5**).

Annual Equivalent Revenue (AER) from Ethanol

As shown in Table **6**, the AER of ethanol production ranges from $1184.85/ha to $2449.29/ha of corn

Table 6: Annual Equivalent Revenue of Ethanol Production under Various Ethanol Conversion Rate and Price Scenarios

Ethanol Wholesale Price ($/l)	Ethanol yield (l/ha)	Total Revenue ($/ha)	AER ($/ha)
$0.83	2,970.54	$2,472.18	$2,499.29
	2,574.47	$2,142.56	$2,166.05
	2,310.42	$1,922.81	$1,943.89
$0.63	2,970.54	$1,875.72	$1,896.29
	2,574.47	$1,625.62	$1,643.45
	2,310.42	$1,458.89	$1,474.89
$0.51	2,970.54	$1,506.85	$1,523.38
	2,574.47	$1,305.94	$1,320.26
	2,310.42	$1,172.00	$1,184.85

Figure 2: Net return from ethanol production under various yield and price scenarios.

stover. This is due to the variations in ethanol yield, as well as ethanol price.

Net Return (NR) from Ethanol

The net return (NR) analysis shows that NR from ethanol was negative for some scenarios, while positive for others, ranging from $-104.91/ha to $848.96/ha of corn stover (Figure **2**).

Investment Opportunities for on-Farm Gasifiers for Electricity Generation from Corn Stover

The profitability of installing and operating an on-farm gasifier is expressed in terms of its Net Return (NR), Net Present Value (NPV), Internal Rate of Revenue (IRR), and Payback period over a project life of 10 years. To calculate the net return from electricity generation through the use of on-farm gasifier, the annual equivalent cost (AEC) of installing and operating a gasifier was subtracted from its annual equivalent revenue (AER).

Annual Equivalent Cost (AEC) of Installing and Operating a Gasifier

As shown in Table **7**, the AEC of installing and operating a small-scale on-farm gasifier (i.e., Power Pallet PP20) was approximately $3,445.39/year with 25% government subsidy for equipment costs.

However, the AEC increased to $4083.81/year without subsidy (Table **7**). Labour cost was excluded in this analysis because the manufacturer of the 'Power Pallet PP20' suggested that the gasifier operator be someone already employed in the vicinity. The gasifier certainly does not require the full attention of an operator all day, as the operator just needs to refill the hopper periodically and then perform maintenance tasks at the end of the day. The 'Power Pallet PP20' gasifier generates 15kW of electricity in 1 hour, which amounts to 36,000kWh of electricity in a year (assuming the gasifier is in operation for 2400 hours/year). Consequently, the AEC of generating unit electricity is 9.6 cents/kWh (with subsidy) or 11.3 cents/kWh (without subsidy). According to the manufacturers of the 'Power Pallet PP20,' the quantity of stover required to power a 15KWh gasifier for one hour is 22kg, which amounts to 52,800 kg/year (at 2400 hours/year). This will require a farm size of 6.67 ha/year (assuming an average stover yield of 7910.85 kg/ha), and consequently a stover harvesting cost of $837.53/ha (assuming the cost of bailing is $125.57/ha).

The Annual Equivalent Revenue (AER) of Installing and Operating a Gasifier

The AER for installing and operating a 'Power Pallet PP20' gasifier was $3,965.34/year (assuming 36,000 kWh of electricity/year at $0.1/kWh).

Table 7:   Annual Equivalent Cost of Small-Scale Gasifier under Various Yield and Price Scenarios

Category	Unit	Average Cost ($/year)	AEC with grant ($/year)	AEC without grant ($/year)
Gasifier (25% Subsidy)	(List Price of $31,245)	$23,430.75	$2,120.90	$2759.32
Oil	$/year	$82.37	$88.52	$88.52
Maintenance	$/year (1% of Capital Cost)	$312.45	$335.77	$335.77
Stover Harvesting Cost	$/ha	$837.67	$900.20	$900.20
Total Cost			$3,445.39	$4083.81

NPV, NR, IRR, and Payback Period of Installing and Operating a Gasifier

As shown in Table **8**, the estimated NPV for the gasifier was negative (-$1960.18) without government subsidy program. However, NPV was positive ($4,329.29) under the government subsidy program for equipment. The IRR was -2.54% (without subsidy) or 3.33% (with subsidy). This means that the return on investment per dollar invested is low and loses money without subsidy. The payback period on initial investment was approximately 8 years without subsidy or 6 years with a subsidy.

Table 8:   Summary of NPV, NR, IRR, and Payback Period of Installing and Operating an On-Farm Gasifier

Category	Value
NPV (without subsidy)	-$1,960.18
NPV (with subsidy)	$4,329.29
NR (without subsidy)	-$118.47
NR (with subsidy)	$519.96
IRR (without subsidy)	-2.54%
IRR (with subsidy)	3.33%
Payback Period (without subsidy) (years)	8.2
Payback Period (with subsidy) (years)	6.2

CONCLUSIONS AND RECOMMENDATIONS

The analysis in the current study shows that under the current conversion rate, the annual equivalent net return from marketing corn stover ranges from $80.61/kg to $394.11/kg under varying price and yield scenarios. The net return analysis shows the potential for marketing corn stover to ethanol biorefineries since it shows a positive net return.

The net return from ethanol production ranges from $-104.91/ha to $848.96/ha of corn stover under varying price and yield scenarios. This positive net return shows the potential for using corn stover for bioenergy production. The minimum ethanol selling price ranges from $0.51/l to $0.60/l of ethanol. Also, there is an investment opportunity for on-farm gasifier given the positive net present value (NPV) and net return (NR) of $4,329.29 and $519.96/ha respectively under the government subsidy that covers 25% of equipment cost. However, the NPV and NR were negative without government subsidy, which shows that bioenergy production from corn stover still needs some form of intervention from the government. As a result, the United States government should continue to provide financial assistance to corn farmers, who want to produce bioenergy crops or install an on-farm gasifier, and provide grants for research in this field. Also, there is a need for the implementation of various policies that focus on farmers' training, operating pilot projects, and information on selling electricity to the main grid.

The enterprise budget and yield data used for this study were limited to four states in the Southern region of the United States. As a result, the data may not be representative of the whole country. Hence, results should be interpreted with caution when applied to other regions. It is recommended that similar studies that explore the economic feasibility of cellulosic feedstock for bioenergy production be replicated in other parts of the US.

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