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Economic Feasibility of a Mobile Fast Pyrolysis System for Sustainable Bio-crude Oil Production

Marco A. Palma①[a], James W. Richardson[b], Brad E. Roberson[c],
Luis A. Ribera[d] Joe Outlaw[e] and Clyde Munster[f]

[a]*Assistant Professor and Extension Economist*
[b]*Regent's Professor and Senior Faculty Fellow*
[c]*Research Associate*
[d]*Associate Professor and Extension Economist*
[e]*Professor and Extension Economist*
Department of Agricultural Economics, Texas A&M University, 600 John Kimbrough Blvd,
2124 TAMU. College Station, Texas, 77843-2124, U.S.A.

[f]*Professor, Department of Biological and Agricultural Engineering, Room 127, Hobgood Building,*
Texas A&M University, College Station, Texas, 77843, U.S.A.

Abstract

This paper analyzed the economic feasibility of a mobile bioenergy pyrolysis system using a Monte Carlo simulation model. Pyrolysis transforms any cellulosic materials into i) a bio-oil similar to crude oil ii) a synthesis gas similar to natural gas, and iii) a bio-charcoal substance. The pyrolyzer machine is currently being manufactured and tested with various types of feedstocks including corn stover and energy sorghum. The economic analysis focused on creating an automated process that integrates a transportation logistics cost optimization model with geographic information system (GIS) data. The geographic data provides possible paths for the mobile bioenergy pyrolysis unit as it moves to and from each harvest area, depending on stochastic availability of feedstock (determined by historical crop yields) and distance to oil refineries. The results indicated that there is a low probability of a positive Net Present Value (NPV) with current economic conditions. In general, the NPV was highest with a stationary scenario and it decreased with additional moving times. A sensitivity analysis is presented to assess the potential probability of success of a mobile pyrolysis system under alternative oil prices and feedstock costs scenarios.

Keywords: biofuels, pyrolysis, economic analysis

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①Corresponding author: Tel: + 1 979.845.5284
Email: mapalma@tamu.edu

J.W. Richardson: jwrichardson@tamu.edu B.E. Roberson: beroberson1@gmail.com
L. Ribera: lribera@tamu.edu J. Outlaw: joutlaw@tamu.edu C. Munster: c-munster@tamu.edu

Introduction

The concept of bioenergy is not new; wood and other plant material have been burned to produce power since man discovered fire. During the twentieth century, hydrocarbon fuels such as coal, natural gas, and diesel were the cheapest method of power generation, but recent global economic trends and rising fuel prices encouraged development of alternative biofuel from feed crops during the early twenty-first century. Biofuels, liquid fuels such as ethanol or bio-diesel derived from plant materials, developed from non-food sources, otherwise known as "second generation biofuels," are currently being researched by land grant universities, private industry, and government agencies around the world.

Pyrolysis (Figure 1) is a process that converts agricultural residues and any other carbon materials into bioenergy through intense heat in the absence of oxygen. Pyrolysis produces 1) a bio-oil similar to crude oil, though not as refined; additional processing is required to generate an equivalent crude oil product, 2) a synthesis gas (syngas) that can be used as fuel for heating or to produce electricity, and 3) a bio-charcoal substance that can be incorporated back into the soil to improve soil properties, or processed for other potential uses (Reed and Jantzen 2002). During pyrolysis the feedstocks are heated to temperatures of 400-600 degrees Celsius (pending initial moisture content of the feedstock) and converted to bio-oil, syngas, and bio-char. The syngas is fed back into the system as an energy source to continue to heat the unit. The bio-oil is the main source of revenue; however, the nutrient contents of the bio-char can be sold as a soil amendment. The pyrolysis process could also be used to offset carbon emissions if a clean energy bill with carbon credits were drafted.

The objective of this paper is to estimate the economic feasibility of a mobile vs. a stationary pyrolysis plant using alternative feedstocks. The feedstocks used for the analysis are corn stover in Illinois and Texas, and energy sorghum in Nebraska. A Monte Carlo financial simulation model will be used to analyze the probability of economic viability of a pyrolysis system for alternative feedstocks, locations, and frequency of plant relocation.

Most biofuel systems (and conventional fuel systems as well) utilize a centralized production facility, where large quantities of feedstock (or coal, for instance) are brought to one location to take advantage of economies of scale. However, in certain regions or at certain times, weather, availability of feedstock, or other economic factors may make biofuel production uneconomical. In the face of such constraints, a mobile production facility could prove advantageous. Roberts et al. (2010) showed that feedstock transportation distance presents a significant problem in proving economic viability of biochar-pyrolysis systems, suggesting that a mobile production facility may help improve profitability.

Mobile pyrolysis units, by definition, are portable and more versatile than conventional centralized biofuel production facilities. Their small size enables them to be transported quickly and easily on a tractor trailer to take advantage of seasonal feedstock availability at multiple locations. However, their size presents potential feedstock transportation issues, so the logistics must considered.

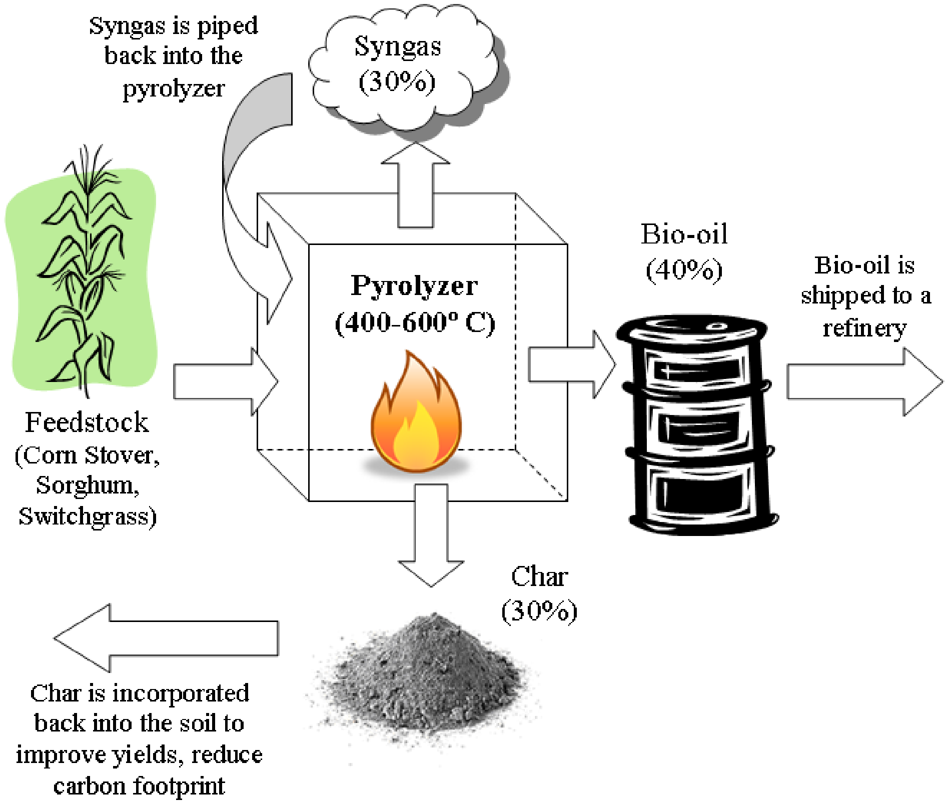

Figure 1. Pyrolysis Conversion Process and Associated Products.
Note: Actual conversion rates will vary by feedstock and initial moisture content. Percentages shown are by volume.

Data and Methods

The simulation model to analyze the mobile pyrolysis unit is an annual Monte Carlo financial statement model that incorporates multiple variables including historical prices and yields, estimated conversion ratios from feedstock inputs to bio-oil, bio-char, syngas outputs, and machine/labor/fuel costs. These variables, along with numerous other items that affect income and expense, are organized in an easy-to-understand format used by Cochran, Richardson and Nixon (1990); Outlaw et al. (2003); Richardson et al. (2007) and Outlaw et al. (2007). Monte Carlo simulation can be applied to econometric models by introducing stochastic components to each of the variables in the equation, then running the simulation model for a large number of iterations. The result is a distribution for each of the key output variables such as profit, yields, and net present value (NPV). The distributions of key output variables are crucial for analyzing feasibility of future business decisions under risk. The financial statement simulation model is programmed in Excel using the add-in SIMETAR©, a simulation and risk analysis software (Richardson, Schumann, and Feldman 2008).

The most critical output variable from the model for evaluating the economics of pyrolysis is the net present value (NPV). The model calculates NPV as follows:

$$(1) \quad NPV = -(BeginningNetWorth) + \sum_{j=1}^{10} \frac{Dividends_j}{(1+i)^j} + \frac{EndingNetWorth}{(1+i)^{10}}$$

Equation 1 calculates NPV (assuming a discount rate of i = 5%) of dividends paid to investors and net worth over the life of the investment (ten years), and compares that value to the net worth at the beginning of the investment. If the value of NPV is greater than zero, the business is considered an economic success (Richardson and Mapp 1976).

The major income-generating product is a bio-oil, equivalent to crude oil, which is transported to the nearest refinery, and sold at a 5% discount from the price of crude oil. The mean bio-oil price for 2011 was $78.54/barrel. The value for bio-char is determined based on the soil amendment value as a soil additive. According to Wise et al. (2011), char produced in 2011 can be sold for $24 per ton and it's value varies by feedstock. Syngas is assumed to be used as an energy source to sustain the pyrolysis unit and it is not generating revenue. Its production also varies with the level of moisture in the initial feedstock and by feedstock. Both the price of bio-oil (PO) and char (PC), along with the price of crude oil, are inflated annually and used to determine net income over the life of the business (Richardson et al., 2011). The model assumes a $1.00/gallon subsidy (S) for pyrolysis bio-oil offered as an incentive throughout the analysis period, as this is the current subsidy for second generation biofuels. Income is calculated as:

$$(2) \quad Income = (P_{Oil} + S)Q_{Oil} + (P_{Char}Q_{Char}) + (P_{Syngas}Q_{Syngas})$$

Income is stochastic because prices are drawn at random from probability distributions estimated from historical series. Other random variables include feedstock yield and prices, as well as the inputs and outputs. Syngas revenue is included for eventual analysis of excess syngas production but not included in this analysis.

An input to the financial simulation model was output from a transportation logistics cost optimization model with geographic information system (GIS). The analysis includes 15 alternative scenarios, including 3 stations/sources of feedstocks, and five frequencies for moving the mobile pyrolysis unit. The three sources of feedstock are corn stover in Illinois and Texas, and energy sorghum in Nebraska; the unit can be moved monthly, bi-monthly, quarterly, bi-annually, or it can be stationary. Table 1 summarizes the model scenarios for pyrolysis bio-oil production.

In addition to the transportation costs, there are also other set up costs associated with moving the pyrolysis unit. A hard surface movable pad and access road is needed around the pyrolysis unit, as this is a high traffic area. A portable military-grade "matting system" from GFI Inc., is used with interlocking mats measuring 6 feet by 6 feet with a unit cost of $450. A ¾ acre area is used requiring 908 mats for a total cost of $408,600. This pad area includes set up of machinery and storage of feedstock area. The access road is a 120 feet by 12 feet with a cost of $18,000. The labor cost to dismantle and assemble the movable mats in a new location each time the mobile pyrolysis unit is moved is $2,500.

Table 1. Model Scenarios for Bio-oil Production

Scenario	Name	Source	Frequency of Moving
1	IL 12M	Corn stover, IL	Monthly
2	IL 6M	Corn stover, IL	Bi-Monthly
3	IL 4M	Corn stover, IL	Quarterly
4	IL 2M	Corn stover, IL	Bi-Annual
5	IL 0M	Corn stover, IL	Stationary
6	TX 12M	Corn stover, TX	Monthly
7	TX 6M	Corn stover, TX	Bi-Monthly
8	TX 4M	Corn stover, TX	Quarterly
9	TX 2M	Corn stover, TX	Bi-Annual
10	TX 0M	Corn stover, TX	Stationary
11	NE 12M	Energy sorghum, NE	Monthly
12	NE 6M	Energy sorghum, NE	Bi-Monthly
13	NE 4M	Energy sorghum, NE	Quarterly
14	NE 2M	Energy sorghum, NE	Bi-Annual
15	NE 0M	Energy sorghum, NE	Stationary

Drying the feedstock presents a logistics issue. Moisture content of the feedstock can be anywhere from 25%-50% depending on field and weather conditions. The maximum optimal moisture content for feedstock at the pyrolyzer is 10% (Capunitan and Capareda 2010). The pyrolysis unit operating at 40 tons of feedstock as is per day generates enough BTUs to dry the feedstock to the 10% acceptable level for efficient operation of the machine (Capunitan and Capareda 2010). Energy start-up costs to initially power (heat up) the unit as well as replacement of bed sand amount to $2,000. Syngas generates sufficient heat to dry and process the feedstock once the unit has reached steady state.

The pyrolyzer can produce an average of 50 gallons of bio-oil per ton of corn stover and 45 gallons of bio-oil per ton of energy sorghum across expected moisture levels ranging from 10-40% wet basis (Capareda 2010). The pyrolysis unit has the capacity to process 40 tons of feedstock as is per day for 290 to 326 days per year, for the 12M vs 0M scenarios, respectively. On average, producers are paid a price of $67.5 per ton of feedstock delivered to the edge of the field, with a range from $60-$75 per ton depending on moisture content. The model assumes 11% of wasted feedstock during the logistics of transporting, storage and processing. The price for the feedstock includes the opportunity costs associated with additional fertilizer applications needed to replace nutrients. It is assumed that one pound of corn grain is equal to one pound of available corn stover (Pordesimo et al. 2004); however, only 25% of the available biomass in the fields will be harvested, leaving the remaining 75% on the fields for erosion control and soil sustainability purposes (Nelson 2002). The mobile pyrolysis business will own all handling, processing, and transportation equipment.

Total capital assets (beginning net worth) for the mobile pyrolysis unit are $2,169,516 and will be financed with 50% equity and 50% debt at a 7% interest rate over a 10 year period. If net cash income is positive, investors receive a dividend equal to 15% of net cash income each year. The initial capital investment in assets includes the pyrolysis machine, movable pads, access road, storage and transportation of feedstock and bio-oil. Mobile pyrolysis model assumptions are presented in Table 2, and initial capital assets in Table 3.

Table 2. Mobile Pyrolysis Model Assumptions

Variable	Unit	Value
Corn stover cost	$/ton	GRKS(60,67.5,75)
Energy sorghum cost	$/ton	GRKS(60,67.5,75)
Corn stover to oil conversion	gal/ton	GRKS(40,50,60)
Energy sorghum to oil conversion	gal/ton	GRKS(35,45,55)
Corn stover to char conversion	ton/ton	0.237
Energy sorghum to char conversion	ton/ton	0.254
Operation processing	tons/day	GRKS(30,40,50)
Wasted feedstock per day	%	11.0
Processing bio-oil to crude equivalent	$/gal	GRKS(0.20,0.30,0.40)
Discount bio-oil from crude	%	5.0
Subsidy for bio-oil	$/gal	1.00
Costs of Mobile Unit		
Fraction of unit financed	fraction	0.5
Length of loan	years	10
Interest rate	%	5.0
Operating Loan Interest Rate	%	7.0
Dividend rate on equity borrowed	%	15.0

Stochastic variables which have limited historical data series are simulated using a GRKS distribution. Similar to a triangular distribution, the GRKS distribution is fully defined by a minimum, middle, and maximum value. In the GRKS, however, the minimum and maximum represent the 2.5% and 97.5% quintiles which allows the distribution to simulate low probability events that could be beyond the assured minimum and maximum (in contrast to the triangular, which does not allow values beyond the specified minimum and maximum). The GRKS distribution has been used by Richardson et al. (2007) for simulating uncertain distributions.

The GIS data provides feedstock hauling distances from the fields to a mobile unit station, optimal routes and distances to move the mobile unit from station to station, depending on availability of feedstock, optimal routes and distances of transporting the bio-oil to a refinery (Ha et al., 2010). Table 4 presents the results of the GIS transportation analysis. These distances are then used to calculate the associated costs of the following transportation components: 1) transporting the feedstock from the fields to the mobile pyrolysis unit; 2) transporting the char from the mobile unit back to the fields to be incorporated into the soil; 3) transporting the bio-oil to the refinery; and 4) transporting the mobile unit from station to station.

Table 3. Initial Capital Assets for a Mobile Pyrolysis Unit

Initial Capital Assets	**Value**
Road to and from the Site for Delivery	18,000
Cost of a Movable Pad Material	408,600
Cost to Dismantle and Assemble slab each time	2,500
Pyrolysis Unit	1,230,833
Purchase 2 Used Tractor/Truck to pull trailers	125,000
Purchase Oil Tanker Trailer (each) 2 of these	100,000
Purchase 40 ton capacity box trailer 2 of these	9,000
Flat Bed Trailer for Feedstock	2,000
Hopper for feedstock	2,000
Decanter/Centrifuge to Separate Oil/Water	10,000
Trailer mounted Feedstock Dryer Unit 5 of these	139,250
Equipment/Tool Storage + Office Building Trailer	22,333
Nitrogen Generator	20,000
Grinder	15,000
In loader -- 3 yard	30,000
Power Generator	30,000
Other	5,000
Total of Capital Assets	**2,169,516**

Results and Discussion

The projected mean values for the total cost of production per barrel of bio-oil from the mobile pyrolysis unit ranged from $142 to $167 depending on the production scenario. Costs were broken down by feedstock costs and other costs. Other costs include the transportation costs, processing costs and finance costs. Total revenue generated included receipts from selling the bio-oil (including the $1/gallon subsidy) and the char. Table 5 presents the mean values for the estimated production costs, revenues and net revenues for all 15 scenarios. In general the mean costs of production increased as the unit moved more frequently. The 3 scenarios with the lowest cost of production for each crop station are the stationary scenarios.

The summary statistics for the NPV across the 15 scenarios are presented in Table 6. The simulation results showed a negative mean NPV for all 15 scenarios. The NPV improves (less negative) as the number of moving times is decreased. For corn stover in Illinois, the mean NPVs go from -$2.2 million with a monthly moving schedule to -$1.4 million with a stationary pyrolysis unit. Corn stover in Texas had mean NPVs from -$2.1 million to -$1.4 million if the plant is moved monthly vs. a stationary pyrolyzer. For energy sorghum in Nebraska the NPV was -$7.7 million with monthly moves and -$4.9 million for a stationary machine. The stationary plants had higher NPVs due to the savings from not moving the plant that were higher than the extra cost of longer hauls for feedstock and biochar to and from the field.

Table 4. Results of GIS Transportation Analysis for a Mobile Pyrolysis Model.

Variable	**Unit**	**IL**	**TX**	**NE**
County		Lee	Dallam	Thayer
Feedstock		Corn stover	Corn stover	Energy sorghum
Biomass yield	tons/acre	4.7	5.4	6.7
Utilized Biomass	tons/acre	1.2	1.4	6.7
Monthly Move (290 operating days)*				
Hauling feedstock	miles/year	433	451	360
Hauling char back to field	miles/year	46	48	39
Hauling bio-oil to refinery	miles/year	6,318	4,011	23,750
Relocation of pyrolysis unit	miles/year	355	160	381
Bi-Monthly Move (308 operating days)*				
Hauling feedstock/char back to soil	miles/year	670	574	670
Hauling char back to field	miles/year	72	62	72
Hauling bio-oil to refinery	miles/year	7,776	3,537	36,577
Relocation of pyrolysis unit	miles/year	340	22	299
Quarterly Move (317 operating days)*				
Hauling feedstock/char back to soil	miles/year	887	985	985
Hauling char back to field	miles/year	95	106	106
Hauling bio-oil to refinery	miles/year	6,537	3,648	28,483
Relocation of pyrolysis unit	miles/year	52	34	300
Bi-Annual Move (320 operating days)*				
Hauling feedstock/char back to soil	miles/year	1,233	1,293	1,233
Hauling char back to field	miles/year	131	137	131
Hauling bio-oil to refinery	miles/year	8,321	3,365	31,306
Relocation of pyrolysis unit	miles/year	49	13	176
Stationary (326 operating days)*				
Hauling feedstock/char back to soil	miles/year	1,945	2,026	2,026
Hauling char back to field	miles/year	209	218	218
Hauling bio-oil to refinery	miles/year	6,183	4,733	38,526
Relocation of pyrolysis unit	miles/year	0	0	0

Note: * divide miles/year by number of operating days to arrive at average transport round trip distance for feedstock. Bio oil loads leave the plant every three days.

Table 5. Mean Values for Estimated Costs of Production and Revenue of Pyrolysis Bio-oil Production for 15 Scenarios

Scenario	Cost Feed	Total Cost	Revenue	Net Revenue
	$/barrel	$/barrel	$/barrel	$/barrel
Illinois				
12 moves	63	151	122	-30
6 moves	63	146	122	-25
4 moves	63	144	122	-23
2 moves	63	144	122	-22
stationary	63	142	122	-21
Texas				
12 moves	63	151	122	-29
6 moves	63	146	122	-25
4 moves	63	144	122	-23
2 moves	63	143	122	-22
stationary	63	143	122	-21
Nebraska				
12 moves	70	167	122	-45
6 moves	70	163	122	-41
4 moves	70	160	122	-38
2 moves	70	159	122	-37
stationary	70	158	122	-36

In addition to looking at the mean values of NPV, it is also important to look at their distributions to assess the risk component associated with each scenario. Richardson and Mapp (1976) used the probability of economic success, defined as the likelihood that NPV was greater than zero, to rank different risky alternatives. The results of the simulation, presented as cumulative distribution functions (CDF), indicated that there is a low chance of a positive net present value ranging from 0% to 15% (Figures 2, 3, and 4). In Illinois the probability of success increases as the number of moving times decreases, with a stationary unit having the highest probability of success (Table 6). In the case of corn stover from Texas and energy sorghum from Nebraska, the probabilities of success increased as the moving schedule is less frequent, except for a stationary unit. Even though the mean NPVs for the stationary scenarios in Texas and Nebraska were higher, their distributions were leptokurtic, and the positive tails of their distributions were smaller, and hence they both had lower probabilities of economic success (defined as positive NPV). For a stationary unit located in Texas and Nebraska, the CDFs are steeper exhibiting a smaller range in returns because a stationary unit has higher and more constant production with more working days per year, compared to mobile scenarios, hence, reducing downside risk and increasing net returns.

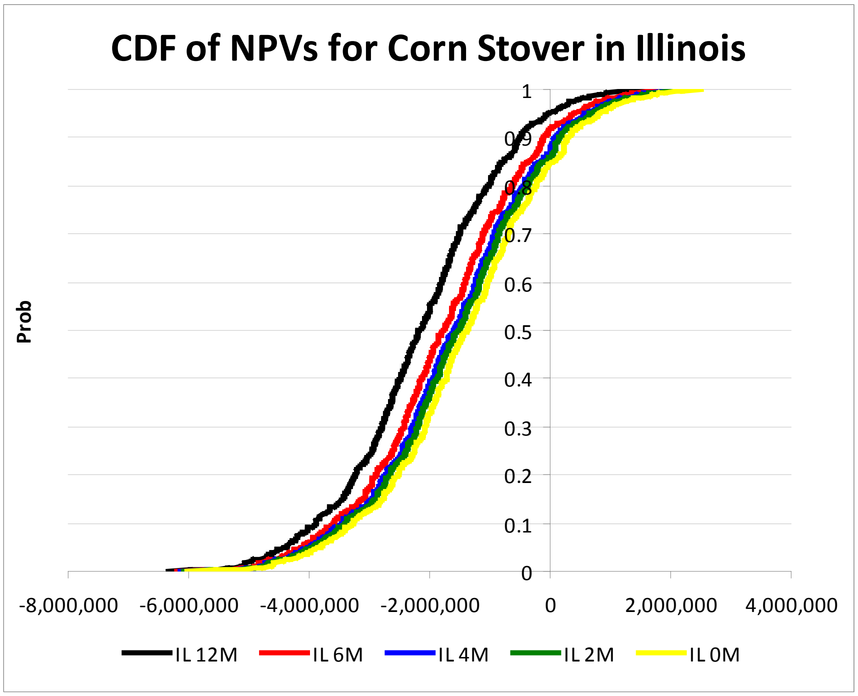

Figure 2. CDF of Net Present Values for Corn Stover in Illinois

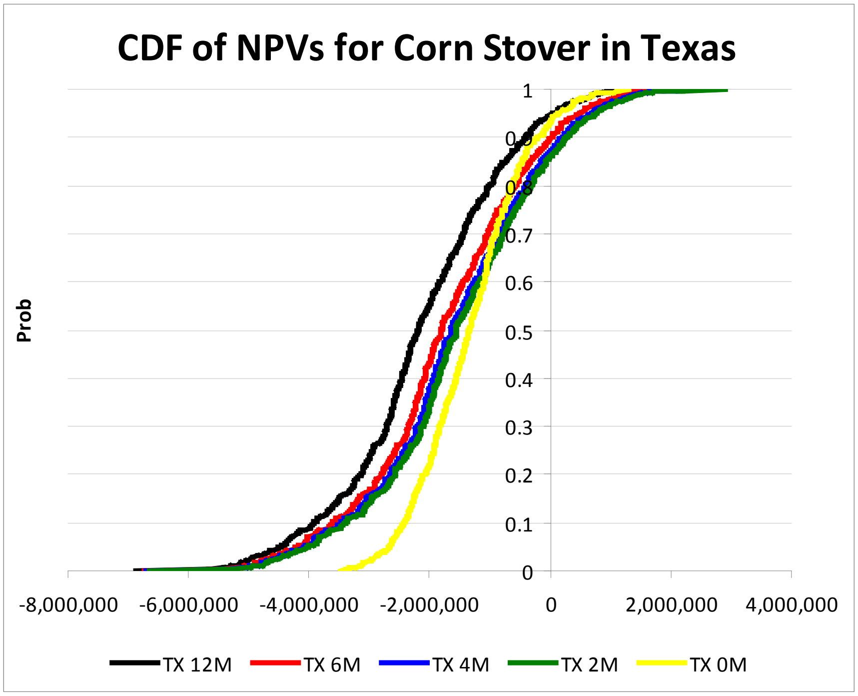

Figure 3. CDF of Net Present Values for Corn Stover in Texas

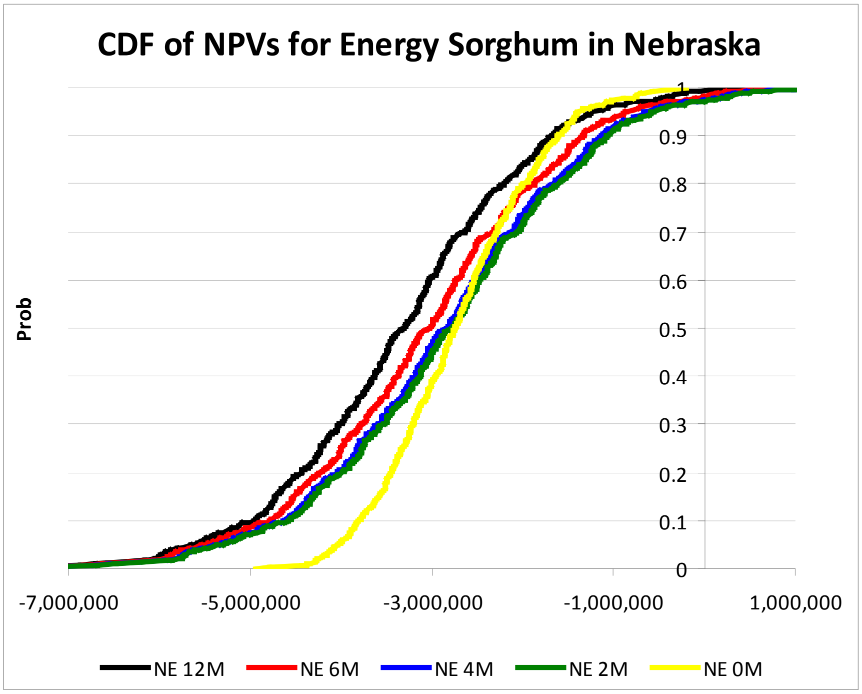

Figure 4. CDF of Net Present Values for Energy Sorghum in Nebraska

Sensitivity Analysis

This section presents a sensitivity analysis with changes in the level of crude oil prices, the costs of feedstock, and conversion efficiency of feedstock to bio-oil, and their impact on the economic feasibility of the mobile pyrolysis model. NPV would improve if feedstocks could be obtained at a lower cost than the current mean of $67.5/ton. Table 7 shows the impact of a reduction in the cost of feedstock of 10, 25, 50, and 75% on the probability of success. A 10% reduction of feedstock purchasing price, i.e. $60.8/ton would increase the probability of success from 16 to 29% for scenario IL 0M, from 15 to 27% for TX 2M and from 2 to 6% for NE 2M. In general, a probability of 90% or higher is typically regarded as a good chance of economic viability of a project as evaluated by investors. A 50% reduction in feedstock price, i.e. $33.8/ton, would increase the probability of success with 8 out of the 15 scenarios having a 90% or higher chance of success. With feedstock costs of about $16.9/ton all scenarios in all locations show a higher than 90% chance of economic success.

Recent Mid-East conflicts in Libya and Egypt, along with other market demand forces have pushed oil prices up above the $100/barrel threshold once again. As a consequence, a sensitivity analysis was conducted on the impact of an increase in oil prices (Table 8) on the probability of success for each scenario (Table 9). An average increase of 10% in oil prices over the ten-year horizon, from $79.4 to $87.3 per barrel in 2011 would increase the range of probability of success from 0-16% to 2-37%, respectively. An average increase of 50% in oil prices ($119.1 in 2011) would increase the probability of success ranges to 59-100%, with 9 scenarios with a 90% or higher probability of economic success. With mean oil prices of $139.0/barrel in 2011 all scenarios in all locations show a greater than 90% chance of economic success.

Table 6. Summary statistics of NPV for 15 scenarios

	12 Moves	6 Moves	4 Moves	2 Moves	No Moves
			Corn Stover Illinois		
Mean	(2,161,588)	(1,791,709)	(1,621,342)	(1,550,866)	(1,417,564)
StDev	1,320,525	1,364,024	1,383,891	1,390,243	1,400,731
CV	(61)	(76)	(85)	(90)	(99)
Min	(6,348,542)	(6,198,641)	(6,133,342)	(6,098,040)	(6,029,520)
Max	1,560,695	2,028,054	2,251,225	2,340,619	2,506,702
Prob(NPV<0)	95.3%	91.7%	87.7%	85.9%	84.7%
P(Success)	4.7%	8.3%	12.3%	14.1%	15.3%
			Corn Stover Texas		
Mean	(2,145,906.5)	(1,766,066.6)	(1,603,973.5)	(1,522,879.1)	(1,336,629.5)
StDev	1,344,715.1	1,390,240.8	1,413,757.2	1,419,220.7	863,696.8
CV	(62.7)	(78.7)	(88.1)	(93.2)	(64.6)
Min	(6,872,576.3)	(6,741,208.7)	(6,702,183.1)	(6,658,678.3)	(3,485,163.2)
Max	2,136,690.5	2,595,902.0	2,809,107.1	2,898,398.2	1,292,795.3
Prob(NPV<0)	94.6%	89.9%	87.0%	86.1%	93.6%
P(Success)	5.4%	10.1%	13.0%	13.9%	6.4%
			Energy Sorghum Nebraska		
Mean	(3,343,260.2)	(3,078,701.1)	(2,893,207.0)	(2,835,253.8)	(2,719,251.9)
StDev	1,355,402.9	1,423,568.7	1,444,986.8	1,455,261.1	838,796.8
CV	(40.5)	(46.2)	(49.9)	(51.3)	(30.8)
Min	(7,679,772.2)	(7,652,181.9)	(7,564,670.6)	(7,548,850.9)	(4,943,911.1)
Max	990,329.6	1,428,887.6	1,653,671.4	1,737,347.6	(196,753.6)
Prob(NPV<0)	99.5%	98.3%	97.4%	97.2%	100.0%
P(Success)	0.5%	1.7%	2.6%	2.8%	0.0%

Finally, preliminary work by Capareda et al. (2010) and Wise et al. (2011) show an increase in the conversion rates of corn stover to bio-oil. Reported conversion rates range from 70 to 90 gallons per ton of corn stover, a 60% increase in conversion efficiency from the conversion rate assumed in the simulation model. These results are yet to be replicated in a commercial scale pyrolizer. A sensitivity analysis with these higher conversion rates show a probability of success higher than 99% for all scenarios in all locations. Both syngas and biochar yields would be reduced in these scenarios but sufficient syngas would still be available for maintaining the heat in the pyrolizer and for drying the feedstock.

Table 7. Sensitivity Analysis of the Impact of Cost of Feedstock to the Probability of Success of each Scenario (NPV>0)

	Baseline	**10%**	**25%**	**50%**	**75%**
	$67.5/ton	$60.8/ton	$50.6/ton	$33.8/ton	$16.9/ton
Illinois					
12M	5%	12%	27%	74%	100%
6M	10%	18%	42%	88%	100%
4M	14%	23%	48%	92%	100%
2M	15%	25%	50%	93%	100%
0M	16%	29%	55%	95%	100%
Texas					
12M	4%	11%	29%	76%	100%
6M	11%	21%	42%	87%	100%
4M	14%	25%	49%	91%	100%
2M	15%	27%	52%	93%	100%
0M	5%	17%	59%	99%	100%
Nebraska					
12M	0%	1%	6%	36%	88%
6M	1%	3%	12%	50%	97%
4M	2%	5%	15%	61%	99%
2M	2%	6%	16%	63%	99%
0M	0%	1%	8%	75%	100%

Table 8. Oil Prices Assumed for the Ten-Year Planning Horizon.

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Base	**79.4**	**93.3**	**97.5**	**101.0**	**103.9**	**107.7**	**111.6**	**113.7**	**115.3**	**115.3**
10%	87.3	102.6	107.3	111.0	114.3	118.4	122.8	125.0	126.9	126.8
25%	99.3	116.6	121.9	126.2	129.9	134.6	139.5	142.1	144.2	144.1
50%	119.1	139.9	146.3	151.4	155.9	161.5	167.4	170.5	173.0	172.9
75%	139.0	163.2	170.6	176.7	181.9	188.4	195.4	198.9	201.8	201.7

Table 9. Sensitivity Analysis on the Impact of Crude-oil prices ($/barrel) to the Probability of Success of each Scenario (NPV>0)

	Baseline	**10%**	**25%**	**50%**	**75%**
Illinois					
12M	5%	15%	46%	90%	99%
6M	10%	25%	58%	94%	100%
4M	14%	32%	63%	96%	100%
2M	15%	33%	66%	97%	100%
0M	16%	37%	70%	97%	100%
Texas					
12M	4%	17%	47%	90%	100%
6M	11%	27%	59%	94%	100%
4M	14%	32%	63%	96%	100%
2M	15%	33%	65%	96%	100%
0M	5%	30%	79%	100%	100%
Nebraska					
12M	0%	3%	15%	59%	92%
6M	1%	6%	23%	68%	95%
4M	2%	7%	28%	74%	97%
2M	2%	8%	29%	75%	98%
0M	0%	2%	24%	88%	100%

Summary and Conclusions

This paper analyzed the economic feasibility of a mobile bioenergy pyrolysis system. Pyrolysis transforms any cellulosic materials into 1) a bio-oil similar to crude oil 2) a synthetic gas similar to natural gas, and 3) a biocharcoal substance. The model integrates a Monte Carlo financial simulation model with a transportation logistics analysis based on geographic information system (GIS) data. The GIS data provides feedstock hauling distances from the fields to a mobile unit station, optimal routes and distances to move the mobile unit from station to station, depending on abundance of feedstock, and optimal routes and distances of transporting the bio-oil to a refinery. These distances are then used to calculate the associated costs of the following transportation components: 1) transporting the feedstock from the fields to the mobile pyrolysis unit; 2) transporting the char from the mobile unit back to the fields to be incorporated into the soil; 3) transporting the bio-oil to the refinery; and 4) transporting the mobile unit from station to station.

The analysis includes 15 alternative scenarios, including 3 stations/sources of feedstocks, and 5 frequencies for moving the mobile pyrolysis unit. The three sources of feedstocks are corn stover in Illinois and Texas, and energy sorghum in Nebraska. The unit can be moved monthly, bimonthly, quarterly, bi-annually, or it can be stationary.

The results showed a low probability of economic success for all scenarios ranging from 0% to 16%. In Illinois, the probability of success increases as the number of moving times is decreased, with a stationary unit having the highest probability of success. In the case of corn stover from

Texas and energy sorghum from Nebraska, the probabilities of success increased as the moving schedule is less frequent, except for a stationary unit. For a stationary unit located in Texas and Nebraska, the maximum and minimum receipts are higher than for the mobile scenarios. A stationary unit has higher production compared to mobile scenarios, hence, reducing downside risk and increasing net returns.

A sensitivity analysis of changes in the cost of feedstock showed that if feedstock cost were reduced to $16.9/ton, all scenarios in all locations would have a 90% or higher probability of a positive NPV. Similarly, if mean crude oil prices are greater than of $139 per barrel in 2011 over the ten-year planning horizon all scenarios in all locations show a higher than 90% chance of economic success. If the conversion efficiency of feedstock to bio-oil is increased to 70-90 gallons of bio-oil per ton of feedstock (Capareda et al. 2010; Wise et al. 2011) then the probability of success is higher than 99% for all scenarios in all locations.

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