

**The Economic Feasibility of Generating Bio-energy from Biomass for  
Peak Demand of Electricity in the South Plains of Texas**

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*Selected paper for presentation at conference of the Economics of Alternative Energy  
Sources & Globalization, Atlanta, Georgia, November 15-17, 2009*

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## **Abstract**

The analysis of economic feasibility is projected by incorporating variability of crop residue biomass in order to address possible risk integrated into bio-energy production. GIS maps are used to identify the locations of ginneries and associated volumes of cotton gin waste. Combined variability related factors, the various distribution of gin trash possible supply are estimated by using Markov chain Monte Carlo method. Economic models are based on the variability to search optimal scales, and net returns in operation process converting biomass to electricity using gasification and pyrolysis/gas turbine or boiler techniques. Sensitivity analysis, cost/benefit analysis and risk analysis are also conducted. Convincing evidence shows explicit profit margin by using gasification for peak load electricity, self consumption and incidental sell. Although bio-oil production using pyrolysis technique seems profitable, capital intensity leads to economic unpractical for the process of electricity generating from bio-oil in the study region.

## **Introduction**

### 1.1 The importance and market trend of bio-fuel

Because of the high price of fossil fuels and the concerns of environment pollution, increased importance and demand for bio-fuel not only exists for the worldwide energy market, but also for national policy development. In 1999, the Public Utility Commission of Texas (PUCT) adopted rules for the state's Renewable Energy Mandate, which called for 2,000 megawatts (MW) of new renewable energy to be installed in Texas by 2009, in addition to the 880 MW of existing renewable energy generation at the time. In August 2005, Senate Bill 20 increased the renewable energy mandate to 5,880 MW by 2015 (about 5% of the state's electricity demand), including a target of 500 MW of renewable energy capacity from resources other than wind. This bill also set a goal of reaching 10,000 MW in renewable energy capacity by 2025.

Jackson and Mayfield (2007) estimated that 460,000 trillion Btu (134 trillion kWh) of electricity could be generated using biomass fuels in Texas. Of this amount, 23.7% would come from agricultural wastes. On average, Texas produced 6,266 thousand bales of upland cotton annually (USDA-NASS, 2001-2008), which equates to an estimated 1,570 thousand tons of cotton gin waste (CGW) based on a thirty percent gin trash rate during the ginning process. The region known as the South Plains of Texas is primarily an agricultural region, producing one of the nation's best cotton crops. was considered to have no monetary value or limited value in the past, but instead CGW was actually considered a liability for the environment. The utilization of CGW includes livestock feed, gardening compost, and raw materials in asphalt roofing products (Holt, 2000). Despite these efforts, most of the waste generated by the gins is discarded back onto the fields from which it came as a soil additive. Nevertheless, approximately 16,448 trillion Btu (4,791 million kWh) of electricity could be generated by using CGW in Texas, which is equivalent nearly to the energy content of 100 thousand tons of corn. Because corn ethanol requires significant amounts of fertilizers, pesticides, energy and water, bio-fuels made from crop residue are expected to supplement corn ethanol in order to assure a much more efficient method of bio-fuel production.

The trend of market demand for bio-fuel in Texas differs with national structure. According to an energy report from Texas Comptroller of Public Accounts and U.S. Energy Information Administration (May, 2008), biomass energy consumption varies by sector of the economy and by state. In Texas, industry use is more pronounced, accounting for 72% of total biomass energy consumption in 2005, according to the most recent data available; residential sector accounted for 18%; electric power and

transportation sectors only accounted for 4% and 3% respectively. The industry sector, like gins, often uses the biomass produced in its operations to generate electricity, heat and steam which are then used on site. Currently the main alternatives of advanced technologies for converting biomass to bio-energy are gasification and pyrolysis.

Biomass based gasification eliminates heating, electricity consumption from the grid and waste disposal make it a valid investment (Craig and Mann, 1996). In the study region, small scaled gasifiers are commonly used to generate energy and heat for internal use or for sell back to the grid at the time it is generated, especially for those industries producing the biomass. Char produced in gasification process also is a potential for income as a fertilizer or additive. As the most attractive technology for bio-energy generation, pyrolysis has outstanding generating efficiency, without any environmental concern. The bio-oil, char and gas produced during the pyrolysis process can be effectively used to generate electricity, which is expected to be the main source of bio-fuel. In addition, transporting and storing semi-processed bio-oils outperform the same processes on syngas/natural gas because of lower fire/explosion risk.

A strong intent exists to acquire bio-energy from the biomass, even under current technology with less converting efficiency or relatively higher costs. Companies will begin or have begun to announce plans and/or constructed facilities for biofuel production. Panda Ethanol has recently announced plans to build three manure gasification facilities in the Northern Panhandle of Texas. The towns of Hereford, Sherman, and Muleshoe in the South Plains of Texas will each be home to a 105 million

gallon per year ethanol plant<sup>1</sup>. Fuels for these plants include corn, grain sorghum, cotton gin residues, and cattle manure<sup>2</sup>.

## 1.2 Problem statement

The change of biomass from a liability to a source of income would be a positive strategy for ginners, oil mills, the textile industry, and also cotton producers. Nevertheless, because of the nature of biomass, the vision to convert it into bio-energy faces a long-standing commercialization obstacle—unstable supply (which mainly depends on weather and market price), limited scale and low efficiency, and relatively higher costs of biomass transportation. As a result, the usually low selling price and unstable profits from such kind of bio-energy generation processes restrict its scale, and are undesirable features for many investors.

In brief, movement toward commercialization demands that technical advances either focus on large processing centers that lower energy production costs for the biomass or pre-processing of the biomass on-site. What kind of technology should be chosen? And under what levels of efficiency, cost and relative scale, can the investment of a bio-energy plant achieve a considerable profit with lower risk? If most of these questions can be addressed, then bio-energy form CGW could be treated equally with other reliable sources of energy. Therefore, contracts could be made at peak load time of electricity, and the profits of bio-energy generation from CGW might present a totally different performance.

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<sup>1</sup> Panda Ethanol. <http://www.pandaethanol.com/facilities/muleshoe/index.html>

<sup>2</sup> State Energy Conservation Office, Texas Ethanol Plants. [http://www.seco.cpa.state.tx.us/re\\_ethanol\\_plants.htm](http://www.seco.cpa.state.tx.us/re_ethanol_plants.htm)

### 1.3 The objectives of this study

Regarding the economic aspects, the core points are how to effectively use the available biomass to generate renewable energy in order to meet specific market demands, while at the same time providing considerable profits with relatively lower risk. The **overall objective** of this study is to provide economic feasibility for effectively utilizing CGW in the study region to generate electricity for peak load demand and attempt to achieve maximum benefits to producers and society. To accomplish the overall objectives, various specific goals are:

- 1) Based on GIS maps and location analysis of available biomass, establish the appropriate area, locations and collectable volume of CGW which could be processed, distributed, and converted to final products for market demand;
- 2) Estimate the variability and distribution of CGW in the study region in order to take into account rainfall and other risks;
- 3) Determine the economic models for possible alternative technology that bio-energy processed and generated in terms of cost/benefit ratio, possible production capacities under regular/peak load prices, etc.
- 4) Conduct relative economic analysis: sensitivity analysis, cost/benefit analysis, rate of return, risk analysis etc.

## **Methods and Procedures**

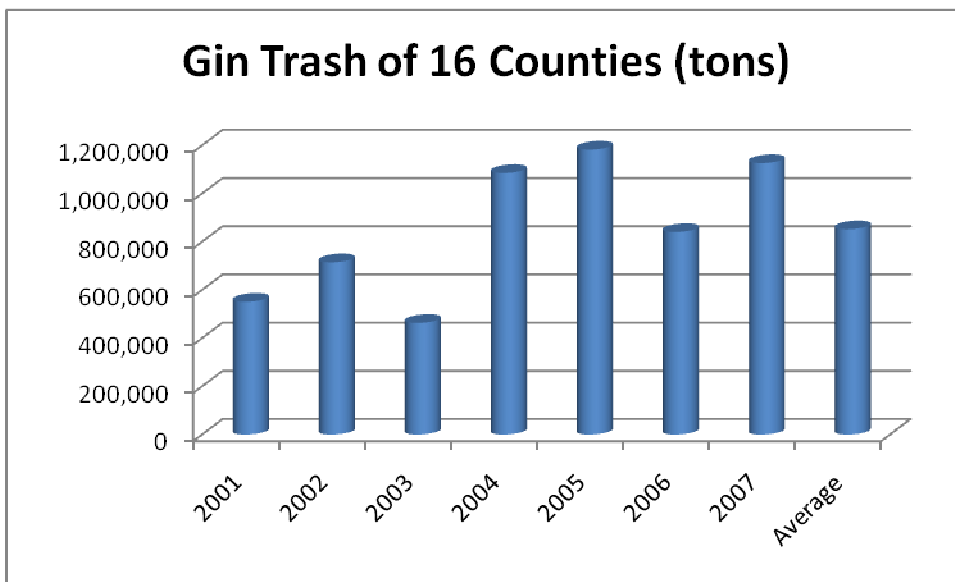
### 2.1 Data Description

Data used to accomplish the objectives include three parts: biomass data, rain fall and cotton price data, parameters and cost data of alternative technologies. The **Biomass data** includes the locations at county and individual ginner level, and the possible amount of available biomass/energy content from 2001 to 2007 according to the information provided by Texas Cotton Ginners' Association (Ginners' Red Book, 2008, Southwest Edition) and individual ginners. 79 ginners from 16 counties were selected as representatives. They are all located in the centre of the cotton production region in the Texas High Plains. The county level of cotton production data, from 2001 to 2007, was retrieved from USDA's National Agricultural Statistics Service. The 16 counties covered by ginners produced about 54% of the total cotton production in Texas; and they are Bailey, Cochran, Yoakum, Terry, Hockley, Lamb, Lubbock, Crosby, Floyd, Hale, Lynn, Garza, Dawson, Swisher, Parmer and Gaines.

Based on county cotton production, the estimated available biomass at each location is assumed in a fixed proportion over time. According to the lint, seed, and trash turnout percentages released during the 2007 and 2008 production season by some ginners in study region, the estimated CGW is 501 lbs per bale of cotton, which is close to the turnout used by Mitchell (Mitchell, et al. 2007). From previous research, it was estimated that only about 80% of the total waste generated by the ginning process would be usable for pellet or other operations (Holt et al., 2000). Consequently, the possible amount of biomass both in total and on site would be specified in order to identify the scales and transportation costs of any potential biomass pre-processing technologies and central bio-energy generation. Figure 1 shows the available CGW in the study region over recent 7 years.

**Rainfall and price data**—Observed rainfall data (NOAA,1917-2008) and farmer received cotton price data (NASS, 2001-2007) in the study region were collected and combined with the onsite CGW data in order to determine the possible distribution and variation of the amount of CGW available by taking into account main risk factors. The source of rainfall data is from Post Station of National Oceanic and Atmospheric Administration (NOAA).

Figure 1. Available CGW in Study Region over 7 Years

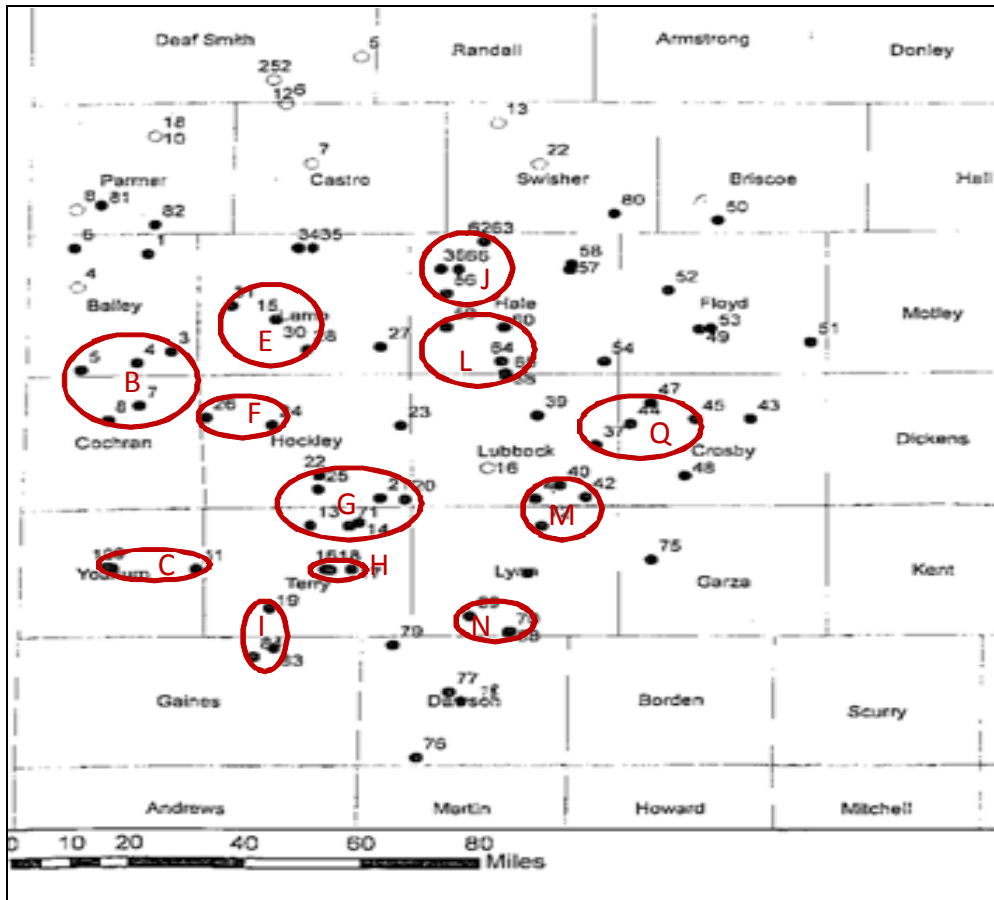


**Technical parameters, cost and other related data**—Curtis et al. (2003) showed that the energy content of a ton of CGW was 13.10 mmBTUs. This reported value is used to determine the energy content of the feedstock, thus resulting in the available supply of energy that can be obtained from CGW. Some technical parameters of gasification and pyrolysis specified for CGW are based on lab experimental data obtained by the department of Biological & Agricultural Engineering, Texas A&M University (Capareda.

S., 2009). A typical figure used in calculations for bio-gasifies is 1 ton of dry matter CGW per hour per MWe produced, in which an ideal 25% efficiency of overall conversion process from CGW to power is used; 60% and 20% of dry weight yields of bio-oil and char respectively for pyrolysis, and bio-oil heat content is 72000 Btu/gal. Other factors for bio-oil production are based on “Bio-oil Commercialization Plan” (Cole Hill Associates, 2004). The estimated capital costs for typical gas turbine-based CHP system are based on Technology Characterization: Gas Turbines (Energy Nexus Group, 2002), which includes the performance parameters, fixed and operation & maintenance costs for setting up difference sizes of gas turbines as electricity generated from bio-oil.

## 2.2 Assumptions and Possible Scenarios

Figure 2. Location information for selected groups



*Grouped CGW:* Bio-energy producers are assumed to be price takers for production inputs purchased and output sold. Their objective is to select an enterprise with a certain scale and appropriate technology that maximizes the net present value of profit or wealth. Instead of paying \$2.00 per bale to dispose of waste, the CGW from ginners is randomly grouped within 10 miles radius area from a potential location of a bio-energy processing plant based on closest rule. Therefore, 19 groups and 11 single gins, which are far away from others, are identified. The average available CGW in groups and in singles are in ranges of 3603 to 74501 tons and 2941 to 14946 tons respectively. This grouping figure is used in the following calculation and analysis through the study, and CGW available at the single gins could be either sent to groups or generated into bio-energy on site. Figure 2 provides the group location information for the selected groups for average CGW above 20,000 tons.

*Alternative technology related scenarios:* The alternative technologies intended for biomass conversion are gasification and pyrolysis in this study. Also, it is assumed that gasification is based on CGW produced by groups and on biomass from nearby or farther gins. In addition, according to Phillip C. Badger (2004), modular Bio-oil plants can be taken to sites and can directly convert biomass into bio-oil. This process is cost effective at relatively small scale (100 tpd, dry tons per day). Under current technology, the modular Bio-oil plant can handle multiple feedstocks, such as agricultural crops and residues, hog and cattle manure solids. The ROI summary for Bio-oil plants is listed as: (1) relative simple technology; (2) multiple feedstock capability; (3) multiple products with multiple markets; (4) financial security for investors; (5) cost effective at a small scale. Therefore, in this study, it is assumed that a number of modular bio-oil plants (100

tpd of size) are operated by one or a few central electric power plants to complete the process of biomass generated to bio-oil then to electricity for peak load demand. The facility of electric power generation is combined with one of the larger feedstock. For both alternative technologies used, the ending outputs of electricity can be contracted to meet high peaking power and secondary peaking power demand and also to meet on site need and incidental sales.

### 3.3 Methods and Procedures

#### *Variations and distribution of CGW supply*

In order to analyze the variations of CGW feedstock, later to determine the possible firm scales and related risk and costs, estimated distribution of CGW is projected in this study. The main factors that cause the variation in CGW production are weather and cotton price. Other factors, such as variety and harvest technology, etc., are assumed fixed based on the recent level from the time period of 2001 to 2007. The possible dimension of cotton production and related ginner's operations was based on the actual data during the time period. Fortunately, during this time period cotton producers encountered different types of weather conditions, which included extremely dry and wet years in the study region. And cotton prices also typically fluctuated during the time period. Bayesian Markov chain Monte Carlo (MCMC) method was used to estimate the parameters which provided relationships between CGW to rainfall and price. Having specified model as a full joint distribution on all quantities, whether parameters or observables, we wish to sample values of the unknown parameters from their conditional (posterior) distribution given those stochastic nodes that have been observed. The

advantages of MCMC method are obvious that samples can be taken many times (30000 iterations used) with several chains (3 chains used) from specified posterior distributions. Not only the error terms, but also the convergences of each parameter, can be observed, which would enhance the diagnostic ability about the confidence level for the estimated parameters. *WinBUGS*<sup>3</sup> software was applied for the estimation. By using a Generalized Linear Model (GLM), *WinBUGS* updates them via the multivariate sampling technique, at any iteration the proposal distribution is formed by performing iteration, starting at the current point, of *Iterative Weighted Least Squares (IWLS)*.

Next, cotton price data is simulated under an empirical distribution based on the actual price data described before. Eventually, by combining the estimated parameters, observed rainfall data and simulated cotton price data, the possible distributions of the attainable CGW for total and for group are obtained in study region. Based on the estimated distribution of CGW and combined with the bio-energy converting rates of technologies used, the possible distribution of bio-energy, such as MWe for electricity measure, can be identified and later assessed as an important risk index of economic model for identifying optimal firm size and transportation distances.

#### *Economic models and determination of optimal firm sizes*

Specifically for this study, gasification and central electric power plants are sized not only according to the amount of the biomass/bio-oil available in group and other specific areas selected under appropriate transportation cost, but also according to the biomass variation related risk issue. As the marginal profit of the bio-fuel generation grows with increasing of output prices, the transport distance of biomass collecting also expands out

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<sup>3</sup> An interactive Windows version of the BUGS program for Bayesian analysis of complex statistical models using Markov chain Monte Carlo (MCMC) techniques.

from the original site selected. The bio-energy producers have three questions to address when deciding how to produce: (1) which technology type should be chosen under specific situation; (2) what is the effective amount of retrieved biomass for optimal profit; (3) what kind of size or scale of the bio-energy generator should be set for maximizing profit and minimizing risk at the same time.

With the estimated probability density function (PDF) of CGW, expected profits could be obtained for specific technology and bio-energy output after combining the establishment expenses, possible transportation costs and variable costs for labor, storage and other operating costs. By using LINGO 11.0<sup>4</sup> program, an operational programming model searches for an optimal capacity, effective volumes for transportation that best allow higher valued peaking power contracts with local utilities, while still meeting its own power demands.

This model can be used to test the model's sensitivity to the prices of inputs/outputs, and hence increased costs associated with retrieving the biomass. Rational producers are assumed to maximize profit given their limited resources and available inputs and opportunities as well as their risk attitudes. If electricity as the end use is preferred at this point, given the maturation of the bio-energy market and technologies, generating electricity from biomass, such as through gasification and pyrolysis to bio-oil then electricity, requires a smaller plant than a motor fuels center or a large scale coal fired power plant. At the time that maintenance costs and the monitoring effort are decreased, the relatively smaller plants also limit the nimbleness of the operation to take full advantage of peak load demand electricity.

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<sup>4</sup> LINGO is a comprehensive tool designed to make building and solving linear, nonlinear and integer optimization models faster, easier and more efficient. LINGO Systems.INC.

## Model Development and Results

### 3.1 Model of Estimating CGW Distribution

$$\log(CGW)_i = \beta_0 + \beta_1 \log(rain)_i + \beta_2 \log(rain)_i^2 + \beta_3 \log(price)_i + \varepsilon, \quad i = 1 \dots 7 \quad (1)$$

Where *rain* represents the observed annual rainfall; *price* represents the cotton price.

The model is specified as a log form of CGW, and assumed to have a normal distribution with specified means and standard deviations. The mean is defined by the equation (1) with a quadratic form of rainfall, and the standard deviation is assumed with log normal prior distribution. In addition, the unknown parameters are defined as multi-normal distributed.

The evidence of convergence is found by examining trace plots of the sample values versus iteration when the simulation appears to have stabilization, which is referred to in Figure 3. The estimated parameters by using the MCMC method are listed in Table 1. All the explanatory variables have the hypothesized sign. The Monte Carlo error (MC error) for each parameter, which assesses the accuracy of the posterior estimates, is less than 5% of the sample standard deviation (SD). Figure 4 provides the estimated distribution of integrated CGW for 16 counties, and the estimated distributions of CGW for each group can be obtained by same method.

### 3.2 Economic Model for Profit Maximization

From a bio-energy producer's perspective, the potential expected profit  $E(\pi)$  of conversing biomass to bio-energy is:

$$E(\pi)_{i,s} = Prob_i * (Revenue - Cost)_{i,s}, \quad (2)$$

where *Prob.* represents the probability of possible amount of CGW available,  $i = 1 \dots k$ ;  $s$  is the size of bio-energy plant.

Figure 3. Convergent diagnosis using trace plots for parameters estimated

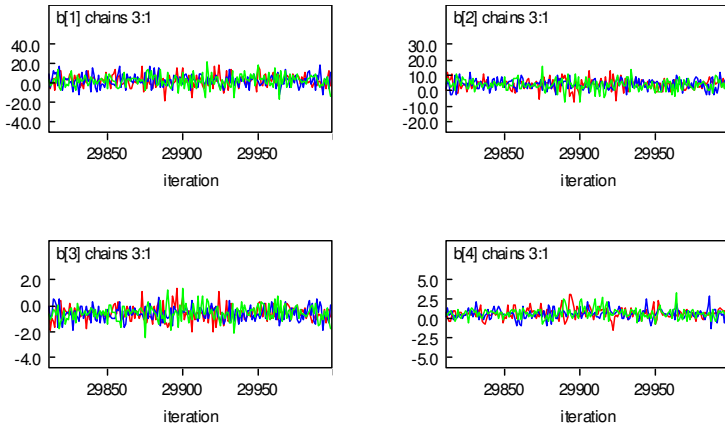
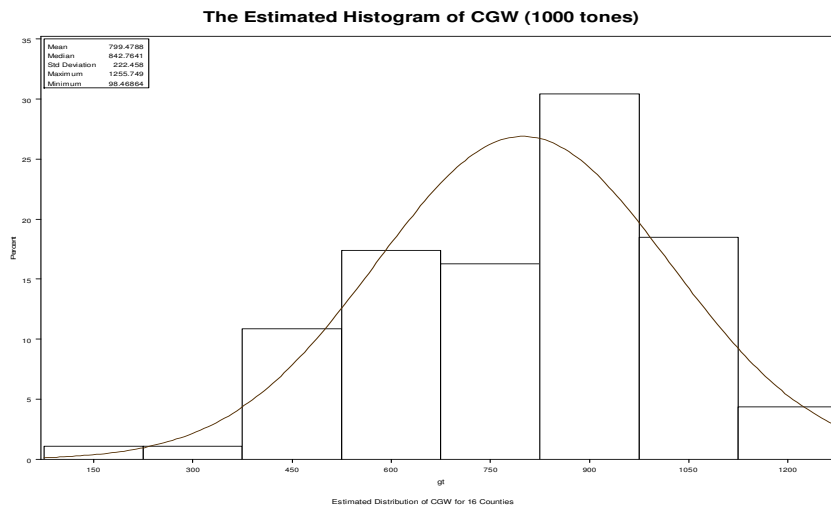


Table 1. Estimated Results of MCMC Model

Node	mean	sd	MC error	2.5%	median	97.5%	start	sample
b[1]	2.576	6.029	0.02035	-9.562	2.605	14.56	501	88500
b[2]	4.257	3.295	0.01108	-2.36	4.269	10.84	501	88500
b[3]	-0.5866	0.5413	0.001818	-1.669	-0.5888	0.5039	501	88500
b[4]	0.668	0.5919	0.001962	-0.5	0.6565	1.894	501	88500
tau	12.95	9.774	0.05568	1.525	10.49	38.17	501	88500

Figure 4.



The *Revenue* can be modeled for gasification or central power plant as:

$$Revenue_{i,s} = \sum_j Price_j * Elec_{j,i,s} + UC * Supl_{i,s} \quad (3)$$

where  $j = 1 \dots 4$  represents the outputs of electricity at peak load time, sub-peak load time, own use and incidental use; *Price* represents the contracted prices at peak and sub-peak time, and the prices of own and incidental use. It is assumed that the prices are \$120, \$65, \$45 and \$30 respectively; *Elec.* represents the quantities of electricity used for the four purposes; *Supl.* represents the possible quantity of electricity supplements if the contracts are failed because of the shortage of CGW, which is usually zero or a negative term; and *UC* is the unit cost of the supplement or penalty, and is assumed as \$140 per MWe. If CGW transportation is imposed, the supplement term will be ignored at equation (3).

Production costs include the establishment costs of facilities (fixed costs), and the annual operating costs of labor, storage and transportation. These costs can be modeled for both technologies as:

$$Cost_{i,s} = EST_s + TRC_{i,s} + VC_{i,s} + Other \quad (5)$$

where *EST* is the establishment expenses, which is depreciated over a time period of fifteen years; *TRC* is the transportation costs and only has value when transportation is imposed; *VC* is the variable costs for labor, storage and other operating costs; *Other* is the other costs of production that do not vary with  $i, s$ . Transportation cost is set out of the variable costs of operation because it varies with cotton production. If there is a drought or many of the crops are wiped out due to spring hail storms, a large amount of CGW may not be available, which again would increase the travel radius to supply the bio-energy generators.

Finally, the expected profit maximization model for gasification/central gas turbines can be established as:

$$\begin{aligned}
 MaxE(\pi) &= \sum_{i=1}^k Prob_i * (Revenue - Cost)_{i,s} \\
 s.t. \quad MW_i &\geq \sum_j Elec_{j,i,s} + Supl_{i,s}; \\
 \sum_j Elec_{j,i,s} &\leq S_i * time; \\
 VC_i &= 5.5 * \sum_j Elec_{j,i,s}; \\
 Own_i &\leq 0.5 * Factor * MW_i.
 \end{aligned} \tag{6}$$

where  $MW$  represents the possible electricity generated given the distribution of available CGW;  $S$  is the scale of the gasifier/power plant;  $time$  is the total operation time (hours per year);  $Own$  is the electricity used by gasification plant owner or the group of CGW/bio-oil suppliers, and it is assumed that only half of total electricity needed could be supported by its own;  $Factor$  here is a converting ratio representing the electricity consumption at cotton ginning and gasification processes. It is assumed \$5.5 per MW electricity generated for the calculation of  $VC$ .

Model (6) is used to search optimize firm scale and possible operational time under given situations, such as given contract hours per year for peak and sub-peak load demand. This model can be used to test the model's sensitivity to the prices of bio-energy products and its co-products, and hence increased prices associated with revenues or profits.

If transportation is imposed, instead of using the term of  $Supl$ , a term called  $TRANS$  represents the converted amount of MWe from transported CGW and an additional constraint for  $TRANS$  in terms of the firm's production capacity are incorporated into model (6) to search the possible profits as transportation is imposed.

The variables with “*i*” suffix are related to risk, such as weather conditions and prices of input and output, and are assumed to be random in all equations. It is the most important risk factor used to determine the optimal scales of bio-energy plants, and also it would exist in each year of bio-energy production.

### 3.3 Results of Economic Models for Gasification

The results of economic models of group M, as representative results of economic models, were provided in Table 2 and Table 3. A summary of assumptions for the economic models is the following: 1) the sell prices for *MWP*, *MWSP*, *OWN* and *IC* are \$120, \$65, \$45, and \$30 per MWe; 2) establishment expense is \$185,000 per MWe annually; 3) variable cost is \$5.5 per MWe generated; 4) supplement (penalty) cost is \$140 per MWe; 5) transportation cost is \$20 per ton of CGW; and 6) 50% of total electricity needed for *OWN* use could be provided by the gasification.

Table 2. Optimal Solutions of Economic Models

	Model1		Model2	
Expected Profits	\$	841,827	\$	882,917
Infeasibilities		1.36E-12		3.64E-12
Total Solver Iterations		46		18
MWP (Mwe/yr)		9227.3		9227.3
MWSP (Mwe/yr)		9764.3		9764.3
FC	\$	1,806,393	\$	1,806,393
HOUR (hour/yr)		7000		7000
Capacity (Mwe/hr)		9.76		9.76

Note: Model1 with Penalty term, Model2 with Transportation term.

The optimal capacity selected for gasification is 9.76 MWh. Operation time at its upper bound is 7000 hours, and the expected profit is \$841,827 per year. After the

transportation cost is imposed, the profit is improved about 5%. The contracted electricity supply at peak and sub-peak load time are 9227 MWe and 9764 MWe respectively.

From the results of performance distribution, the optimal capacity is selected at a point where supplements (penalties) are zero at whole range of CGW distribution; also where there is a 5% chance to affect own electricity use and a 50% chance to reduce incidental supply of electricity. After transportation imposed, the capacity excess disappears even when on-site CGW encounters shortage; both own use and incidental electricity supply are fulfilled, and the expected profit is increased.

Table 3. Distributions of Model Performance

Performance Distribution of Model 1								
Prob	Mwe	IC	OWN	Surpl.	VC	Revenue	Profits	
0.05	68350	41984	7374	0	\$ 375,925	\$ 3,333,318	\$ 1,151,053	
0.05	68350	42699	6659	0	\$ 375,925	\$ 3,322,593	\$ 1,140,328	
0.15	68350	43089	6269	0	\$ 375,925	\$ 3,316,741	\$ 1,134,476	
0.25	68350	43673	5686	0	\$ 375,925	\$ 3,307,988	\$ 1,125,723	
0.25	55780	32148	4640	0	\$ 306,790	\$ 2,915,203	\$ 802,073	
0.15	42185	19684	3509	0	\$ 232,018	\$ 2,490,390	\$ 452,032	
0.05	34870	12978	2901	0	\$ 191,785	\$ 2,261,812	\$ 263,687	
0.05	20330	0	1338	0	\$ 111,815	\$ 1,802,179	\$ -115,976	

Performance Distribution of Model 2								
Prob	Mwe	IC	OWN	Trans.	VC	Revenue	Profits	
0.05	68350	41984	7374	0	\$ 375,925	\$ 3,333,318	\$ 1,151,053	
0.05	68350	42699	6659	0	\$ 375,925	\$ 3,322,593	\$ 1,140,328	
0.15	68350	43089	6269	0	\$ 375,925	\$ 3,316,741	\$ 1,134,476	
0.25	68350	43673	5686	2.00E-03	\$ 375,925	\$ 3,307,988	\$ 1,125,723	
0.25	68350	44718	4640	12570	\$ 375,925	\$ 3,292,304	\$ 1,097,469	
0.15	68350	45849	3509	26165	\$ 375,925	\$ 3,275,340	\$ 1,066,910	
0.05	68350	46458	2901	33480	\$ 375,925	\$ 3,266,212	\$ 1,050,467	
0.05	68350	47667	1691	48020	\$ 375,925	\$ 3,248,070	\$ 1,017,785	

Price (\$/Mwe)				
Given:	<b>Capacity</b>	9.764	<b>IC</b>	30
	<b>Hour</b>	7000	<b>Own</b>	45
	<b>MWP</b>	9227.25	<b>MWP</b>	120
	<b>MWSP</b>	9764.286	<b>MWSP</b>	65
	<b>FC</b>	1806340		

*Sensitivity Analysis* To evaluate how sensitive the solution is to changing assumption, sensitivity analysis or ‘what if’ analysis provides a useful tool. The **dual prices** (shadow prices) of variables before and after transportation imposed are: \$92.6 and \$86.6 for *time*, \$89.3 and \$90.0 for *MWP*, \$34.3 and \$35.0 for *MWSP*, which are interpreted as the amount of the expected profit would improve as the constraints are increased by one unit. On the other hand, the shadow price also tells how much one should be willing to pay for additional units of a resource.

In additional, the optimal results also expose the range over which each objective coefficient can vary without changing the variables in the basis. The **objective coefficient ranges** of *MWP* and *MWSP* are [100, 145] and [46, 89] respectively, which imply that their sell prices could be changed in the ranges without causing any of the optimal values of the decision variables to change. For example, the current objective coefficient of *MWP* is 120; the contract price at peak load time could be decreased to \$100/MWe or increased to \$145/MWe without causing any changes to the optimal capacity (9.76 MWe/hour) and the optimal operation time (7000 hours/year). The objective coefficient of fixed costs is allowed to increase 0.1272 or to decrease 0.1045 from its current coefficient value of negative one. This result means that the establishment expense of the gasification plan allows a reduction of 12.72% or an increase of 10.45% from the current value. Moreover, the optimization results of the economic models tell us how far we can either increase or decrease the peak (or sub-peak) load of electricity supply without causing a change in the optimal values of its dual price. In this case, the optimal electricity supplies of *MWP* and *MWSP* are 9227 MWe and

9764 MWe yearly, and the allowable amounts of increase (decrease) for both of them are 1338 (353) MWe yearly, while their dual prices stay at \$89 and \$34 per MWe respectively.

Because the method and assumptions are same for all defined CGW groups, the optimal results of scale and dimension related variables are either expanded or shrunk based on available amount of CGW. Take group Q as an example, its optimal capacity is 4.77 MWh, operation time is 7000 hours, and the expected profit is \$411,357. However, the solution sensitivity to changing assumptions stays the same. Table 4 provides the optimal results of economic models for selected CGW groups.

Table 4. Optimal Results of Economic Models for Selected Groups

	Group G	Group M	Group J	Group L	Group Q	Group R
Expected Profits (\$/yr)	\$ 935,115	\$ 841,827	\$ 754,508	\$ 573,571	\$ 411,357	\$ 262,523
Production Capacity (Mwe/yr)	75,925	68,350	61,260	46,575	33,400	21315
MWP (Mwe/yr)	10,250	9,227	8,270	6,288	4,509	2,878
MWSP (Mwe/yr)	10,846	9,764	8,751	6,654	4,771	3,045
Fixed Cost (\$/yr)	\$ 2,006,589	\$ 1,806,393	\$ 1,619,014	\$ 1,230,911	\$ 882,714	\$ 563,325
HOUR (hour/yr)	7000	7000	7000	7000	7000	7000
Plant Scale (Mwe/hr)	10.85	9.76	8.75	6.65	4.77	3.05

### 3.4 Results of Economic Models for Bio-oil/Electric Power Generation

The calculation of financial features for bio-oil is based on the main conversion factors and costs listed in Table 5. The proposed income statement of standalone 100 tpd bio-oil plant is provided in Table 6. The breakeven bio-oil price is \$0.59/gal, which is less than half the value of its heating equivalent price of \$1.22/gal (from conventional heating oil price \$2.35/gal). If the bio-plant stands with gas turbine or boiler/steam turbine, breakeven price of bio-oil can be reduced to \$0.47/gal. Because of relatively lower

feedstock costs for CGW, this result shows a sufficient potential of profits even before adding any government subsidies.

However, after the cost of a gas turbine-based CHP system is added, which includes \$.86MM/MW of plant's capital costs and \$4.9/MWh variable costs, the economic model shows such a plant operating at a loss of \$2.2MM annually. A less costly option would be to use a more conventional boiler/steam turbine configuration. Capital equipment costs are estimated to be 30-50% lower than that of the gas turbine according to Cole Hill Associates. At the same time, taking into account \$25/ton of biomass cost along with federal subsidy, the bio-oil combined power plant would be barely operating at \$120/MW breakeven of electricity. Therefore, such a plant is capital intensive and is not considered economically viable using any reasonable economic model. This result is similar to the results obtained by Cole Hill Associates for New Hampshire Bio-oil Opportunity Analysis (Cole Hill Associates, 2005).

## **Conclusions**

This study successfully establishes the locations and collectable volume of biomass in appropriate area, and attempts to better identify the possible firm scale and relative transportation cost, which are all location specified critical points for bio-energy generation. Meanwhile, a reasonable variability and distribution of CGW is estimated in order to address risk integrated into biomass from agricultural production. The economic optimization models provide convincing evidence that gasification with certain plant scale is a profitable way to generate electricity for peak load needs, self consumption and incidental sell if necessary facilities for connecting to the grid are available. Although

bio-oil production using pyrolysis technique seems profitable, capital intensity leads to economic unviability for the process of generating electricity from bio-oil in the study region.

Table 5. Conversion Factors & Costs Used in Financial Calculation for Bio-oil Plan

Item	Amount	unit
Plant Size	100	tpd
Plant Availability	330	90%, days/yr
Raw Feedstock consumed	39,600	ton
Feedstock Composition	CGW	
Moisture Content*	20%	wt. %
Bio-oil Yield*	60%	wt. %
Bio-oil Production	3,960,000	gal/yr
Bio-oil Yield/ton	200	gal/ton bio-oil
Bio-oil heat content*	72,000	btu/gal
Density Bio-oil	10.04	lb/gal
Char Yield*	20%	wt. %
Char Production	6,600	ton/yr
Plant Capital Cost	5.6	\$MM
Equity	20%	
Debt Financed	4.48	\$MM
Return on Investment (ROI)	20%	
Debt Amortization	15	yr
Finance Rate	7%	
Electricity Consumed	7,750	mWh
Cost of Electricity	72	\$/mWh
Labor Rate (Salaried)	62,500	\$/yr
Production and G&A Staff	16	\$ 31,200
Process Heat	Bio-gas and Bio-oil for pyrolysis heat, Char for dryer heat	
Bio-oil Consumed	6%	
Char Consumed	15%	
Maintenance Cost (%Capital)	5%	
Consumable (%Sales)	5%	
Other fees (%Sales)	3%	

Source: Cole Hill Association, 2004; factors with \* are from Capareda.S, 2009.

Table 6. Income Statement of Standalone 100 tpd Bio-oil Plant

Net Sale			
Bio-oil	\$	4,547,510	
Char	\$	263,670	
Others			
Total Sales		\$	4,811,180
Cost of Goods Sold			
Labor & Overhead	\$	561,700	23%
Transport Cost	\$	27,720	1%
Electricity	\$	558,000	23%
Consumables	\$	240,559	10%
Maintenance	\$	280,000	11%
Total CGS		\$	1,667,979
Gross Profit/Loss		\$	3,143,201
Operating Expenses			
SG&A	\$	131,160	5%
Cost of Money	\$	491,880	20%
Property Tax	\$	168,000	7%
Total Operating Expense		\$	791,040
Net Profit / Loss		\$	2,352,161 ROI 96%
Break Even Bio-oil Price		\$	0.59
20% ROI Bio-oil Price		\$0.72 /lb	

Assumptions:

Bio-oil Sale Price	1.22	\$/gal
Char Sale Price	47	\$/ton
Transportation Cost	0.14	\$/ton/mile,

SG&A--Selling, General & Administrative Expense is the sum of all direct and indirect selling expenses and all general and administrative expenses.

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