Economic Aspects of Renewable Energy from Agricultural Waste on the Southern Plains of Texas

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Abstract

Motivated to explore sustainability of renewable energy from bio-waste, this study attempted to discover the economic feasibility of effectively utilizing the existing agricultural waste to generate bio-energy, to complement local nucleus business by meeting specific market demands while assessing the reasonable risk associated with bio-energy production for an area with heavy concentration of agricultural production and serious water constraints.

Since the problems to be addressed are all location specified critical points for bio-energy generation, GIS maps are used to identify the locations and the associated attainable volumes of agricultural waste. Meanwhile, reasonable variation and distribution of attainable cotton gin waste was identified by using a Monte Carlo Markov Chain simulation. Consequently, the constrained expected profit maximization model was specified to assess the optimal plant size, application of technologies and associated production outputs under multiple scenarios of market situations.

Conclusions based on the study results include that the possibility of peaking power contact for bio-energy outputs is critical for taking advantage of larger scales of bio-energy production, reducing the production risk and enhancing the competitiveness of bio-energy products. Gasifying biomass is a feasible way to generate electricity for peak load needs while satisfying self consumption and incidental sale if necessary facilities connecting to the grid are available. Mobile pyrolysis plants have sufficient potential for profits all the way through effectively converting biomass to bio-oil, hence increasing the feasibility of a large-scale bio-energy facility and the capability to meet the needs of higher valued peaking power by utilizing an existing facility at local power plants in the study region. Also, the study results imply that production of bio-energy from agricultural waste has higher risks, and the variance of profits could be immense even though at a typical area with heavy concentrations of agricultural production. Technology improvement associated with reduced expenses for plant facilities or the increased converting efficiency would be the key components for dealing the risk and commercializing bio-energy products in long term.

Keywords: sustainability bio-energy agricultural waste economic feasibility risk

I. Introduction and Problem Statement

The sustainable development of renewable energy alternatives can offer many benefits both in socioeconomic and ecological principles, such as less reliance on the earth's finite supply of fossil fuels; reduction of greenhouse gas emissions and environmental pollution. More importantly, the use of residual/waste biomass for renewable energy coould extend these general benefits, and have some special reimbursements: release the potential impacts of bio-fuels production on land and water use, avoid the conflict of "food versus fuel", and minimize total carbon emission of bio-energy production. Moreover, its unique charms are the diversified products of bio-waste conversion. The use of agricultural waste becomes a brilliant spot among the whole alternative feedstock of the bio-energy system, because it provides room for rural development and a path for high technology associated industry. Specifically, it prepares a platform to bring high value streams on line more rapidly that complement locale core business, market position and human capital on hand. From an ecological and conservational perspective, it is even more critical in an area with a heavy concentration of agricultural production and serious water constraints at the same time. The Southern Plains of Texas is a typical area just like this.

I.1 The importance of sustainable bio-fuel and the motivation for the study

Biomass is any plant or animal matter that can be used to produce energy. Many plants and plant-derived materials can be used for energy production, including food crops, grasses, agricultural residues, manure and methane from landfills. Because of the effort to be less reliant on the earth's finite supply of fossil fuels and due to the concerns about environment pollution, there is an increased importance and demand for bio-fuel not only in worldwide energy market, but also in the perspectives of national policy development. The combined federal and state mandates and subsequent subsidies on renewable energy, such as the Ethanol Mandate in the 2005 energy bill and adopted rules on the state's Renewable Energy Mandate by the Public Utility Commission of Texas (PUCT), typically provide very large profits to ethanol producers (Tyner, W. E., 2007) and thereby a substantial incentive for the industry to grow, especially in converting energy crops (corn, sugarcane and sorghum) to ethanol. Consequentially, many associated problems arise, such as impacts on land-use and other resources (water), "food versus fuel" conflicts and contribution to greenhouse gas emissions. Creating ethanol from energy crops requires significant increase in land use and amounts of fertilizers, pesticides, energy and water (Rauber, P., 2007; Environmental Defense Fund, 2007; Fargione, J. et al., 2008; Searchinger, T. et al., 2008).

Before allowing it to go too far, researchers and policy makers incorporate both socioeconomic and ecological principles into the development of renewable fuel alternatives, and realize the importance of sustainability and biodiversity through analyzing potential land-use changes associated with bio-fuel production using different feedstock (Dale, V. H. et al. 2010, ESA). Agricultural biomass residues have the potential for sustaining production of bio-fuels and offsetting greenhouse gas emissions. In fact, these residues represent an abundant, inexpensive and readily available source of renewable energy resource. Of all the renewable energy resources, agricultural biomass is the largest, most diverse and most readily exploitable resource. Bio-energy technologies provide opportunities for conversion of biomass into liquid and gaseous fuels as well as electricity (Singh, J., B.S. Panesar and S.K. Sharma, 2010). Because of the naturally existing feature of agricultural residual/waste, the use of it for bio-fuel, on one hand, would avoid the conflicts of land use, additional energy input and carbon emission. On the other hand, it also would alleviate environmental pollution associated with heavily dense wastes. In addition, the relatively concentrated agricultural residuals/wastes can be converted onsite in order to shrink the transformation costs, which is a common bottleneck of bio-energy production from biomass. Moreover, the charms of diversified products (electricity, heat, bio-oil, char fertilizers and special chemicals) of bio-waste conversion could provide room for rural development and a path for industry to adopt advanced technology, and would prepare a platform to bring high value streams on line more rapidly that complement the core business, local market position and human capital on hand. All of these are the motivation of this study, an urgent attempt to explore the economic aspects of bio-energy from agricultural waste for areas with a heavy concentration of agricultural production and serious water constraints at same time.

I.2. Availability of agricultural biomass and its characteristics

With the strong motivation, subjects then go on to assess the possible dimensions of existing agricultural residues/wastes. Cotton in Texas represents an important cash crop with relatively few alternatives. 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 thirty percent of gin trash rate during ginning process. The region known as the Southern Plains of Texas is in West Texas and is comprised of the area north of the Caprock Escarpment on the Llano Estacado, extending north into the Texas Panhandle. This area is primarily an agricultural region, producing one of the nation's best cotton crops, as well as cattle. The heaviest concentration of cotton acreage in Texas lies in the northwestern High Plains region, which is specified in Figure 1.1. Most of the cotton grown in the Texas High Plains is in two areas, an irrigated area north and east of Lubbock, and a huge dryland area south and west of Lubbock. Cotton production is the only dryland agricultural enterprise with any profit potential in this semi-arid region. Many industries, such as cotton gins, have substantial bio-waste supplies which exist already for use. The magnitude and density of the Texas cotton industry creates a very large regional fixed investment in cotton-related human capital, farm level machinery, gins, compresses, and warehouses.

Livestock manure also provides another significant resource of biomass. Manure produced from the 7.2 million head of fed cattle amounts to more than 5 million tons/year on an as-collected basis in Texas[1], especially centralized in the High Plains area. The Texas Panhandle is regarded as the "Cattle Feeding Capital of the World", producing 42% of the fed beef cattle in the United States within a 200-mile radius of Amarillo. In addition, there are about 160,000 dairy cattle in this region which is 44% of the total number of dairy cows in Texas (NASS, 2008), many of which are milked and kept in larger dairy operations. The changes in dairy operation size have increased concerns about water pollution because of the growing amount of manure biomass generated from these farms.

In the past, agricultural residues existing in the waste streams from commercial crop processing plant, such as CGW from gins and feedlot manure, have not been considered to have monetary value or have little inherent value, but have traditionally constituted a

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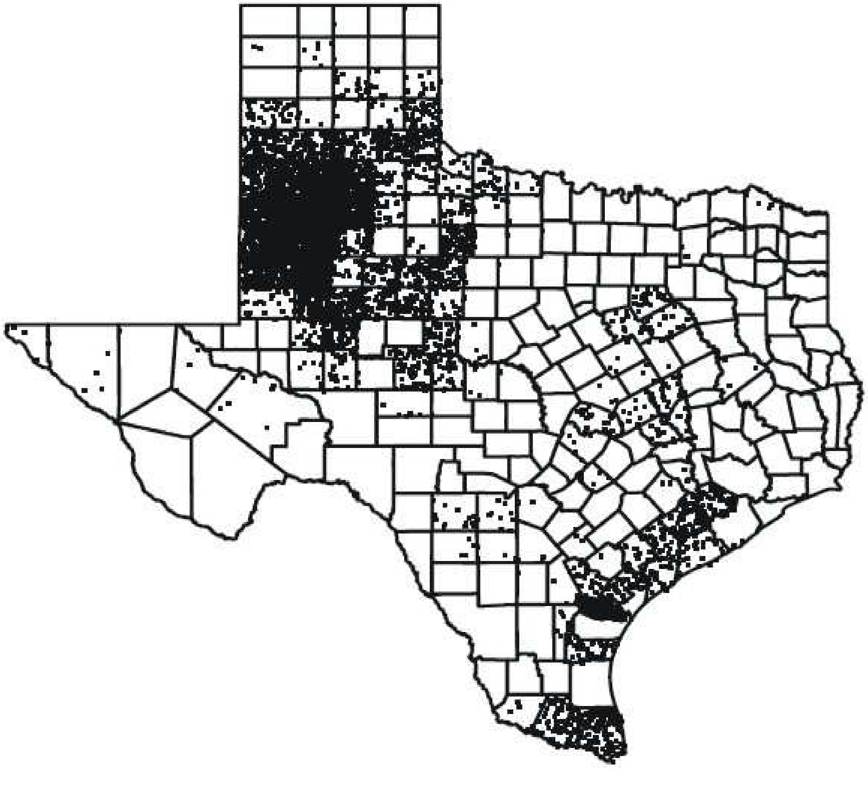
[1] Total Manure Production in Texas, Year 2004 Estimates. Texas Animal Manure Management Issues Unit, Texas A&M University. http://tammi.tamu.edu/Manuretotals(1).pdf

disposal problem. 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 and cattle feedlots is discarded back onto the fields from which it came as a soil additive. Somehow this discarding causes environmental pollution because of the huge amount of such waste dumping in a specific area. Nevertheless, approximately 16,448 trillion Btu (4,791 million kWh) of electricity could be generated by using only CGW in Texas, which is nearly equivalent to the energy content of 100 thousand tons of corn.

Figure 1.1 Regional Concentration of Texas Cotton Planting (Source: USDA/TASS)



I.3 Potential market and conversion technologies for bio-fuel

According to an energy report from Texas Comptroller of Public Accounts and U.S. Energy Information Administration (May, 2008), compared with national structure, biomass energy consumption in Texas is more pronounced by industry sector with accounting for 72% of total biomass energy consumption (2005, the most recent data available), while the contacting sector in the U.S. accounts for 55% in 2006. The industry sector, like gins and feedlots, often uses the biomass it produces in its operations to generate electricity, heat and steam which are used on site. In the study area, a strong intent exists to acquire bio-energy from the biomass. Companies will begin or have begun to announce plans and/or constructed facilities for bio-fuel 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[2]. Fuels for these plants include corn, grain sorghum, cotton gin residues, and cattle manure[3].

The conversion process of residue biomass to renewable energy is more complex than that of energy crops to ethanol. Three technical options, Enzymic hydrolysis, gasification and pyrolysis, are still in developmental stages, and currently no clear winner is apparent. Although the products of Ensymic hydrolysis compete with fossil fuel at $50-65 per barrels of oil (bbl), the most competitive one but requires additional research and large scale. The techniques of gasification and pyrolysis both are near their fully maturing stage, and compete with fossil fuel at $70-80/bbl and $70-75/bbl respectively. The

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[2] Panda Ethanol. http://www.pandaethanol.com/facilities/muleshoe/index.html

[3] State Energy Conservation Office, Texas Ethanol Plants. http://www.seco.cpa.state.tx.us/re_ethanol_plants.htm

former usually requires large scale; yet, the latter can be small scale, even on site (Campbell, A., 2010).

Biomass based gasification is a process by which biomaterial is partially combusted in the absence of air to produce carbon monoxide (CO) and hydrogen (H). This extracted gas can be fed into a gas turbine to produce electricity. The entire gasification system is relatively inefficient as the material has to be heated initially in a fluidized bed which on its own requires a lot of energy, and the collected gases must then be re-burned to produce energy which has its own efficiency losses. As another attractive technology for bio-energy generation, pyrolysis has outstanding generating efficiency, without any environmental concerns. Its product bio-oil can be hydrotreated/refined into useful liquids; bio-char and gas produced can be effectively used as an energy source for internal or external process. In addition, transporting and storing the inter-mediate bio-oils outperforms the same processes on syngas/natural gas because of a lower fire/explosion risk. It is commonly used to pre-process biomass, and then to transport it to a central power plant or a refining plant.

I.4 The problem statement and study objectives

The change of agricultural waste biomass from a liability to a source of income would be a positive strategy for ginners, oil mills, the textile industry, and cotton producers/feedlot owners. Nevertheless, because of the nature of waste biomass, the vision to convert it into bio-energy faces long-standing commercialization obstacles, which can be categorized as 1) unstable supply of waste biomass; 2) limited scale and low converting efficiency; 3) relatively higher costs of biomass transport associated with its low energy content and spread locations; 4) and converting technologies associated with higher investment risk. Most of the time, these problems have causal and interacting relationships between each other. As we can see, because of being less competitive with the conventional fuels, the usually low selling price of bio-energy products and following unstable profits restrict production scale, and lead to some undesirable features for many investors.

A biomass based energy industry may have a very different set of business and financial risks than coal and oil industries. Uncertainty over the production of the cotton crop exists in drought-stressed Texas. Around 1.8 million acres of dryland cotton exist annually on the Southern High Plains of Texas. With the promotion of water conservation programs, the acreages of dryland cotton are speculated to have an increasing potential. Cotton harvested acres, especially the harvested acres of dryland cotton, vary considerably and are heavily influenced by the incidence of dry weather (Robinson, 2009). Considerable variation and risk are un-ignorable features for most agriculture related firms. However, a few of the prior studies specify the characteristics of bio-energy generation from existing onsite agricultural waste. In addition, their studies (McCarl, B. A. et al., 1998 and 2000) most often stay general while discussing the variation of biomass. The estimation of variation distribution on agricultural wastes and its corresponding effects on bio-energy production is an area almost never being touched currently.

Because of its high moisture content, irregular shape and sizes, low bulk density and spatial distribution, biomass is very difficult to handle, transport, store and utilize in its original form. The spatial distribution of this resource and associated collection and transportation are major bottlenecks for the success of biomass energy conversion facilities (Searcy, E. et al. 2007). In fact, process improvements to date often have need of larger size operation, which require larger volumes of feedstock and therefore longer distance of biomass delivery. Moreover, the movement toward commercialization requires 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. Nevertheless, the loose, solid forms of biomass can be converted into a liquid bio-oil (pyrolysis oil), which has energy density ratios of 1/15 to loose, un-compacted straw or hay, and 1/8 to baled. Therefore, it would simplify handling transportation, storage and use of biomass. The combination of simplified handling and greater energy density significantly reduces the cost of biomass transportation and increases the feasibility for large-scale bio-energy facility. The attributes also allow biomass energy to provide base load or peaking power (Badger, P. and P. Fransham, 2006). It is clear that current technologies have abilities to relieve some of the problems, but the adoption of on-going innovations and technologies for higher valued bio-products usually require large monetary investment and strong financial support, even federal policy supports, etc. Stockholders should bear and or share business/financial risk and technological risk. Many questions arise, associated with more understandings and the ways to address the problems. Regarding the economic aspects on sustainable renewable energy, the **overall objective** of this study is to explore the feasibility of effectively utilizing the existing bio-waste to generate bio-energy, to complement locale nucleus businesses and to meet specific market demands, while at the same time providing considerable profits with relatively lower risk for an area with a heavy concentration of agricultural production and serious water constraints. To accomplish the overall objectives, various **specific goals** are as the following:

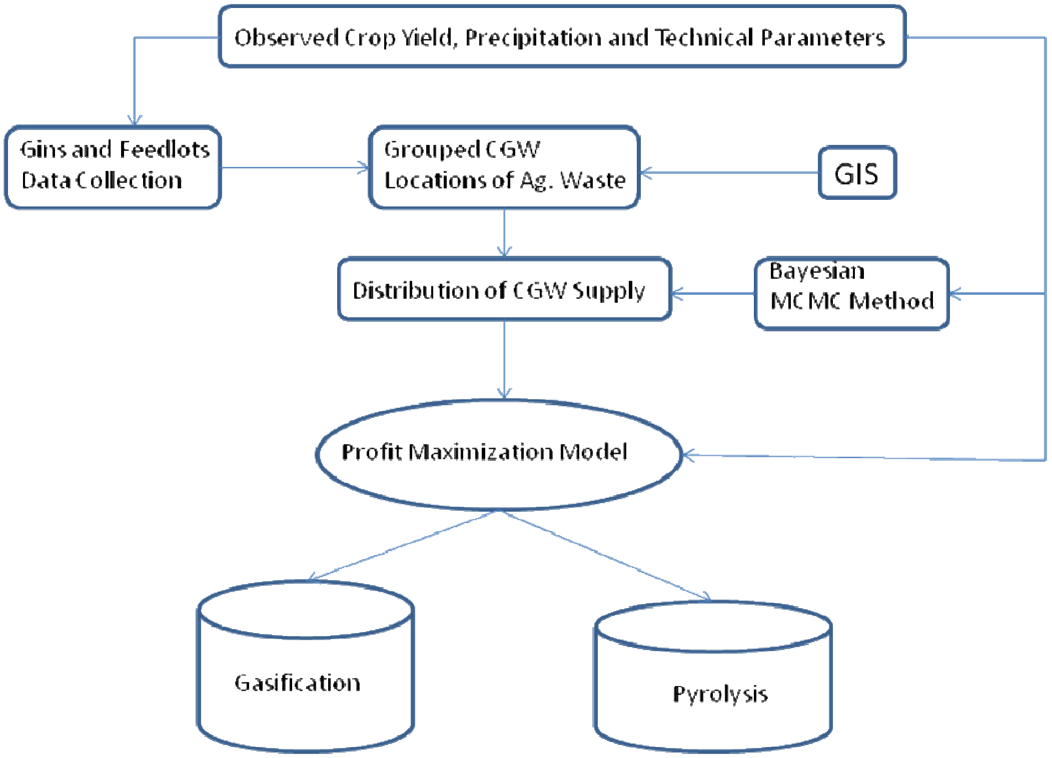
1) Identify the appropriate sites where there is sufficient, volume of CGW and manure for bio-energy production based on GIS maps and location analysis;
2) Estimate the probability distribution of obtainable CGW in the study region in order to account the particular risk associated with identifying a considerable economic scale of the new emerging industry;
3) Establish economic models for selecting optimal production scales under alternative technologies, and associated multiple scenarios of costs and market uncertainties;
4) Conduct relative analysis joined with economic models, such as cost/benefit analysis, sensitivity analysis associated model assumptions, and transport costs versus demand of biomass, etc.;

II. Methods and Procedures of the Study

To derive the economic aspects of converting agricultural waste to bio-energy on the Southern Plain of Texas, several procedures are used to step by step achieve the objectives of this study. First of all, in section one—data description states the sources and processes used to obtain a figure where sufficient biomasses exist and there is enough supplement of biomass nearby. The following section discusses the assumptions and possible scenarios used in the analysis and economic model through this study. Rather than focusing on individual gin or aggregated CGW in the study region, CGWs are grouped more with geographic location and density features as base scale for the study.

Alternative technology associated bio-energy converting processes and scenarios of input costs and output prices are also described in this section. As the core part, the last section expresses MCMC methods employed to estimate variation distribution of CGW and construction of the constraint profit maximization model in details. The steps and procedures that linked each component of the model are illustrated in Figure 2.1.

Figure 2.1 Linkages between Analytical Components



II.1 Data Description

Data collected to approach the objectives include three parts: agricultural waste (CGW and cattle feedlot manure) data, observed precipitation in the study region, and technical parameters and cost data of alternative technologies.

The **agricultural-waste** data includes the locations and volumes at a county level (NASA, 2001to 2007), and the individual ginner/feedlot level. 16 counties covered by ginners are the study focus, and they produce about 54% of the total cotton production in Texas. At the same time, referring to the information provided by Texas Cotton Ginners' Association (Ginners' Red Book, 2008, Southwest Edition), Texas Cattle Feeders' Association, and individual ginners and cattle feedlot owners, 79 ginners from the16 counties and 27 cattle feedlots nearby are selected as representatives. They are all located at the centre of cotton production and cattle feeding region on the Texas High Plains. Figure 2.2 is generated by Geographic Information System (GIS[4]) and provides the locations of the representative gins (the solid spots) and feedlots (the hollow spots) by zooming into the study area with heavily concentrated cotton acreages and cattle feeding industry.

According to the lint, seed, and trash turnout percentages released in the 2007 and 2008 production season by some ginners in the study region, the estimated CGW is 501 lbs per bale 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 is usable for pellet or other operations (Holt et al., 2000). The amount of accessible biomass at each individual gin is assumed to be fixed at a current proportion over time. Consequently, the possible volumes of biomass both on a county level and onsite level are specified. The amount of manure estimated is based on current head on feed at feedlots, numbers of days on feed, average marketed vesus on feed ratio (NASS, 2001-2007), and "Manure Production and Characteristics" (Mukhtar, S., 2007).

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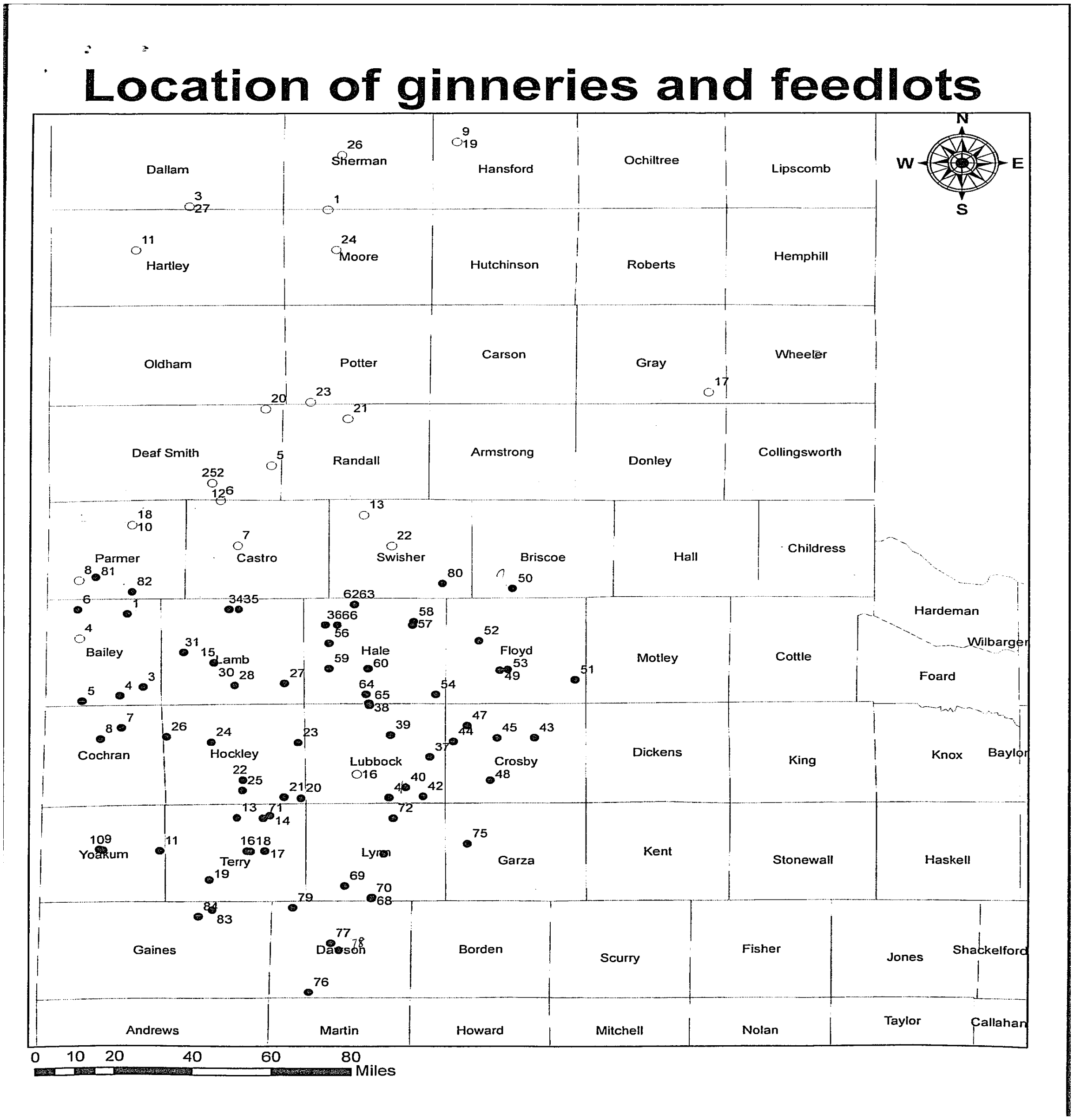
[4] A geographic information system captures, stores, analyzes, manages and presents data that is linked to location. GIS.com

Figure 2.2 Locations of Ginners and Feedlots



Notes: the solid spots are gins, and the hollow spots are feedlots.

Precipitation data—Observed precipitation data (NOAA, 1917-2008) for several locations in the study region were collected. The locations of precipitation data include the sites with a high proportion of irrigated cotton, the sites with a high proportion of non-irrigated cotton and the link sites of both typical practices of cotton production in the study region. This data combined with the onsite CGW data is used to determine the possible distribution and variation of amount of CGW available by taking into account weather and other main factors.

Technical parameters, cost and other related data—Curtis et al. (2003) showed that the energy content of a ton of CGW was 13.10 mm BTUs. Some technical parameters of gasification and pyrolysis specified for CGW are based on experimental lab data obtained by the department of Biological & Agricultural Engineering, Texas A&M University (Capareda. S., 2009). A typical figure used in calculations for bio-gasifing is 1 ton of dry matter CGW per hour per MWe produced, in which an ideal 25% efficiency for the 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 the "Bio-oil Commercialization Plan" (Cole Hill Associates, 2004 and 2005).

II.2 Assumptions and Possible Scenarios

Grouped CGW as the base scale of study

Bio-energy producers are assumed to be price takers for production inputs purchased and output sold. Their objective is to select certain scale and appropriate technology which maximizes the net present value of profit or wealth. Locations and densities of biomass are important factors for decision makers to set plant scale, avoid higher costs of biomass transportation. For this study region, available CGW with particular geographic locations and density features might be deliberated for the investors who pursue taking advantages of achievable plant scale combined technologies of bio-energy production. Therefore, rather than focusing on aggregated CGW or CGW at individual gins, the CGW from ginners is grouped within a certain radius area from a central location only based on a closest rule geographically. In this paper, we just pick a 10 mile radius area as a base scale for grouping, a middle grouping scale to represent site location and density of available CGW onsite. If further studies prefer to look at the features of other dimensions of collectable CGW, just simply change the grouping scale or the base scale and take into account the additional costs of collecting more biomass.

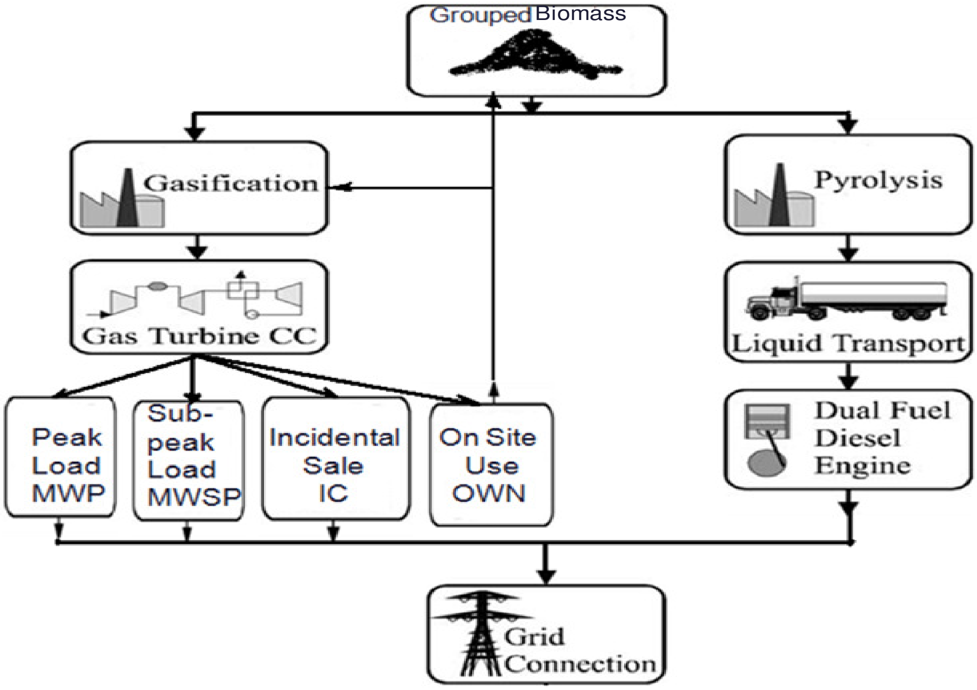
By using the base scale of 10 miles grouping, 19 groups and 11 single gins, which are far away from others, are identified. The average available CGW for groups is in range of 3603 to 74501 tons. Obviously the variety of CGW densities varies tremendous site by site. Among the 19 groups, 13 of them have CGW above 20,000 tons annually. This grouping figure is used in the following calculation and analysis through the study.

Alternative technology related bio-energy converting processes

Technology selection for bio-energy converting from agricultural waste is mainly affected by market demand for the types of bio-fuel, conversion efficiency and related cost, government policies (subsidies), etc. As discussed before, biomass based gasification eliminates heating, electricity consumption from the grid and waste disposal at the same time makes it a valid investment (Craig and Mann, 1996). In fact, under current technology, the modular Bio-oil plants can be taken to site and can directly convert biomass into bio-oil. After the pre-process, bio-oil is transport to a central power plant or a refining plant for higher valued products.

Therefore, the study scenario associated with gasifying process can be described in that 1) gasification is based on CGW available at base groups and biomass supplements from nearby or farther gins/feedlots if necessary; 2) its main outputs are electricity and heat that can be used onsite (OWN), and electricity that may be sold back to grid both for peaking demand (MWP), secondary peak demand (MWSP) and incidental needs (IC). The study scenario associated with application of pyrolysis technique can be described in that 1) a number of modular bio-oil plants (100 tpd of size) are operated and moved site by site in the study region to complete the process of converting biomass to bio-oil and other products; 2) the main product—bio-oil is transported to one or a few central electric power plant(s) to complete the process of converting bio-oil to electricity for the needs of higher valued peaking power and extreme seasons. Production purposes associated the two technologies have little difference. The production of gasification has multiple goals: MWP, MWSP, onsite needs (OWN) and incidental sales (IC) at the same time; while the use of pyrolysis technology are pre-processing biomass and to achieve higher valued outputs, such as electricity needs on MWP, MWSP and extreme seasons. The following diagram in Figure 2.3 provides a draft idea about the process scenarios for each alternative technology discussed.

Figure 2.3 Diagram of the process scenarios on alternative technologies



Scenarios on input costs and output prices

Peaking Power Contract and Regular Sale are both considered for the achievable situations. Converting agricultural waste biomass requires that the right plant scale is selected over possible input costs and output prices. Currently, one can see that bio-energy outputs can meet the gin's 'own' power demand and incidental sale to the grid, it is called "regular sale" in the study. Nevertheless, with considerable production scale combining advanced technologies, it becomes possible for commitment to a higher valued peaking power contract while satisfying power demands of the gins during ginning process. Once a contract has been committed, there is a direct supplement of electricity (Surpl.) or "penalty" for any reasonable failures of a contract. In order to avoid the "penalty", the supplement of biomass from nearby gins/fedlots is also considered, and associated transportation cost (TRANS) is set aside from variable cost in this situations. In addition, technology related plant facility cost and associated financial cost play an important role for decision makers. The **fixed costs** include capital, financing, licensing, and ‘fixed’ operating expenses associated with each MWe capacity installed. Financial assumptions made include ten years payback at an average interest rate of 7%, with 20% equity investment by processors.

Therefore, under ‘peak’ and ‘regular’, two possible circumstances of output sale, the processors have the opportunity to sell electricity within low and high bounds of prices and, also to lessen fixed cost by selecting appropriate installed capacity. Six scenarios obtained from the combinations of high or low costs/prices with respective output types are summarized in Table 2.1.

Table 2.1 Scenarios on Input Costs and Output Prices

Scenarios ($/MWe)	Peak High	Peak Low	Peak Tough	Peak Optimistic	Regular High	Regular Low
IC Price	30	25	25	30	40	40
Own Price	45	30	30	45	45	45
MWP Price	120	100	100	120	-	-
MWSP Price	65	60	60	65	-	-
Surpl.(penalty)	-140	-125	-125	-140	-	-
TRANS ($/ton)	20	20	20	20	20	20
Fixed Cost ($/MWh)	185,000	125,400	185,000	125,400	185,000	125,400

Note: $/MWh means amount of dollar cost per MWh plant capacity annually.

II.3 Model for Estimating Variation 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, the estimation of probability distribution for CGW supply is projected in this study. Although, the main factors that relate to the variation of CGW is not just the precipitation in the study region, market prices and government policies (subsidies) associated with crop structure adjustments might have considerable impacts on it. However, there are some modeling restrictions and tradeoffs when adopting long term historical data in order to incorporate more variables into the model. First of all, the spatial and density features of CGW data at gins require present state for precision; second, it becomes impossible to assume that other factors, such as cotton varieties and harvest technology, etc., are fixed at current levels for a long time period. Hence, the possible dimension of cotton production and related ginner's operations was based on the data in the time period from 2001 to 2007. Fortunately, during this time period, weather was typically fluctuating, and cotton producers encountered extremely dry and wet years in the study region.

Bayesian Markov chain Monte Carlo (MCMC) method was used to estimate the parameters which provided relationships between CGW and rainfall. Based on statistic theory and subjective probabilistic interpretation, the model is specified as a log form of CGW, and assumed to have a normal distribution with specific means and standard deviations, which is as the following

$$\log(CGW)_i = \beta_0 + \beta_1 \log(rain)_i + \beta_2 \log(rain)_i^{\,2} + \varepsilon_i, \quad i = 1 \ldots 7 \tag{2.1}$$

where *rain* represents the observed annual rainfall in the study region.

The mean of CGW supply is defined by the equation (4.1) with a quadratic form of rainfall, and the standard deviation is assumed with log normal distribution. In addition, the unknown parameters are defined multi-normal prior distributed with covariance matrix. Having specified the 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 in 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*[5] software was applied for the estimation, and updates unknown parameters via the multivariate sampling technique, at any iteration in which the proposal distribution is formed by performing iteration.

Eventually, combined the estimated parameters, observed rainfall data, the possible distributions of the attainable CGW for total and for group can be identified. In order to take into account the different features of variation distributions on achievable CGW associated with different production practices, three typical representatives (group M as mixed, group J as irrigated and group N as dryland) were discussed.

II. 4 Economic Models for Profit Maximization

Rational producers are assumed to maximize profit given their limited resources and available inputs and opportunities as well as their risk attitudes. Specifically for this study, the scale selections of gasify plants or bio-oil plants depend not only on the amount of the biomass available on sites (base groups) and the possible amount of biomass supplement

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[5] An interactive Windows version of the BUGS program for Bayesian analysis of complex statistical models using Markov chain Monte Carlo (MCMC) techniques.

from selected areas nearby under appropriate transportation cost, but also depend on the variation of biomass related risk issues.

Based on economic production theory, the expected profit maximization model for gasification/central power plant can be established as:

$$MaxE(\pi) = \sum_{i=1}^{k} \Pr ob_i * (\mathrm{Re}venue - Cost)_{i,s} \tag{2.2}$$

$$subject\ to: \ MW_i + Supl_{i,s} (or\ MWTR_{i,s}) \geq MWP_s + MWSP_s + Own_i + IC_{i,s}; \tag{2.3}$$

$$MWP_s + MWSP_s + Own_i + IC_{i,s} \leq S * time; \tag{2.4}$$

$$MWP_s = T_1 * S; \tag{2.5}$$

$$MWSP_s \leq T_2 * S; \tag{2.6}$$

$$VC_i = B_1 * (MWP_s + MWSP_s + Own_i + IC_{i,s}); \tag{2.7}$$

$$FC_s = B_2 * S; \tag{2.8}$$

$$Own_i \leq 0.5 * Factor * MW_i; \tag{2.9}$$

$$time \leq T. \tag{2.10}$$

Where *Prob.* represents the probability of attainable amount of CGW onsite, $i = 1 \ldots k$ along its probability distribution; *S* is the plant scale; *Revenue* is the production revenue; *Cost* include fixed cost (*FC*) that is associated with plant scale, variable cost (*VC*) that is associated with amount of production outputs, electricity supplements (*Supl.*), and biomass transportation cost (*TRC*) if supplement of biomass is needed. In the equations of constraints, *MW* represents the possible amount of convertible electricity given the distribution of available CGW onsite through a specific technology; *MWTR* represents the amount of MWe from transported biomass; *time* is the total operation time (hours per year) with upper boundary of *T*, T_1 and T_2 are the time constraint for peak and sub-peak respectively; *Factor* here is a converting ratio representing the electricity consumption needs on the cotton ginning processes. Other terms have the same explanations in the prior sections.

To be more specific, it is assumed that only half of total electricity needed by the gins could be supported by the bio-energy plant at the given price. Due to the lack of detailed information on technology associated costs specified for bio-waste, the model is assumed to be a linear relationship between the amount of output and variable cost and between plant scale and fixed costs. Also, referring to the information provided by similar studies (Energy Nexus Group, 2002), \$5.5 per MW electricity generated is temporally used for B_1, and the different levels of B_2 is associated with scenarios of input costs and output prices.

All in all, it is obvious that the economic model is established with enough flexibility to satisfy different situations or different preferences among decision makers, which can be specified in the following three features. First of all, the constrained expected profit model can be run under the condition of with and without transportation of biomass supplement separately for all six scenarios on input cost versus output price. Second, through adjustments on constraint equations, the model can be run for the outputs with peaking contract and with regular sells only separately. Third, the economic model can be used as well to test the model's sensitivity to the prices of inputs/outputs assumptions, and hence to detect the changes of transportation costs associated with adjustment on the amount of retrieving biomass. As a consequence of the model flexibility, comparisons of model solutions, most importantly on the profit variation, can be obtained and provide more straight forward references to the practical problems we are interested.

The variables with "*i*" suffix are related to risk. Although weather conditions and prices of input and output are all uncertain, in order to simplify the problem, the model established only allows CGW and/or its corresponding variables (i.e. *MW*) to be changed following their identified distribution. In another sentence, the variance of CGW is treated as the most important risk factor for determining the optimal scales of bio-energy plants; at the same time, the uncertainty of prices is handled through different scenarios used in the analyses.

LINGO 11.0[6] was used to perform an operational programming for profit maximization model, and to obtain optimal plant capacity, effective volumes for transportation that best allow with and without higher valued peaking power contracts with local utilities, while still meeting its own power demands and maybe incidental sale.

III. Results and Analyses

Results of parameters estimated and the corresponding CGW distributions identified are stated in the first section. Then in the following section, the results of economic models for gasification are provided, including results under different scenarios, model sensitivity analysis, and effects of biomass transportation cost. The results of bio-oil/power generation are described in the third section. Finally, comparison of economic features on application of the two technologies gives a summary for the entire results.

III.1 Results of Parameter Estimation and CGW Distribution

The estimated parameters by using MCMC method are listed in Table 3.1. Among the three categories of production practices discussed — mixed practice (average CGW), dryland and irrigated cotton, all the explanatory variables have the hypothesized sign. The Monte Carlo error (MC error) for each parameter, which assesses the accuracy of the

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[6] 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.

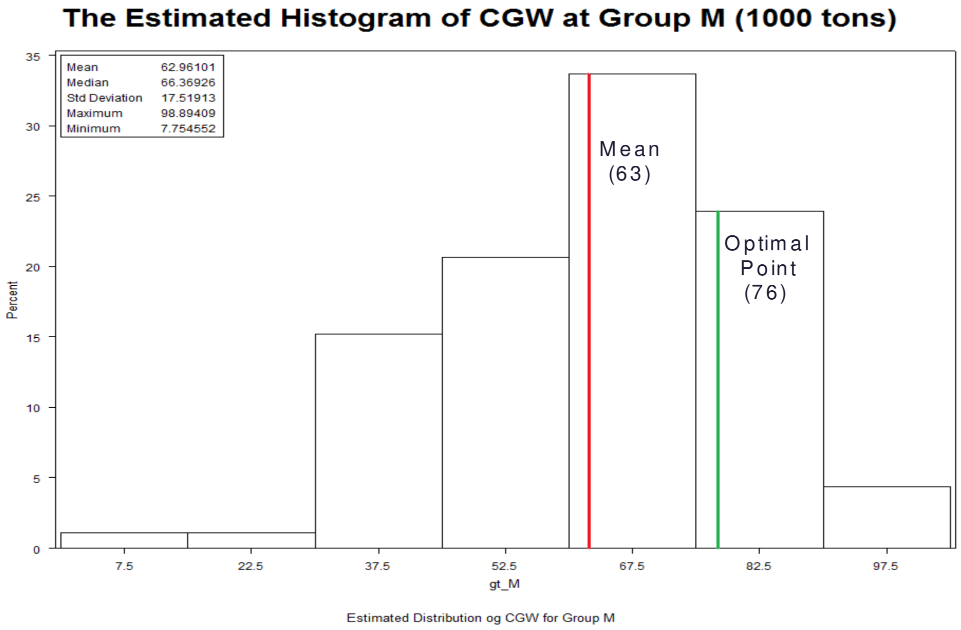
procedures of posterior estimates, is less than 5% of the sample standard deviation (SD). However, the estimated parameters have big variances, and most slope parameters estimated are close to being significant, but the intercepts of irrigated and dryland CGW are insignificant.

As the representatives of mixed practices, Figure 3.1 provides the estimated variation distribution of CGW for group M, and its location of mean level and one of the optimal points selected for plant scale by economic model later have been marked also. As we all know that the mean level usually is the base of plant scale without knowing its distribution. Additionally, the distribution of CGW is skewed to right for the irrigated site, and skewed to left for the dryland site compared to the distribution of CGW at mixed practice site. In fact, these results do contain some realistic ingredients, and could be a reference for decision makers when facing other than mixed cotton production practices.

Table 3.1 Estimated Parameters Using MCMC Method

Mixed	node	mean	sd	MC error	2.5%	median	97.5%	start	sample
	b[1]	7.031	5.058	0.01749	-3.459	7.183	16.77	501	88500
	b[2]	3.704	3.338	0.01144	-2.723	3.596	10.65	501	88500
	b[3]	-0.5014	0.5483	0.001862	-1.642	-0.4857	0.5574	501	88500
	tau	11.09	7.491	0.04014	1.7	9.392	29.93	501	88500
Irrigated	node	mean	sd	MC error	2.5%	median	97.5%	start	sample
	b[1]	-0.8795	5.377	0.01972	-10.99	-1.089	10.4	501	88500
	b[2]	7.367	3.602	0.0131	-0.1928	7.517	14.12	501	88500
	b[3]	-1.121	0.6004	0.002162	-2.246	-1.147	0.1456	501	88500
	tau	15.24	10.43	0.05613	2.266	12.83	41.78	501	88500
Dryland	node	mean	sd	MC error	2.5%	median	97.5%	start	sample
	b[1]	1.454	6.787	0.02389	-11.75	1.417	15.05	501	88500
	b[2]	4.734	4.475	0.01563	-4.243	4.766	13.44	501	88500
	b[3]	-0.5993	0.7418	0.002568	-2.041	-0.6052	0.8925	501	88500
	tau	2.892	1.846	0.009211	0.4936	2.5	7.534	501	88500

Figure 3.1 Estimated distribution of CGW for Group M (Mixed practice)



III. 2 Results of Economic Models for Gasification

The constrained profit maximization model was used to determine the optimal levels of the decision variables in the model: plant scale (S), output level (MWP, MWSP, OWN, and IC), demand of supplement biomass (MWTR) and production operating time. Additionally, the distributions of associated production profits and expected profits could be obtained for specific technology and bio-energy output. To be clear, the consequent analyses were conducted on group M, a representative of the sites with mixed cotton production practices. The followed results from the economic model can be used to test the model's sensitivity to the prices of bio-energy products and its co-products, and hence the change of prices on transportation costs associated with demand of biomass supplement, revenues or profits.

Results of economic model under different scenarios

Table 3.2 Summary of Optimal Solutions on Economic Models

Model 1 with '*Surpl.*'	Pk_High	Pk_Low	Pk_Tough	Pk_Optimistic	Reg._High	Reg._Low
Expected Profits ($)	841,827	960,788	387,378	1,457,234	315,072	782,473
MWP (Mwe/yr)	9227.3	10174.3	7530.3	10807.4	--	--
MWSP (Mwe/yr)	9764.3	10766.4	7968.6	11436.4	--	--
Fixed Costs ($)	1,806,393	1,350,110	1,474,186	1,434,128	1,114,889	999,259
HOUR (hour/yr)	7000	7000	7000	7000	7000	7000
Capacity (Mwe/hr)	9.76	10.77	7.97	11.44	6.03	7.97
Model 2 with '*TRAN*'	Pk_High	Pk_Low	Pk_Tough	Pk_Optimistic	Reg._High	Reg._Low
Expected Profits ($)	882,917	964,278	387,378	1,545,123	373,916	933,096
MWP (Mwe/yr)	9227.3	10174.3	7530.3	10807.4	--	--
MWSP (Mwe/yr)	9764.3	10766.4	7968.6	11436.4	--	--
Fixed Costs ($)	1,806,393	1,350,110	1,474,186	1,434,128	1,474,186	1,350,110
HOUR (hour/yr)	7000	7000	7000	7000	7000	7000
Capacity (Mwe/hr)	9.76	10.77	7.97	11.44	7.97	10.77

The optimal solutions of economic model are provided by Table 3.2. It is clear that optimal capacities selected for the situations with peak contracts are usually bigger than the corresponding ones without peak contracts, except when the fixed cost of plant is reduced to a low level. In order to take more advantage of the high value peak contracts, the model allows the selecting of plant size to reach a level as big as it can. Therefore, imposing transportation of biomass only increases the expected profits and has no effects on plant size selection for the situations with peak contract; however, it does affect the selections of plant scales under another situation—without peak contract/ regular sale only. After the transportation of biomass is imposed, the expected profits under regular sale are improved about 19% because of the increased plant scale; and the corresponding improvements are just about 5% or 6% for the situation with peak contracts. The operation time is always its upper bound 7000 hours. The quantities of electricity outputs at peak time (MWP) and sub-peak time (MWSP) vary with the changes of plant sizes because of the fixed contract times for the outputs. As expected, the unit fixed cost show a divergence along the changes of plant scale selected. In another sentence, the fixed costs also restrict the scale of bio-energy production.

Some detailed information on the results of economic models, such as distributions of profits and associated revenues, variable costs, and production outputs, are provided for each scenario. In this paper, we mainly discuss the results around Regular_High (Table 3.3), Regular_Low (Table 3.4), and Peak_High (Table 3.5), Peak_Low (Table 3.6). For the production of bio-energy from agricultural waste, it is apparent that the variances of production profits could be immense, especially under the condition of regular sale only without peak contracts. Transporting biomass supplements the onsite needs and shrink the variance of production profits dramatically.

Table 3.3 Performance Distribution of Economic Model under Scenario of Regular_High

Performance Distribution of Model 1 with 'Supl.' and Reg._High

Prob	Mwe	IC	OWN	Supl.	VC	Revenue	Profits
0.05	42185	34811	7374	--	$ 232,018	$ 1,724,272	$ 377,365
0.05	42185	35526	6659	--	$ 232,018	$ 1,720,697	$ 373,790
0.15	42185	35916	6269	--	$ 232,018	$ 1,718,746	$ 371,840
0.25	42185	36499	5686	--	$ 232,018	$ 1,715,829	$ 368,922
0.25	42185	37545	4640	--	$ 232,018	$ 1,710,600	$ 363,694
0.15	42185	38676	3509	--	$ 232,018	$ 1,704,946	$ 358,039
0.05	34870	31969	2901	--	$ 191,785	$ 1,409,303	$ 102,629
0.05	20330	18639	1691	--	$ 111,815	$ 821,656	$ -405,048
Expacted Value	40727	35747	4979		$ 223,996	$ 1,653,957	$ 315,073

Performance Distribution of Model 2 with 'TRAN' and Reg._High

Prob	Mwe	IC	OWN	TRAN	VC	Revenue	Profits
0.05	55780	48406	7374	0	$ 306,790	$ 2,268,072	$ 487,096
0.05	55780	49121	6659	0	$ 306,790	$ 2,264,497	$ 483,521
0.15	55780	49511	6269	0	$ 306,790	$ 2,262,546	$ 481,570
0.25	55780	50094	5686	0	$ 306,790	$ 2,259,629	$ 478,653
0.25	55780	51140	4640	0	$ 306,790	$ 2,254,400	$ 473,424
0.15	55780	52271	3509	13595	$ 306,790	$ 2,248,746	$ 184,504
0.05	55780	52879	2901	20910	$ 306,790	$ 2,245,703	$ 29,047
0.05	55780	54089	1691	35450	$ 306,790	$ 2,239,656	$ -279,956
Expacted Value	55780	50800.525	4979.47	4857	$ 306,790	$ 2,256,097	$ 373,916

Note: MWe—total electricity output; Unit: MWe, and $ as noted.

Table 3.4 Performance Distribution of Economic Model under Scenario of Regular_Low

Performance Distribution of Model 1 with 'Supl.' and Reg._Low							
Prob	Mwe	IC	OWN	Supl.	VC	Revenue	Profits
0.05	55780	48406	7374	--	$ 306,790	$ 2,268,072	$ 962,023
0.05	55780	49121	6659	--	$ 306,790	$ 2,264,497	$ 958,448
0.15	55780	49511	6269	--	$ 306,790	$ 2,262,546	$ 956,497
0.25	55780	50094	5686	--	$ 306,790	$ 2,259,629	$ 953,580
0.25	55780	51140	4640	--	$ 306,790	$ 2,254,400	$ 948,351
0.15	42185	38676	3509	--	$ 232,018	$ 1,704,946	$ 473,669
0.05	34870	31969	2901	--	$ 191,785	$ 1,409,303	$ 218,259
0.05	20330	18639	1691	--	$ 111,815	$ 821,656	$ -289,418
Expacted Value	50923	45943	4979		$ 280,075	$ 2,061,807	$ 782,473
Performance Distribution of Model 2 with 'TRAN' and Reg._Low							
Prob	Mwe	IC	OWN	TRAN	VC	Revenue	Profits
0.05	75365	67991	7374	0	$ 414,508	$ 3,051,472	$ 1,286,854
0.05	75365	68706	6659	0	$ 414,508	$ 3,047,897	$ 1,283,279
0.15	75365	69096	6269	0	$ 414,508	$ 3,045,946	$ 1,281,328
0.25	75365	69679	5686	7015	$ 414,508	$ 3,043,029	$ 1,132,247
0.25	75365	70725	4640	19585	$ 414,508	$ 3,037,800	$ 865,110
0.15	75365	71856	3509	33180	$ 414,508	$ 3,032,146	$ 576,190
0.05	75365	72464	2901	40495	$ 414,508	$ 3,029,103	$ 420,732
0.05	75365	73674	1691	55035	$ 414,508	$ 3,023,056	$ 111,729
Expacted Value	75365	70386	4979	16404	$ 414,508	$ 3,039,497	$ 933,097

Note: MWe—total electricity output; Unit: MWe, and $ as noted.

Generally, biomass transportation is preferred for most of the scenarios; however, the need base amount of transported biomass is fluctuated distinctly, especially for the situation with peak contact. Under the scenarios of Peak_High, the amount of transported biomass combined with onsite CGW allows the operation of production to be fulfilled at plant capacity at any time. However, under the scenarios of Peak_Low, biomass transportation seems no longer necessary as long as the output prices are dropped. Nevertheless, under the scenarios of Regular_High and Regular_Low, biomass transportation is necessary not only for expanding the dimension of production and increasing profits, but also for reducing the variance of the profits and production risk, and for fulfilling the plant capacity, etc.

Table 3.5 Performance Distribution of Economic Model under Scenario of Peak_High

Performance Distribution of Model 1 with 'Supl.' and Pk_High							
Prob	Mwe	IC	OWN	Supl.	VC	Revenue	Profits
0.05	68350	41984	7374	0	$ 375,925	$ 3,333,318	$1,151,000
0.05	68350	42699	6659	0	$ 375,925	$ 3,322,593	$1,140,275
0.15	68350	43089	6269	0	$ 375,925	$ 3,316,741	$1,134,423
0.25	68350	43673	5686	0	$ 375,925	$ 3,307,988	$1,125,670
0.25	55780	32148	4640	0	$ 306,790	$ 2,915,203	$ 802,020
0.15	42185	19684	3509	0	$ 232,018	$ 2,490,390	$ 451,979
0.05	34870	12978	2901	0	$ 191,785	$ 2,261,812	$ 263,634
0.05	20330	0	1338	0	$ 111,815	$ 1,802,179	$ -116,029
Expected Value	57208	33254	4962	0	$ 314,643	$ 2,962,863	$ 841,827
	Performance Distribution of Model 2 with 'TRAN' and Pk_High						
Prob	Mwe	IC	OWN	TRAN	VC	Revenue	Profits
0.05	68350	41984	7374	0	$ 375,925	$ 3,333,318	$1,151,000
0.05	68350	42699	6659	0	$ 375,925	$ 3,322,593	$1,140,275
0.15	68350	43089	6269	0	$ 375,925	$ 3,316,741	$1,134,423
0.25	68350	43673	5686	0	$ 375,925	$ 3,307,988	$1,125,670
0.25	68350	44718	4640	12570	$ 375,925	$ 3,292,304	$ 848,077
0.15	68350	45849	3509	26165	$ 375,925	$ 3,275,340	$ 547,848
0.05	68350	46458	2901	33480	$ 375,925	$ 3,266,212	$ 386,305
0.05	68350	47667	1691	48020	$ 375,925	$ 3,248,070	$ 65,207
Expacted Value	68350	44379	4979	11142	$ 375,925	$ 3,297,395	$ 882,917

Note: MWe—total electricity output; Unit of MWe for the unnoted.

To sum it up, the production of bio-energy from agricultural waste has higher risk since the variance of production profits could be immense. Peak contracts can provide a safe nest for bio-energy production from agricultural waste by allowing the production to rely less on costly biomass transportation and preparing more flexible procedures to deal with rough market circumstances.

Table 3.6 Performance Distribution of Economic Model under Scenario of Peak_Low

Performance Distribution of Model 1 with "Supl.' and Pk_Low

Prob	Mwe	IC	OWN	Supl.	VC	Revenue	Profits
0.05	75365	47050	7374	0	$ 414,508	$3,060,892	$ 1,296,275
0.05	75365	47765	6659	0	$ 414,508	$3,057,317	$ 1,292,700
0.15	75365	48155	6269	0	$ 414,508	$3,055,366	$ 1,290,749
0.25	68350	41724	5686	0	$ 375,925	$2,877,074	$ 1,151,039
0.25	55780	30199	4640	0	$ 306,790	$2,557,596	$ 900,696
0.15	42185	17735	3509	0	$ 232,018	$2,212,066	$ 629,939
0.05	34870	11029	2901	0	$ 191,785	$2,026,149	$ 484,254
0.05	20330	0	0	611	$ 115,174	$1,587,075	$ 121,791
Expacted Value	58961	33156	4895	31	$ 324,456	$2,635,354	$ 960,788

Performance Distribution of Model 2 with 'TRAN' and Pk_Low

Prob	Mwe	IC	OWN	TRAN	VC	Revenue	Profits
0.05	75365	47050	7374	0	$ 414,508	$3,060,892	$ 1,296,275
0.05	75365	47765	6659	0	$ 414,508	$3,057,317	$ 1,292,700
0.15	75365	48155	6269	0	$ 414,508	$3,055,366	$ 1,290,749
0.25	68350	41724	5686	0	$ 375,925	$2,877,074	$ 1,151,039
0.25	55780	30199	4640	0	$ 306,790	$2,557,596	$ 900,696
0.15	42185	17735	3509	0	$ 232,018	$2,212,066	$ 629,939
0.05	34870	11029	2901	0	$ 191,785	$2,026,149	$ 484,254
0.05	22632	0	1691	2302	$ 124,475	$1,714,147	$ 191,601
Expacted Value	59077	33156	4979	115	$ 324,921	$2,641,707	$ 964,278

Note: MWe—total electricity output; Unit of MWe for the unnoted.

Model sensitivity analysis

To evaluate how sensitive the solutions are to changing assumptions, sensitivity analysis or 'what if" analysis provides a useful tool. In this study, the sensitivity analyses are conducted through discussing the dual prices (shadow prices) of decision variables, the objective coefficient ranges of profit maximization model, and the allowable ranges of right hand side on the constraints of profit optimization model. The **dual prices** (shadow prices) of variables are interpreted as the amount of expected profits which would improve as the constraints are increased by one unit. Once more, the dual prices also tell how much one should be willing to pay for additional units of a resource. The **objective coefficient ranges** of profit maximization model specify the amount of allowable increase and decrease from current coefficients (based on assumptions) of objective function, while not causing any of the optimal values of the decision variables to change. In addition, the **right hand side ranges** of constraints in profits optimization model explore the allowable amount of increase or decrease from current value while their dual prices stay at same. Table 3.7 provides the detailed information of model sensitivity analyses for scenarios of Peak_High and Peak_Low.

Table 3.7 Model Sensitivity Analysis

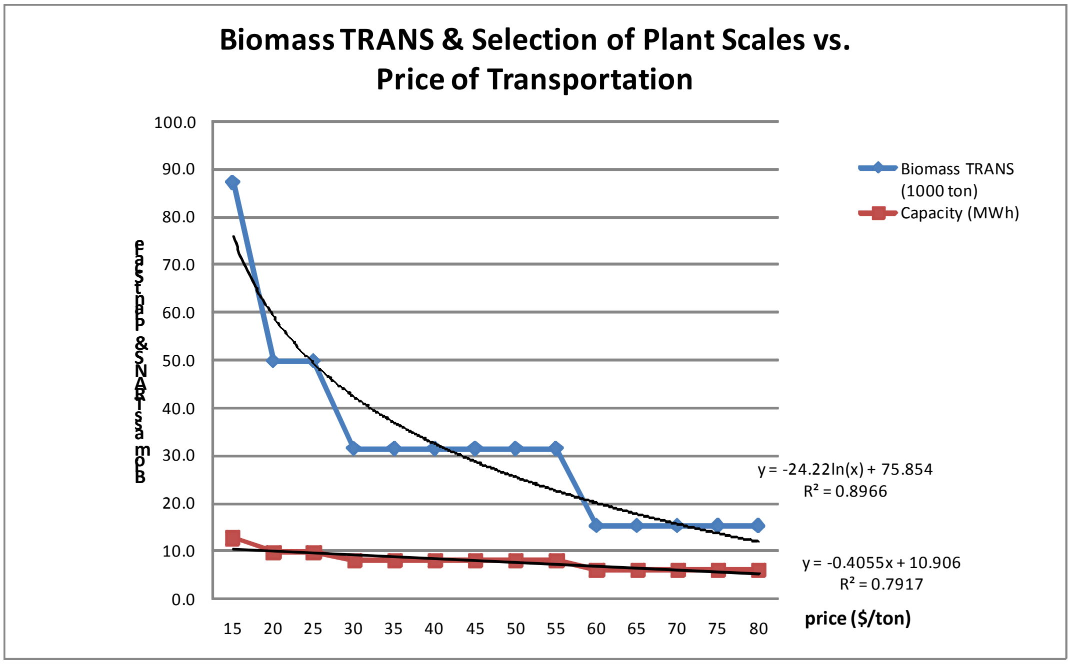
Scenario	Dual Price ($)	Range of Objective Coefficient			Allowable (Mwe/yr)	
Peak_High	(Shadow Price)	Low Bound	Current	High Bound	Increase	Decrease
MWP	89.3	100	120	145	1338	353
MWSP	34.3	46	65	89	1338	353
Fixed Cost	-	-1.1045	-1	-0.8728	-	-
Scenario	Dual Price ($)	Range of Objective Coefficient			Allowable (Mwe/yr)	
Peak_Low	(Shadow Price)	Low Bound	Current	High Bound	Increase	Decrease
MWP	69.7	95.4	100	117	11029	611
MWSP	29.7	55.7	60	76	11029	611
Fixed Cost	-	-1.0346	-1	-0.8713	-	-

Special topic—Biomass transportation

As noted earlier, because of spatial distribution and loose type of agricultural biomass, the associated costs of collection and transportation are the major bottleneck in the success of biomass energy-conversion facilities. CGW, being loose and scattered at gins, could have huge collection and transportation costs for a large bio-energy plant. Consequently, the costs of biomass collection and transportation will affect the demand of biomass and associated production capacity or plant scale selection.

Figure 3.2 shows that the demand of biomass transport is elastic to the change of transportation price. In the scenario of Peak_High, plant scale is selected at 9.76 MWh as transportation price is assumed at $20/ton. Nevertheless, as the price just drops $5 per ton to $15/ton, the preferred plant scale is increased to 12.66 MWh; conversely, as the price increase $10 to $30/ton, the preferred plant scale starts dropping to 7.97 MWh and is unchanged untill the price is increased to $60/ton. Among the three stages of selected plant scale from 12.66 to 9.76 and then to 7.97 MWh, the expected annual demands of transported biomass are 87.2 tons at 95% of time, 49.8 tons at 50% of time and 31.5 tons at 25% of the time.

Figure 3.2 Biomass transportation & selection of plant scale vs. transportation price



III.3 Results of Economic Models for Bio-oil/ Power Generation

The results of economic analyses are discussed separately for mobile pyrolysis plant and central power plant in order to trace the whole process of biomass to bio-oil and then to electricity. For a modular bio-oil plant with processing capacity of 100 tpd, raw feedstock consumed is about 39,600 tons under 20% moisture content and 330 days of plant availability; and bio-oil production is 3,960 thousand gallons (19,800 tons) annually. As might be expected, about thirteen such kind of bio-oil plants, each with plant capital cost around $5.6 million (MM), might be needed to convert CGW to bio-oil from gin to gin in the study region. Assuming 20% equity investment and borrowing of $4.48MM over a period of 15 years at an average interest rate of 7%, the annual debt payment (principle and interest) will be approximately $500,000. Furthermore, with the knowledge that the heat content of bio-oil is approximately 52% that of No. 2 fuel oil, to obtain the same energy release as that of conventional heating oil it would take 1.92 times more bio-oil. Consequently, the energy equivalent price of bio-oil would be $1.22/gal contrasting with $2.35/gal retail price on No. 2 fuel oil[7].

According to cost/benefits analysis, breakeven price of bio-oil is calculated as $0.59/gal, $0.42/gal after adding $25/ton biomass cost affordable with a federal subsidy. To attract serious investors and bank financing, a minimum 20% return on investment (ROI) would be needed, which would require a bio-oil sale price of $0.72/gal ($0.56/gal with subsidy). Since the concentrated feature of CGW associates a relatively lower collecting cost in the study region, there is a sufficient potential for profits on converting CGW to bio-oil. Following are the considerations for the feasibility of bio-oil commercialization. Compared to the use of conventional heating fuel at a power plant, the less heat content of bio-oil almost doubles the transportation cost of bio-oil for one unit electricity output; besides, additional facility cost associated with handling bio-oil also are required in power plants. To keep competitive with other sources of heating oil, bio-oil prices have to be dropped to $0.41/gal because of the higher transporting costs, which is close to the

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[7] Current retail price at U.S. Energy Information Administration, http://tonto.eia.doe.gov/dnav/pet/PET_SUM_MKT_A_EPD2_PRT_CPGAL_M.htm

breakeven price ($0.42/gal) of bio-oil when adding a federal subsidy of $25/ton biomass. On the other hand, Badger, P.C. and Fransham, P. (2006) estimated $2,168 thousand capital costs on equipment and installation costs for such bio-oil handling systems at a 50 MWe power plant. The estimated profit dropped down associated with this cost is about $1.89 per MWe electricity at peaking load.

III.4 Comparison of economic features on the two technologies

To conduct a simple comparison on aggregated results from the two technologies in the study region, first we look at their total outputs of bio-energy from agricultural waste in the study region. The use of pyrolysis technique could achieve 663,267 MWe electricity output annually, which is 28.9% higher than it from applying gasification. Moreover, more than 70% of electricity outputs from gasification is for the gin's own use and incidental sale, which have relatively lower ability to contribute production profits. Conversely, because of the easily handling, storage and transporting features of bio-oil, the whole output of electricity from bio-oil has the ability to meet the needs of higher valued peaking contract and extreme seasons. Consequently, the associated production revenues or profits in total would be tremendously increased through the whole processes of agricultural waste to bio-oil and then bio-oil to electricity.

On the other hand, we must consider the fixed costs of the two technologies. The thirteen mobile pyrolysis facilities estimated have a fixed cost of about $6.5 million annually and $1.25 million additional costs on bio-oil handling system at five power plants each with 50 MWe of capacity. However, the aggregated fixed costs of gasification facilities are about $13.6 million annually. Obviously, the total annual fixed costs of bio-oil and electricity production are estimated much lower than corresponding costs of gasification, since the collaboration with local power plants provides a possibility to utilize existing facilities of electricity generation.

The final point is about the possibility of electricity generation and accessing the electricity market through the two technologies. Because renewable energy generating facilities generally depend on the availability of energy resources at specific sites--often at sites remote from major electricity grids--transmission issues will affect the penetration of renewable fuels into the electricity generation market. Therefore, unlike storable and deliverable bio-oil offering location flexibility for electricity generation, the use of gasification technology to market electricity might be restricted by transmission grids. In other words, the economic feasibility could be physically infeasible for converting biomass to electricity through gasification. As a matter of fact, because electricity generation from renewable sources generally is more expensive than power from conventional sources, unconstrained competition in electricity generation would likely result in a reduced role for renewable energy facilities. In regards to sustainable renewable energy generation, it is essential for the emerging industry that a highly integrated system exists between biomass suppliers, pre-processing conductors, services of delivery and electricity generators. Contracts with combined policy supports from the federal government could be fundamental for achieving the entire goal.

IV. Summary and Conclusions

Motivated to explore sustainable renewable energy from bio-waste, this study attempted to discover the economic feasibility of effectively utilizing the existing agricultural waste to generate bio-energy, to complement local nucleus business and to meet specific market demands, while assessing the reasonable risk associated with bio-energy production for an area with heavy concentration of agricultural production and serious water constraints. Even though there are limited prior studies on the topic, especially on the variation of agricultural waste and its corresponding effects on bio-energy production, an effort has been made in this study to better identify the feasible firm scale and relative transportation costs under production and marketing risk, which are all location specified critical points for bio-energy generation.

The summary of study results is in the order of specific objectives. First of all, the locations and collectable volume of agricultural biomass were identified successfully in the central area of the Southern Plains of Texas, based on GIS maps and associated location analysis.

Meanwhile, some reasonable variations and distributions of attainable CGW were projected for the sites with different cotton production practices and consequently provide a solid base for addressing particular risk integrated into the new emerging industry in the study region. More specifically, the estimated distributions of attainable CGW prove an observable shifting to right or to left among the irrigated sites and the dryland sites from the mixed sites, and these shifted distributions of CGW also provide solid foundation on plant size selection for risk averse investors.

The third, economic optimization model provides convincing evidence that, no matter which technology is applied, the possibility of peak contract for bio-energy outputs is critical for taking advantages of larger scales of bio-energy production, reducing the production risk and enhancing the competitiveness of bio-energy products. As an assist pump for bio-energy production with peak contract, transport biomass would increase the expected profits, shrink the variance of profit distribution dramatically, and then, lessen the investment risk consequently. It is apparent, especially for the application of gasification technique, that the costs of biomass transportation plays an important role in the selection of plant scale and associated amount of biomass demand for bio-energy production. On the other hand without peak contract, the considerations on firm sizes of bio-energy production become more conservative. Even though, transporting supplement of biomass allows increasing the firm size, the consequent “bottleneck problem” of higher transportation costs causes the firm to be exposed in a situation of even higher market risk, without any considerable shelter.

Additionally, the cost of plant facility (fixed costs) is another vital factor that is associated with selection of plant scale, variation of profits and flexibility of bio-energy production. Technology improvement associated with reduced expenses on plant facilities or increased converting efficiency would be the key components for dealing the risk and commercializing bio-energy from biomass long term.

It has been shown that there is a sufficient potential for profits when converting CGW to bio-oil since concentrated features of CGW are associated with a relatively lower assembling costs in the study region. Pre-processing agricultural biomass to bio-oil significantly reduces the cost of transportation, increase the feasibility for large-scale bio-energy facility and the capability to meet the needs of higher valued peaking power. Nevertheless, compared to other heating fuel, the less competitiveness caused by additional costs associated with using bio-oil obviously becomes the biggest barrier for commercialization of bio-oil.

The main conclusions and implications of this study are as the follows:

1) The production of bio-energy from agricultural waste has higher risks, and the variance of production profits could be immense even though located at a typical area with heavily concentrations of agricultural production. Technology improvement associated with reduced expenses for plant facilities or increased converting efficiency would be the key components for dealing the risk and for commercializing bio-energy products in a long term;
2) Peak contracts can provide a safety net for bio-energy production from agricultural waste by allowing the production to less rely on the costly biomass transportation and preparing more flexibility when dealing with rough market circumstances;
3) For most biomass owners in the study region, gasification with certain plant scale is a feasible way to generate electricity for peak contracts while satisfying self consumption and incidental sale if necessary facilities connecting to the grid are available;
4) Mobile pyrolysis plants have sufficient potential for profits all the way through effectively converting biomass to bio-oil, hence increasing the feasibility of a large-scale bio-energy facility and the capability to meet the needs of higher valued peaking power by utilizing an existing facility of power generation in the study region. At the same time, highly integrated systems by means of contracts or federal support is critical to achieve the goal, such as the integration between biomass supply, pre-processing to bio-oil, services of delivery and power generation.

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