A PROBABILISTIC INVENTORY ANALYSIS OF BIOMASS FOR THE STATE OF TEXAS FOR CELLULOSIC ETHANOL

A Thesis

by

MATTHEW ALAN GLEINSER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2009

Major Subject: Agricultural Economics

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Approved by:

Chair of Committee,	James W. Richardson
Committee Members,	Joe Outlaw
	F. Michael Speed
Head of Department,	John P. Nichols

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ABSTRACT

A Probabilistic Inventory Analysis of Biomass for the State of Texas for Cellulosic Ethanol. (May 2009)

Matthew Alan Gleinser, B.S., Texas A&M University, College Station

Chair of Advisory Committee: Dr. James Richardson

Agricultural and forestry wastes for the use of creating cellulosic ethanol were inventoried for each county in Texas. A simple forecast was created for each of the agricultural wastes and then a multivariate empirical distribution was used to simulate the range of biomass available by county and district. The probability that a district could support a 25, 50, 75, or 100 million gallon cellulosic ethanol plant is estimated from the Monte Carlo simulation results.

Biomass in Texas is concentrated in the Northern and Eastern areas of the state. The areas of South and West Texas have little to no biomass available to use for cellulosic ethanol. The North East, South East, and Upper Coast districts include forestry waste that increase the amount of available biomass. With 100 percent certainty the North East and South East districts can support four 100 million gallon cellulosic ethanol plants each. The research found that there is more than enough biomass to support numerous cellulosic ethanol plants in Texas, and decision makers can use the results of this study to identify regions of low and high risk for available biomass from agricultural and forestry waste.

DEDICATION

To Gene and Lesa Bowers, Chris, Deb, and Jon Gleinser, and Gerald and Pat Klinkerman

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Richardson, for his guidance and patience in my research. I also would like to extend my gratitude to Dr. Outlaw and Dr. Speed for serving on my committee. I also would like to thank Caroline Gleaton and Vicki Heard for their help during my time in the Agricultural Economics Department. Special thanks to Mom and Gene, Dad and Deb, Jon, Mike, and Mark for their help throughout my life.

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CHAPTER I

INTRODUCTION

Over the past 5 years crude oil prices have increased from less than $30 a barrel to over $115 a barrel and are now less than $60 per barrel. The dramatic increase in crude oil prices spurred an interest in alternative energy. Alternative energy sources range from solar, wind, geothermal, and ethanol. The first three have the potential to aid in the process of making electricity, however, they do not help to alleviate the high fuel prices that have occurred due to high crude prices. Ethanol has the potential to become an alternative fuel source for gasoline. Not only can it be an alternative it can also be an additive, which will help decrease the United State's dependency on foreign oil, and provide a fuel source that can be made from renewable resources.

Ethanol can be made from either corn grain or from biomass using a cellulosic process. Conventional ethanol is made from corn grain. However, the conversion yields for this process are small and inefficient. Also, corn grain is costly with prices rising rapidly in 2007 and 2008. According to Sanderson (2008), currently, bioenergy from second generation cellulosic feedstocks cost more than fossil fuels. Another issue in dealing with corn grain as the feedstock for ethanol is that corn is used for food and livestock feed. The cellulosic process takes cellulosic material and uses cellulase or sulfuric acid to get five and six carbon sugars. Recombinant yeast or bacteria is applied to these sugars and the result is ethanol (McCoy). The cellulosic process uses cheaper

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feedstocks than conventional corn grain ethanol. However, the process to convert to ethanol is more costly because the extensive process required. The enzyme cellulase used to convert cellulose to sugar is currently too expensive for commercial use (DiPardo 2000). The cellulosic material used to create ethanol is agricultural and forestry biomass products and/or wastes.

Agricultural products such as sweet sorghum, switchgrass, and other dedicated energy crops can be grown specifically for cellulosic ethanol production, but a downside for these products is that they compete with food crops for land use. Agricultural wastes available for ethanol conversion include crop residues, such as: wheat straw, corn stover (leaves, stalks, and cobs), rice straw and bagass (sugar cane waste). Forestry wastes include under utilized wood and logging residues; rough, rotten, and salvable dead wood, and excess saplings and small trees (DiPardo 2000). The quantity and concentration of these wastes vary by type and location.

Agricultural wastes such as corn stover and wheat straw are concentrated in the Midwest in states such as Iowa and Nebraska. Forestry wastes are concentrated to areas in the Southeast (such as Georgia) and the Pacific Northwest (Oregon and Washington). These regions have their specialties and can contribute cellulosic material to the process of making ethanol. Texas has both crop and forestry waste products and is one of the nations leading agricultural producing states.

Problem Statement – With the cellulosic production technology nearing commercial availability to produce ethanol, where and what is the concentration of cellulosic feedstocks available in Texas? What is the probability that adequate supplies of agricultural and forestry wastes would be available in each county?

Objective

The objective of this study is to develop a probabilistic inventory of agricultural and forestry wastes for the state of Texas. This probabilistic inventory will show the type and quantity of biomass available on a per county and district basis for Texas. Not only will there be an expected volume of biomass associated with each county, but we calculate the probability that a district has enough biomass to support different size cellulosic ethanol plants.

Justification

Legislators have taken several steps to increase the production of cellulosic ethanol. The Energy Independence and Security Act of 2007 calls for increasing production of renewable fuels from 4.0 billion gallons to 36.0 billion gallons by 2022. The Energy Policy Act of 2005 calls for a cellulosic biomass program to deliver the first 1 billion gallons of annual cellulosic biofuel production by 2015. These mandates indicate Congress wants increases in the production of cellulosic ethanol. However, to produce ethanol from a cellulosic process, the location and concentration of a reliable supply of agricultural and forestry wastes is needed.

An inventory assessment provides the location of the biomass available for the production of cellulosic ethanol. Biomass inventories have been done by Washington

State, Oregon Department of Energy, and the United States Department of Agriculture (USDA). However, these studies only show a deterministic or point forecast for the amount of biomass in an area. This study will use stochastic simulation to incorporate variability into the forecast of residue production. The probability distribution associated with the amount of biomass that a county or district can produce is essential when choosing the location and size of a cellulosic ethanol plant.

Outline for the Study

Chapter II provides a review of the literature. The assumptions and methodology for this study are provided in chapter III. The results for this research are provided in chapter IV. The paper concludes with some final thoughts and summaries of the methods and results.

CHAPTER II

REVIEW OF LITERATURE

Biomass assessments have been done for specific regions, states, and even for the entire United States. However, there has not been an assessment that focuses strictly on Texas while estimating the variability for biomass production. This review of literature will focus on:

- Cellulosic ethanol and production
- Biomass inventories.

Cellulosic Ethanol

The process for making cellulosic ethanol is explained by Wyman (1999). The material-handling operation brings the feedstock into the plant, for storage and preparation for processing. Biomass must be stored properly to not lose the cellulose and hemicellulose content. Pretreatment of the biomass is used to open up its cell structure and to stop or slow the resistance to biological degradation. Following pretreatment the biomass is soaked in dilute sulfuric acid for 10 minutes at 100 degrees C and then heated to 160 degrees C for 10 minutes to break down the hemicellulose to form its component sugars of acabinose, galactose, glucose, mamose, and xylose. Then it is neutralized and conditioned to remove any compounds that may slow down the process of fermentation.

The hydrolyznte is then sent to the five-carbon sugar fermentation step where genetically engineered Escherichia coli or other suitable organisms convert the free sugars to ethanol. The ethanol is then recovered and the wastes, which include lignin, water, enzymes, organisms, and other components, fall out and are used for electricity production. The biomass that is used for the production of cellulosic ethanol comes from different sources.

According to DiPardo (2000) cellulosic feedstocks include agricultural wastes, grasses and woods, and other low-valued biomass including municipal wastes. Even though these feedstocks are cheaper than the conventional ethanol feedstock of corn it is more costly to convert to ethanol. However, the cost of converting the feedstock to ethanol could be reduced significantly if a sufficient demand for inputs develops. For input demands to increase an inventory analysis must be taken to find out where sufficient feedstock is located.

The location of sufficient feedstock is necessary but for cellulosic ethanol to take effect biomass must be economically viable every year. The two main conclusions as reported by DiPardo (2000) to the economic feasibility of cellulosic ethanol is: 1) the need for a stable and low cost supply of biomass, and 2) the chemicals used to break down the cellulose are presently to expensive at the commercial level. According to the USDA Billion-ton Annual Supply report (2005), they found that there is enough biomass from forestry and agricultural wastes to supply over one-third of the nation's current petroleum consumption. For the United States to reach their goal of $1.33 per gallon cost for cellulosic ethanol by 2012 the price paid for feedstock will have to decrease from $60 in 2007 to $46 in 2012 (Aden 2008).

Lange (2007) reports that the biomass conversion process is still to expensive for commercial production. The enzyme cost per gallon will have to decrease from $0.32 to

$0.16 to help reach the 2012 goal of $1.33 per gallon (Aden 2008). The net present value (NPV) can be calculated for various scenarios to examine if cellulosic ethanol plants are economically viable. Lau (2004) did this in his study by using sorghum silage as feedstock and the MixAlco process, which was developed by Holtzapple (2004) at Texas A&M University. Lau’s research shows that for all the scenarios he presents there is a positive net present value (NPV) over the 16 year planning period with only a small probability of there being a negative NPV. The cost of production for ethanol in Lau’s research ranges from $1.01 to $1.12.

Biomass Inventories

Biomass inventories have been done for two regions of the United States taking into account local biomass that can be used for not only cellulosic ethanol but for electricity production. The biomass inventories included in this literature review are: “Biomass Resource Assessment and Utilization Options for Three Counties in Eastern Oregon” which was prepared by McNeil Technologies (2003); “Biomass Inventory and Bioenergy Assessment: An evaluation of Organic Material Resources for Bioenergy Production in Washington State” which was prepared in conjunction by Washington State University and The Washington State Department of Ecology researchers; and the last inventory is “Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply” prepared by the United States Department of Agriculture.

The purpose of the “Biomass Resource Assessment and Utilization Options for Three Counties in Eastern Oregon” was to promote cost-effective, sustainable biomass use for power and liquid fuel manufacturing in Baker, Union, and Wallowa counties. The assessment includes both forestry wastes and agricultural residues within the three counties. The estimate of agricultural residues was done by obtaining an average over the ten year span 1992 to 2001. The assessment then calculated supply curves of residue collection for both forestry and agricultural wastes. Optimal locations for plant sites are also shown for each county assessed. However, there is no risk incorporated in the residue production and collection which can lead to incomplete evaluations about the amount of residue for an area.

"Biomass Inventory and Bioenergy Assessment," by Frear et al. (2005), geographically identified, categorized, and mapped 45 potential sources of biomass in Washington at the county level. The 45 potential sources are broken down into field residues, animal manures, forestry residues, food packing/processing wastes, and municipal wastes. A five step method was used for inventorying and determining the biomass and potential electrical energy from Washington's biomass. The results for their study show that Washington State has an annual production of over 16.9 million tons of underutilized dry equivalent biomass. However, as stated previously about the Oregon inventory, the Washington State inventory does not incorporate risk for residue production.

The United States Department of Agriculture in conjunction with the Department of Energy did an inventory analysis for the entire United States called "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply." The purpose of their report was to determine if the land resources of the United States are capable of producing a sustainable supply of biomass sufficient to displace 30 percent or more of the county's present petroleum consumption. To accomplish this goal the study estimates that approximately 1 billion dry tons of biomass feedstock is needed per year. The assessment shows that by only using agriculture and forestry wastes the United States would be able to supply 1.3 billion dry tons of biomass annually. However, this assessment is contingent on crop production increasing, changes in tillage practices and harvest technology. This inventory also does not take into account the variability of crop production.

The inventory studies reviewed are good for there intended purpose. However, the common thread that all share, is that they do not account for the variability associated with crop production. Crop residues are based on crop production and if there is variability in the crop yields then there will be variability in the residue production. The range of production variability can be valuable knowledge for investors in cellulosic ethanol plants. The following chapter describes the methodology used to estimate the Texas inventory as well as having yield risk was included in the results.

CHAPTER III

METHODOLOGY

This thesis uses Monte Carlo simulation of biomass inventories by county to forecast the likely production of biomass for Texas. Stochastic simulation can incorporate risk and variability to allow "What if…" questions to be analyzed. Stochastic simulation is the preferred method for dealing with uncertainty and variability.

Simulation can be either: deterministic or stochastic. Deterministic simulation results do not include risk or variability. The results are shown on an "on average basis." Prior studies for inventorying biomass for the process of cellulosic ethanol are deterministic. A deterministic forecast assumes perfect knowledge because the result is only one number for each variable.

Stochastic simulation incorporates risk for input variables that are not certain, to determine their impacts on the key output variables in a model. For an inventory analysis model the key output variables are the production of biomass for each commodity. The stochastic variables are the yields for each commodity. This inventory analysis is aimed at geographically identifying and mapping the biomass production probability distribution for each county and district in Texas. The analysis used the SIMETAR © simulation package, developed by Richardson, Schumann, and Feldmann (2002) to simulate the random variables.

Inventory Framework

The inventory combines the 254 counties for Texas into fifteen statistical districts. These districts are: Northern High Plains, Northern Low Plains, Southern High Plains, Southern Low Plains, Trans-Pecos, Crosstimbers, Blacklands, North East, South East, Upper Coast, Coastal Bend, South Texas, Lower Valley, Edwards Plateau, and South Central. These districts allow for comparisons between counties in a similar area and show the potential biomass production for an ethanol plant's feedstock area.

Historical commodity production data was gathered from the National Agricultural Statistical Service (NASS) for 1987 to 2006 (NASS). Commodities include: corn, cotton, sorghum, oats, and wheat. Hay data over the same time period was obtained from the Texas Extension Service and includes all hay except for alfalfa. Forestry data was gathered from the Texas Forestry Service for the year 2005. Since the commodity data was reported by NASS on a per acre yield basis equations are needed to convert yield production to total residue production.

Commodity Equations

The commodities of corn, oats, sorghum, and wheat used equation 3.1 to estimate residual production.

$$TR = (Y * BW * RC * A * MC * HA)/2000 \qquad (3.1)$$

Where:

TR = Total residue (tons)
Y = Yield production (bushels/acre)
BW = Bushel weight
RC = Residue coefficient
A = Availability
MC = Moisture content
HA = Harvested acres

To calculate the total available residue biomass production, the yield (Y) is multiplied by the bushel weight (BW). To calculate yield production in pounds of biomass production, BW is multiplied by a residue coefficient (RC), which indicates how much residue is available according to grain harvested. The equation also takes into account the fraction (A) of residue which can be gathered without causing excessive soil erosion and fertilizer use. Also, to convert these numbers into a dry ton basis a moisture content (MC) coefficient is used. Multiplying by the harvested acres (HA) will yield the total residue production for a county. Table 3.1 presents the bushel weight, collection and residue factors, and the moisture content for each grain commodity used in the inventory.

Table 3. 1 Residue Conversion Numbers for Grain Production

Commodity	Bushel Weight in lbs	Collection Factor	Residue Factor	Moisture Content
Wheat	60	0.25	1.7	0.15
Corn	56	0.25	1.1	0.15
Oats	32	0.25	2.125	0.15
Sorghum	56	0.25	1	0.15

Sources: Collection factor: Washington Inventory
Residue factor: Corn: Washington Inventory
Wheat, Oats, and Sorghum: USDA Billion Ton Annual Supply
Moisture Content: Hess et. al. (2006)

The hay data is already in a dry ton basis, so no conversions were needed.

Cotton trash was estimated using equation 3.2.

$$CT = ((CY/CLT) * CTT)/2000 \quad (3.2)$$

Where:
CT = Cotton Trash (tons)
CP = Cotton Yield (lbs/acre)
CLT = Cotton Lint Turnout
CTT = Cotton Trash Turnout

A simple conversion is used to calculate the amount of cotton trash that can be used for cellulosic ethanol. Cotton yield is the cotton lint that is gathered during harvest in pounds per acre. Dividing the cotton yield by the percentage of cotton lint turnout, which is the percentage of how much cotton lint is obtained from harvest, will estimate how much lint, trash, and seed was actually gathered. Multiplying the amount of lint, trash, and seed gathered by the cotton trash turnout, which is the percentage of trash gathered during harvest, estimates the cotton trash produced per acre. Table 3.2 summarizes the percentages for the cotton lint turnout, the cotton trash turnout, and the cotton seed turnout

Table 3. 2 Cotton Conversion Factors for Residue Collection

Cotton Conversion	
Bale Weight	480
Cotton Lint Turnout	30.06%
Cotton Seed Turnout	51.01%
Cotton Trash Turnout	18.93%

Source: 2006 Cotton Variety Trials

Forestry data was gathered for the most recent year of 2005 from the Texas Forestry Service (TFS) and for the three districts of North East, South East and the Upper Coast. Total forestry waste includes softwood and hardwood species for both logging residues and mill wastes. Logging residue is a total of stumps, top limbs, and unused cull and mill residue encompasses chips, sawdust, shavings, and bark.

Stochastic Variables

To develop a stochastic simulation model for a biomass inventory, historical yield data is needed to estimate parameters for the probability distribution of yields for each county. Twenty years of historical crop yields for Texas counties obtained from NASS, the Texas Extension Service, and TFS were used to estimate the probability distribution parameters for years. The stochastic yields are multiplied by the five year average acres harvested for their respective crops to simulate total biomass production in each county. Wastes from forestry are added to the simulated total biomass production from commodities in the counties for the three forestry districts.

Richardson, Klose, and Gray (2000) indicate a multivariate empirical distribution is preferred when there is a limited number of observations available and the variables are correlated. A multivariate empirical distribution is used to simulate yields account for the correlation between the variables and in recognition of the limited number of observations. To simulate 254 multivariate empirical probability distributions we first need to estimate the parameters for each distribution. Richardson, Klose, and Gray (2000) describe the steps to estimate parameters for a multivariate empirical distribution. The first step is to separate the random and non-random components for each of the stochastic variables. Due to the presence of trend a simple regression was used to remove systematic variability from trend. The second step for estimating parameters for a MVE distribution is to calculate the random component of each stochastic variable, which is the residual from the linear trend regression. The third step is to convert the residuals to relative deviates about their respective trend forecasted values. The fourth step is to sort the relative deviates for each random variable. The fifth step is to assign probabilities to each of these sorted relative deviates. The sixth step is to calculate the M × M intra-temporal correlation matrix for the unsorted residuals. SIMETAR© was used to estimate the parameters for the probability distributions and to simulate the multivariate empirical distributions.

A simulation model was developed for each county in Texas. The 5 year average for harvested acres (2003-2007) were multiplied by the stochastic yields and converted to tons of biomass using equations 3.1 and 3.2. The simulated results for the counties are aggregated into fifteen statistical districts. Total biomass production is reported for each commodity and as a total for available biomass. Probabilistic forecasts of biomass per county and per district are reported from the simulation results.

The process to estimate the probability that a district has enough biomass to support a 25, 50, 75, or 100 million gallon cellulosic ethanol plant uses the cumulative distribution function (CDF) for biomass production. According to Green (2003), for any random variable X, the probability that X is less than or equal to a is denoted F(a) so F(x) is the cumulative distribution function. Therefore, one minus F(a) equals the probability that X will be greater than or equal to a, where a is the minimum amount of biomass to support a 25, 50, 75, or 100 million gallon cellulosic ethanol plant. According to Aden (2008) a conversion yield of 72 gallons of cellulosic ethanol per dry ton of biomass the minimum amount of biomass needed for a 25, 50, 75, or 100 million gallon plant is 347,223, 694,445, 1,041,667, 1,388,889 tons, respectively. The results from the research are reported in the next chapter.

CHAPTER IV

RESULTS

The simulation results for the fifteen districts are reported in this chapter. The results for each district present the total biomass from the commodities in expected value, and if the district contained forestry wastes it is included as well. Also reported is the probability that enough biomass is available in the district to support four different cellulosic plant sizes (25, 50, 75, and 100 MMGY).

Northern High Plains

The Northern High Plains district consists of 23 counties located at the northern tip of the Texas Panhandle (Figure 4.1). The residue production in this district consisted of corn stover, cotton trash, hay, oat residue, sorghum residue, and wheat straw. The expected value of the biomass produced is roughly 1.7 million dry tons (Table 4.1). The counties that produce the largest amounts of biomass also can be found in Table 4.1 (Dallam: 222,209, Castro: 196,291, Hale: 120,302, Sherman: 145,500). Figure 4.1 shows' the concentration of biomass is located in the northeast corner of the district.

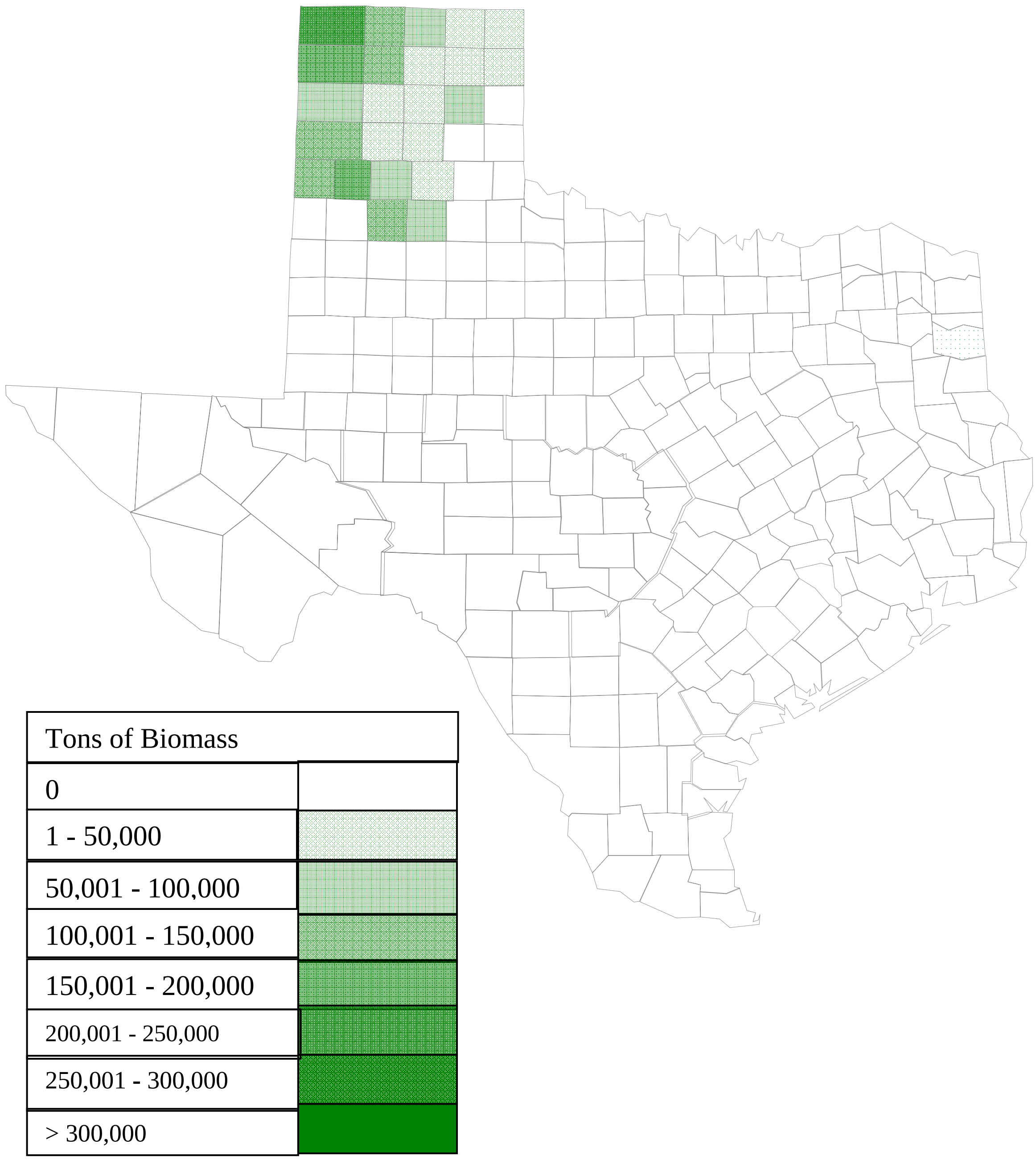

Figure 4. 1 Annual Residue Available from Commodities in the Northern High Plains

Table 4. 1Annual Biomass by County for the Northern High Plains

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Armstrong	16,408	16,815	4,196	25	7,801	30,419
Briscoe	17,437	19,579	8,869	45	8,484	47,121
Carson	45,603	47,616	8,945	19	27,833	76,621
Castro	196,291	190,624	21,781	11	128,044	234,523
Dallam	222,209	221,483	19,130	9	179,114	261,987
Deaf Smith	126,620	129,771	27,356	21	59,100	199,978
Floyd	67,047	68,614	11,710	17	39,121	104,740
Gray	50,671	52,039	10,070	19	31,080	75,635
Hale	124,252	1,131,454	3,568,918	315	81,633	16,805,346
Hansford	91,478	97,400	10,647	11	72,956	129,718
Hartley	179,832	188,416	22,748	12	146,847	262,954
Hemphill	9,768	9,271	3,538	38	2,539	17,114
Hutchinson	27,121	27,215	2,611	10	21,055	33,550
Lipscomb	12,375	26,312	62,195	236	6,826	366,882
Moore	119,319	119,923	11,142	9	88,818	152,657
Oldham	76,696	80,271	15,204	19	45,353	125,698
Orchiltree	24,066	23,649	7,409	31	9,219	45,151
Parmer	103,703	102,668	8,294	8	73,153	120,186
Potter	16,163	13,392	6,805	51	3,348	26,313
Randall	13,281	13,738	2,484	18	8,803	19,897
Roberts	6,146	6,207	1,146	18	3,481	9,212
Sherman	145,400	146,277	9,866	7	122,165	174,659
Swisher	54,921	54,801	7,043	13	38,735	78,085
Total Dry Matter Biomass	1,746,807	2,787,534	3,567,117	128	1,611,132	18,524,525

Figure 4.2, which is a cumulative distribution function (CDF), shows that about 91 percent of the time the Northern High Plains district has less than roughly 2.2 million dry tons of biomass available. It also shows that it will have more than 1.6 million dry tons available 100 percent of the time. There is a 90 percent chance that biomass from agricultural wastes will exceed 1.7 mt per year. This level of production will support 100 mgpy of ethanol by one 100 mgpy plant or one 25 mgpy and one 75 mgpy cellulosic ethanol plants (Table 4.2) .

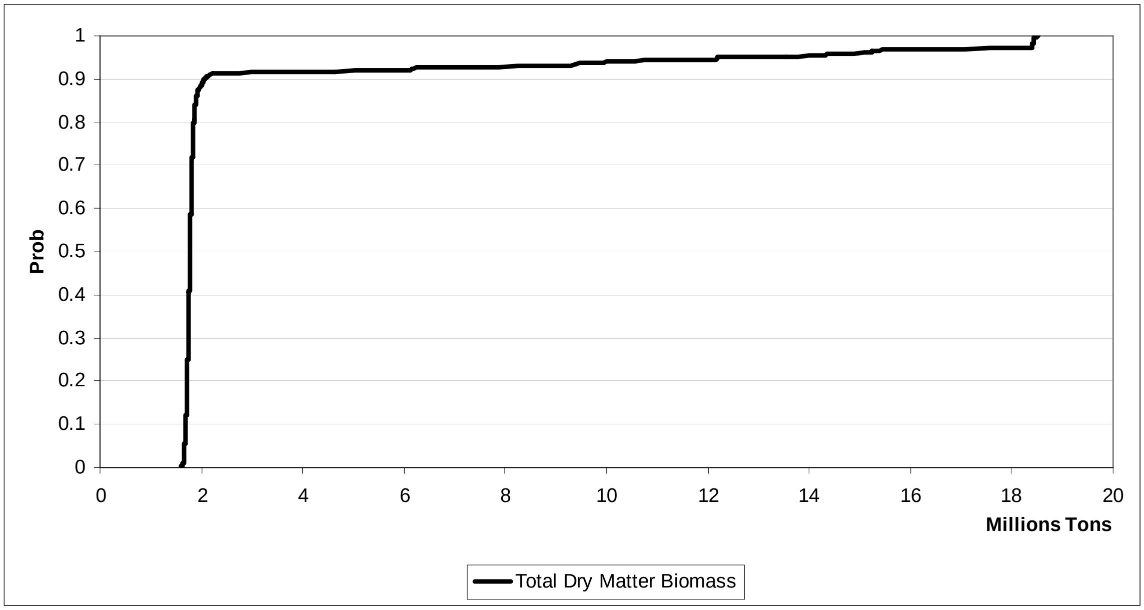

Figure 4. 2 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas Northern High Plains

Table 4. 2 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas Northern High Plains

Cellulosic Ethanol Plants	P(Sufficient Biomass)	Dry tons needed
25 Million Gallons	100.00%	347,223
50 Million Gallons	100.00%	694,445
75 Million Gallons	100.00%	1,041,667
100 Million Gallons	100.00%	1,388,889

Southern High Plains

The Southern High Plains district consists of 16 counties located in the southwest area of the panhandle region (Figure 4.3). The primary source of residue in this district comes from cotton trash, hay, sorghum residue, and wheat straw with few counties producing corn stover.

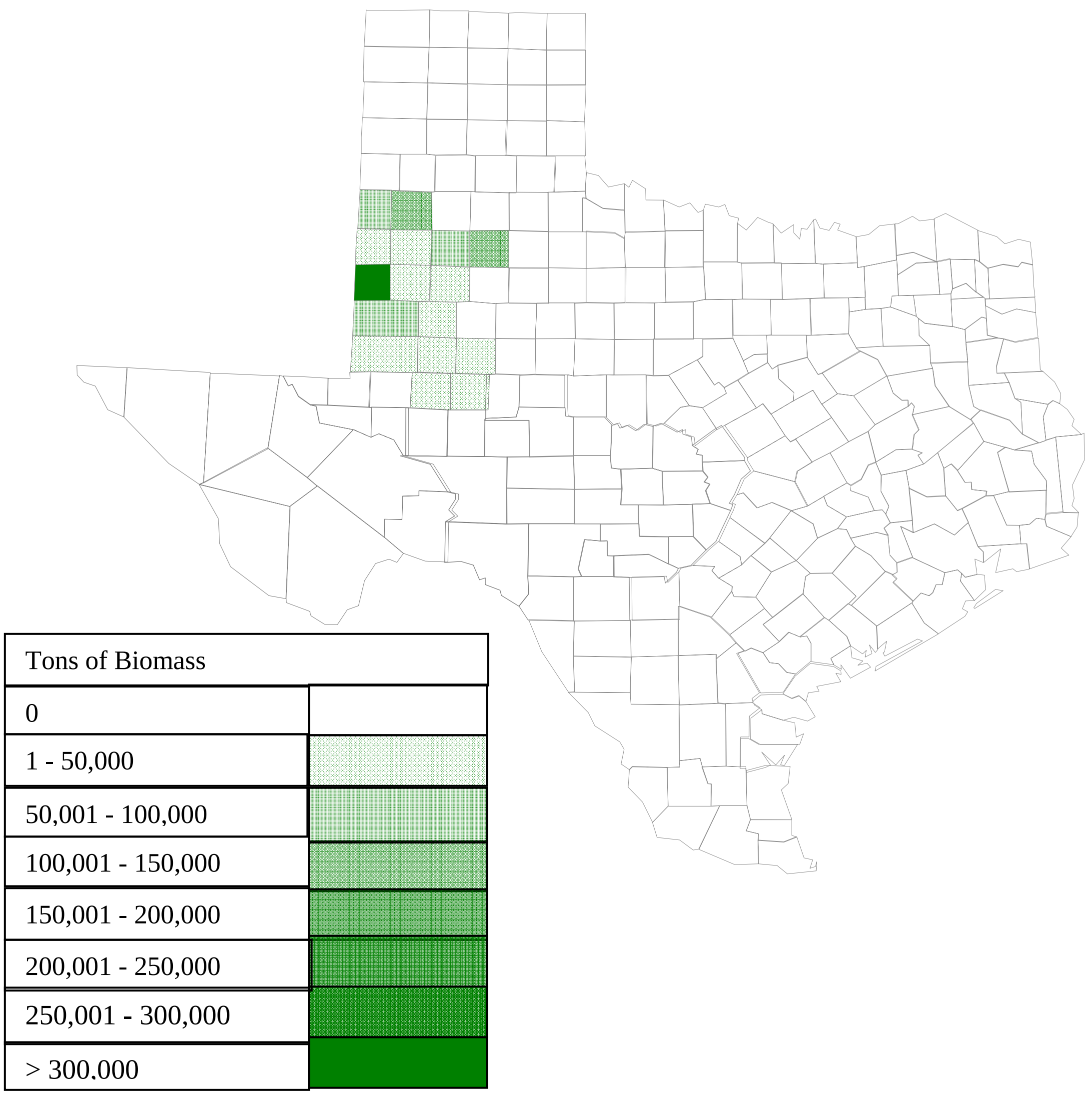

Figure 4. 3 Annual Residue Available from Commodities in the Southern High Plains

Table 4. 3 Annual Biomass by County for the Southern High Plains

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Andrews	8,487	8,510	3,634	43	2,228	18,662
Bailey	59,469	56,378	16,165	29	26,114	109,698
Cochran	33,810	34,425	6,324	18	18,206	51,226
Crosby	100,902	133,827	130,074	97	55,495	780,794
Dawson	41,006	41,315	7,652	19	30,454	58,729
Gaines	71,991	74,560	13,118	18	41,801	105,730
Glasscock	14,893	15,343	4,441	29	7,280	27,532
Hockley	46,290	48,295	10,026	21	28,109	69,424
Howard	17,738	22,418	9,435	42	7,755	56,546
Lamb	111,242	109,038	26,559	24	60,253	175,714
Lubbock	94,968	94,163	24,732	26	38,635	155,035
Lynn	37,232	42,101	14,867	35	23,117	108,926
Martin	43,916	48,913	15,964	33	15,582	95,116
Midland	13,524	13,029	4,172	32	6,022	21,566
Terry	39,769	43,257	9,852	23	26,499	79,039
Yoakum	1,259,739	1,337,025	679,475	51	355,974	2,695,503
Total Dry Matter Biomass	1,994,983	2,122,605	692,770	33	1,001,756	4,002,739

The counties producing the most biomass are Yoakum (1,259,739 dt), Lamb (111,242 dt), Crosby (100,902 dt), Lubbock (94,968 dt) as presented in Table 4.3. The concentration of biomass within this district is located in the northern area, which can be seen from Figure 4.3.

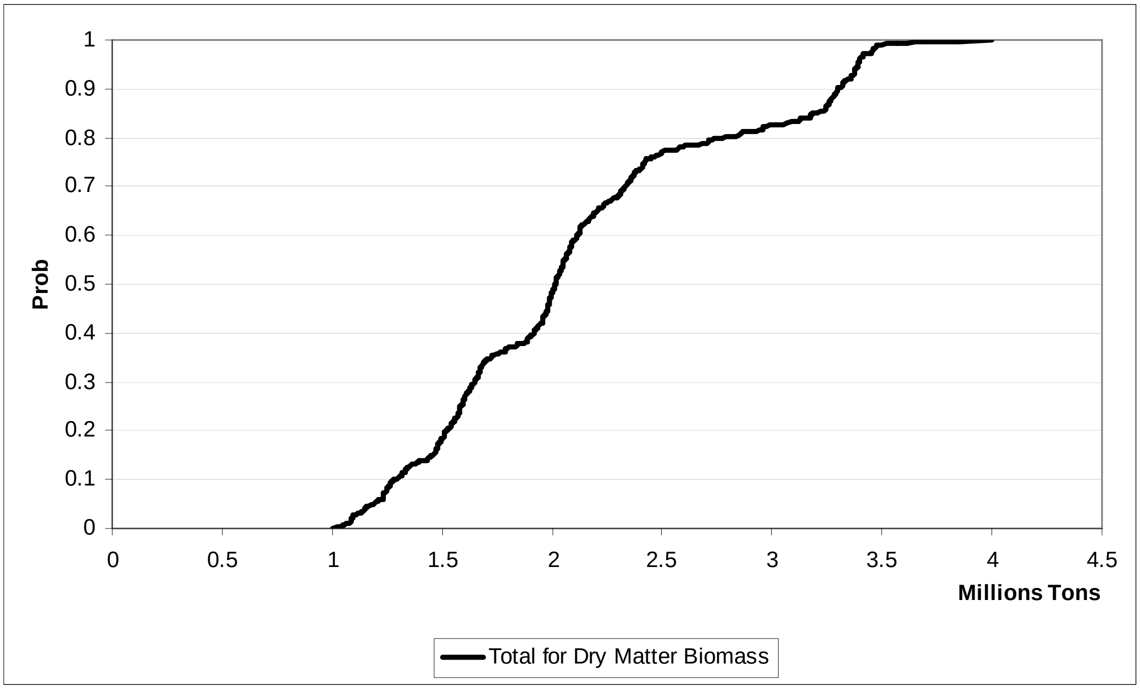

Figure 4. 4 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas Southern High Plains

Figure 4.4 shows that the biomass within the Southern High Plains ranges from roughly 1,000,000 dry tons to more than 4,000,000 dry tons. Ninety percent of the time the district will produce 1.25 million dry tons of biomass, which indicates the Southern High Plains can produce enough agricultural wastes to support three 25 or one 75 million gallon cellulosic ethanol plant (Table 4.4).

Table 4. 4 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas Southern High Plains

Cellulosic Ethanol Plants	P(Sufficient Biomass)	Dry tons needed
25 Million Gallons	100.00%	347,223
50 Million Gallons	100.00%	694,445
75 Million Gallons	99.51%	1,041,667
100 Million Gallons	86.30%	1,388,889

Northern Low Plains

The Northern Low Plains district contains 16 counties and is located to the east of the Southern High Plains District (Figure 4.5). The biomass produced in this district comes from cotton trash, hay, sorghum residue, and wheat straw.

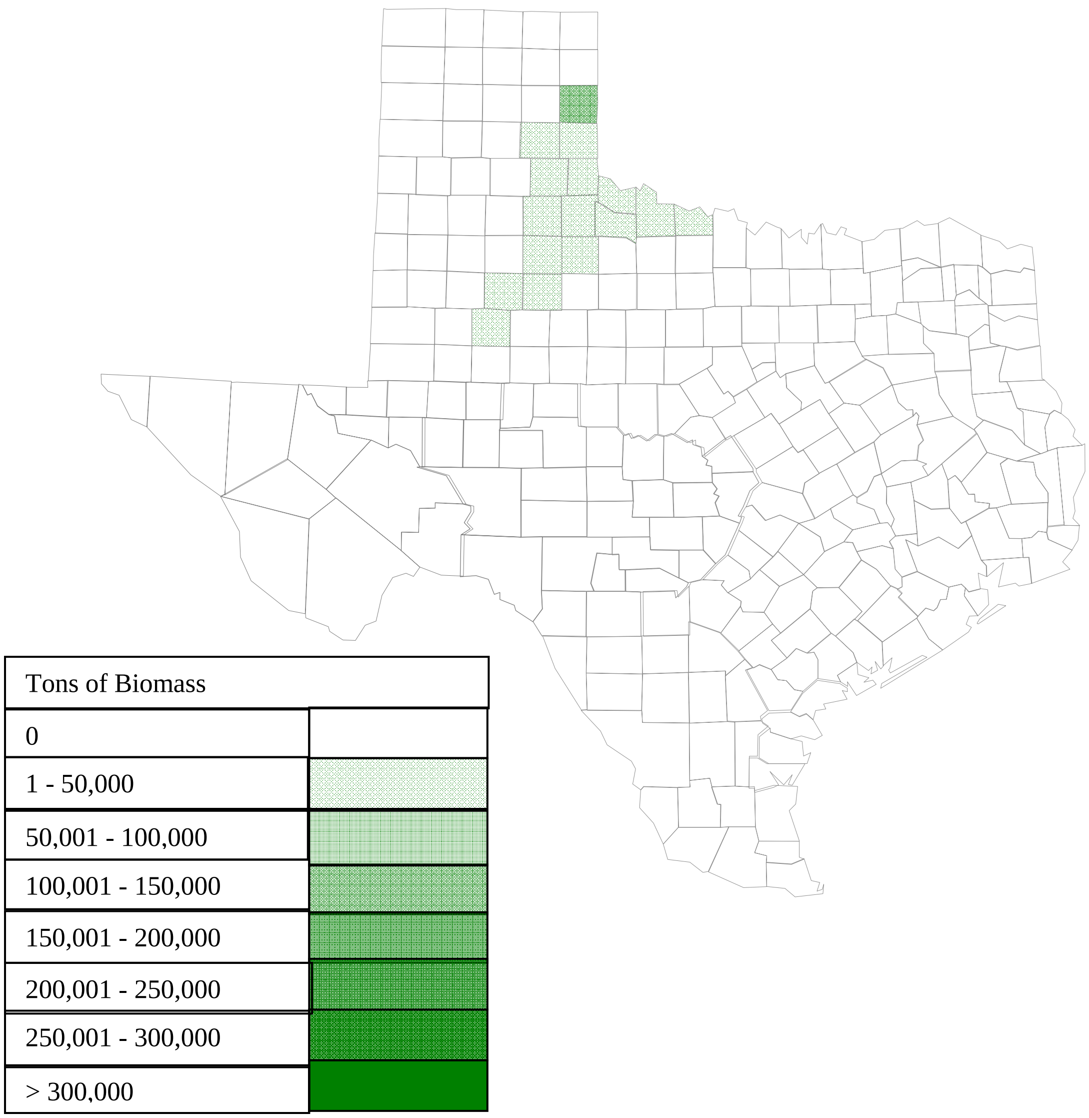

Figure 4. 5 Annual Residue Available from Commodities in the Northern Low Plains

The top three producing counties within the district are Wheeler (119,086), Wichita (49,392), and Wilbarger (45,717) as indicated by Table 4.5. Figure 4.5 shows Wheeler is the only county to produce more than 100,000 dry tons of biomass per year. The remaining fifteen counties produce less than 50,000 dry tons per year.

Table 4. 5 Annual Biomass by County for the Northern Low Plains

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Borden	3,846	4,307	1,117	26	2,170	7,774
Childress	12,867	15,200	4,874	32	6,314	29,583
Collingsworth	43,770	48,243	22,036	46	16,873	142,569
Cottle	13,841	14,491	7,450	51	2,642	37,382
Dickens	13,268	13,201	7,556	57	3,176	32,502
Donley	13,756	14,862	3,828	26	6,837	27,478
Foard	23,516	34,423	33,151	96	5,449	159,237
Hall	16,173	19,200	7,267	38	7,445	38,655
Garza	5,773	6,162	1,784	29	3,634	11,216
Hardeman	29,007	33,071	14,839	45	11,901	87,879
Kent	2,031	2,293	856	37	870	5,887
King	3,392	3,620	1,292	36	1,311	7,222
Motley	8,128	9,559	5,275	55	1,217	21,884
Wheeler	119,086	127,445	65,754	52	40,713	263,408
Wichita	49,392	46,482	10,327	22	19,760	74,019
Wilbarger	45,717	47,865	12,726	27	19,630	87,144
Total Dry Matter Biomass	403,573	440,431	79,958	18	270,615	661,381

The amount of total residue produced in this district ranges from roughly 270,000 dry tons to about 660,000 dry tons (Figure 4.6). The Northern Low Plains can produce 325,000 dry tons of agricultural wastes with a 90 percent certainty which is almost enough biomass to support a 25 million gallon per year cellulosic ethanol plant as indicated by Table 4.6.

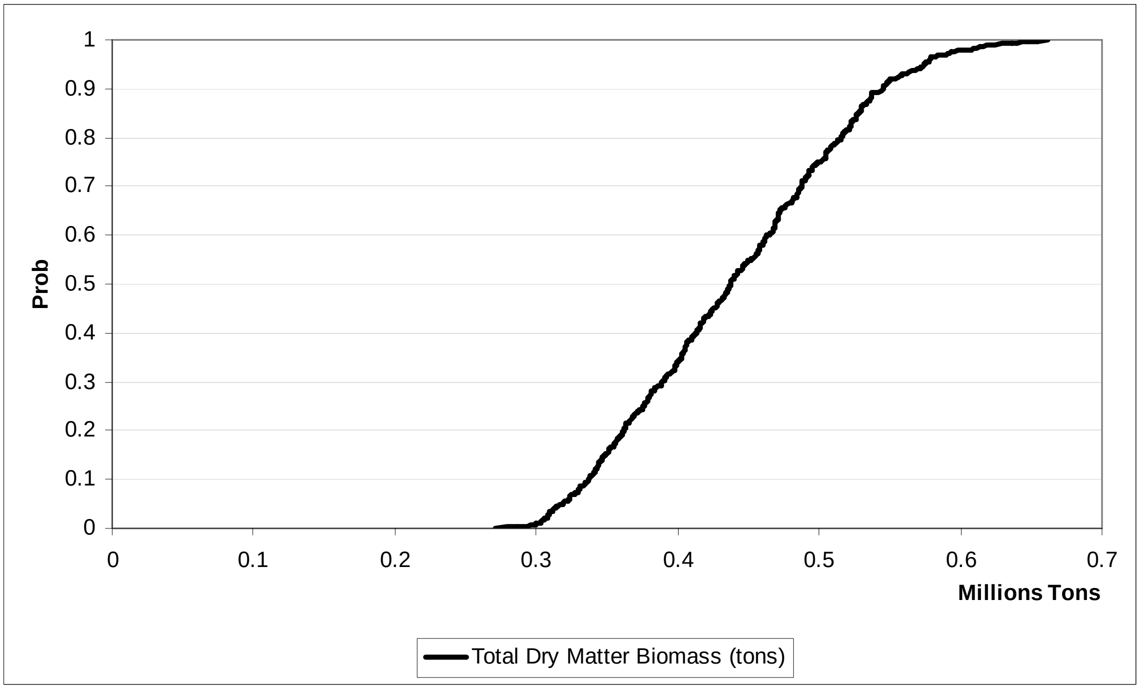

Figure 4. 6 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas Northern Low Plains

Table 4. 6 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas Northern Low Plains

Cellulosic Ethanol Plants	P(Sufficient Biomass)	Dry tons needed
25 Million Gallons	85.44%	347,223
50 Million Gallons	0.00%	694,445
75 Million Gallons	0.00%	1,041,667
100 Million Gallons	0.00%	1,388,889

Southern Low Plains

The Southern Low Plains district is located just to the south of the Northern High Plains district and contains 12 counties (Figure 4.7).

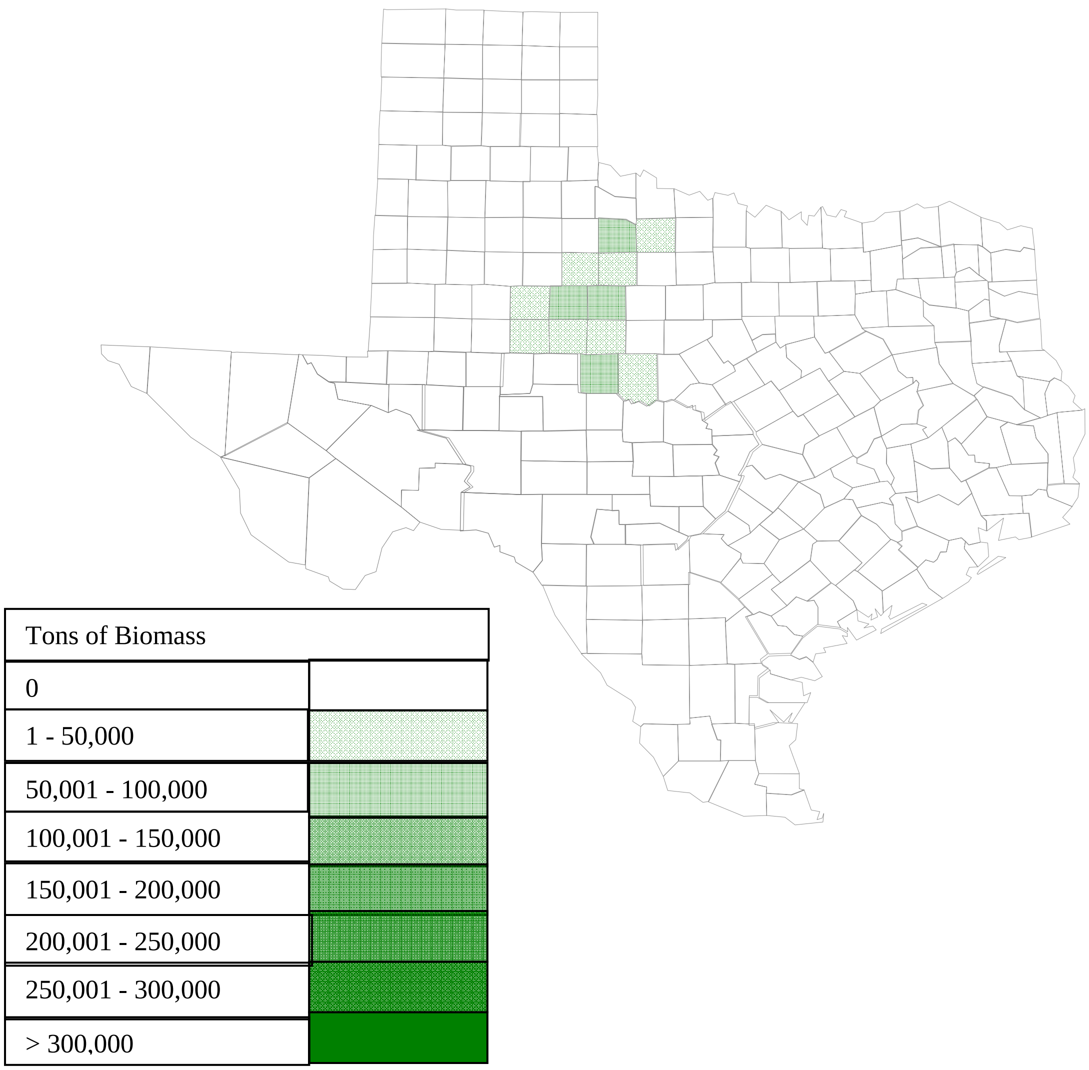

Figure 4. 7 Annual Residue Available from Commodities in the Southern Low Plains

The district has three counties that produce more than 50,000 dry tons per year, while the remaining nine produce less than 50,000 dry tons (Figure 4.7). The top four producing counties are Fisher (59,761), Runnels (57,171), Jones (54,858), and Knox (50,996) as presented in Table 4.7. The biomass produced in this area comes from cotton trash, hay, sorghum residue, and wheat straw.

Table 4. 7 Annual Biomass by County for the Southern Low Plains

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Baylor	37,382	37,646	13,116	35	13,738	70,215
Coleman	23,499	25,287	7,681	30	11,334	43,577
Fisher	59,761	61,576	32,023	52	10,405	178,438
Haskell	38,750	39,849	6,911	17	22,037	57,637
Jones	54,858	250,001	666,673	267	12,208	3,165,744
Knox	50,996	49,906	7,194	14	28,129	72,486
Mitchell	17,497	16,465	6,332	38	3,866	28,952
Nolan	14,120	14,173	4,070	29	5,651	24,019
Runnels	57,171	54,823	21,785	40	18,791	113,990
Scurry	5,932	6,869	2,222	32	2,789	11,814
Stonewall	6,242	6,408	1,548	24	3,195	10,201
Taylor	42,157	46,327	26,304	57	9,175	126,278
Total Dry Matter Biomass	408,372	609,335	667,110	109	270,075	3,619,665

Figure 4.8 shows that annual biomass produced in this district ranges from roughly 270,000 to over 3,500,000 million dry tons with about 350,000 dry tons being produced with 90 percent confidence. This amount of biomass produced can support a 25 million gallon plant; however, for 50, 75, and 100 million gallon cellulosic ethanol plants the district does not have enough biomass at a 90 percent certainty (Table 4.8).

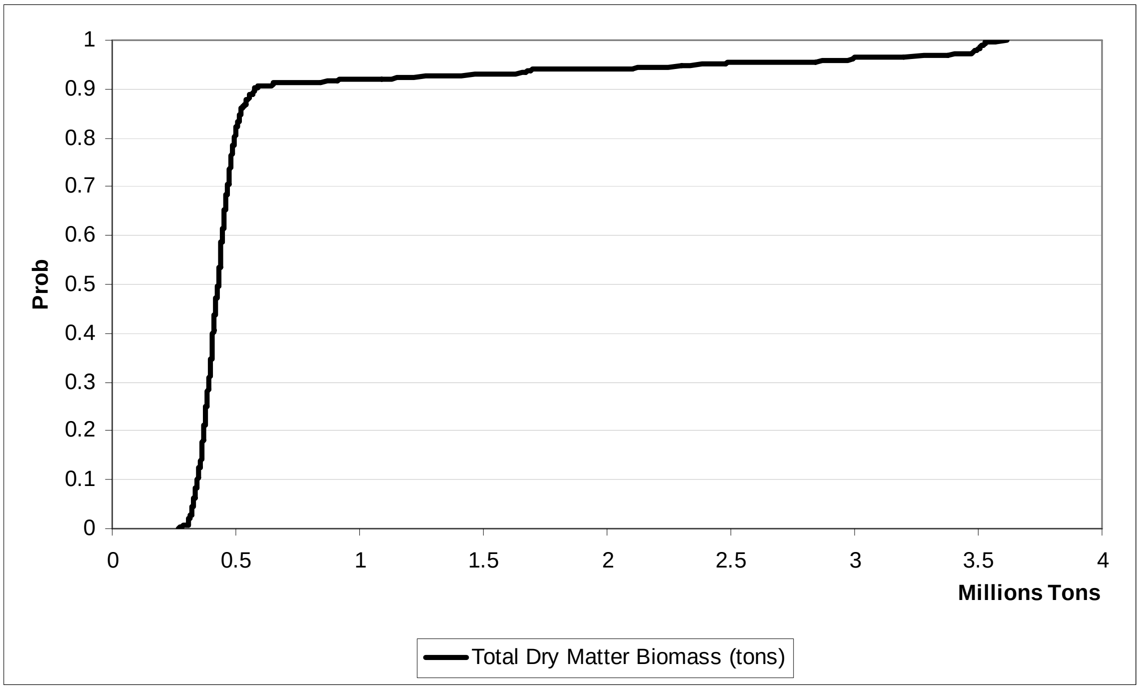

Figure 4. 8 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas Southern Low Plains

Table 4. 8 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas Southern Low Plains

Cellulosic Ethanol Plants	P(Sufficient Biomass)	Dry tons needed
25 Million Gallons	88.83%	347,223
50 Million Gallons	8.76%	694,445
75 Million Gallons	7.86%	1,041,667
100 Million Gallons	7.18%	1,388,889

Crosstimbers

The Crosstimbers district contains 19 counties and is located to the east of the Southern Low Plains (Figure 4.9).

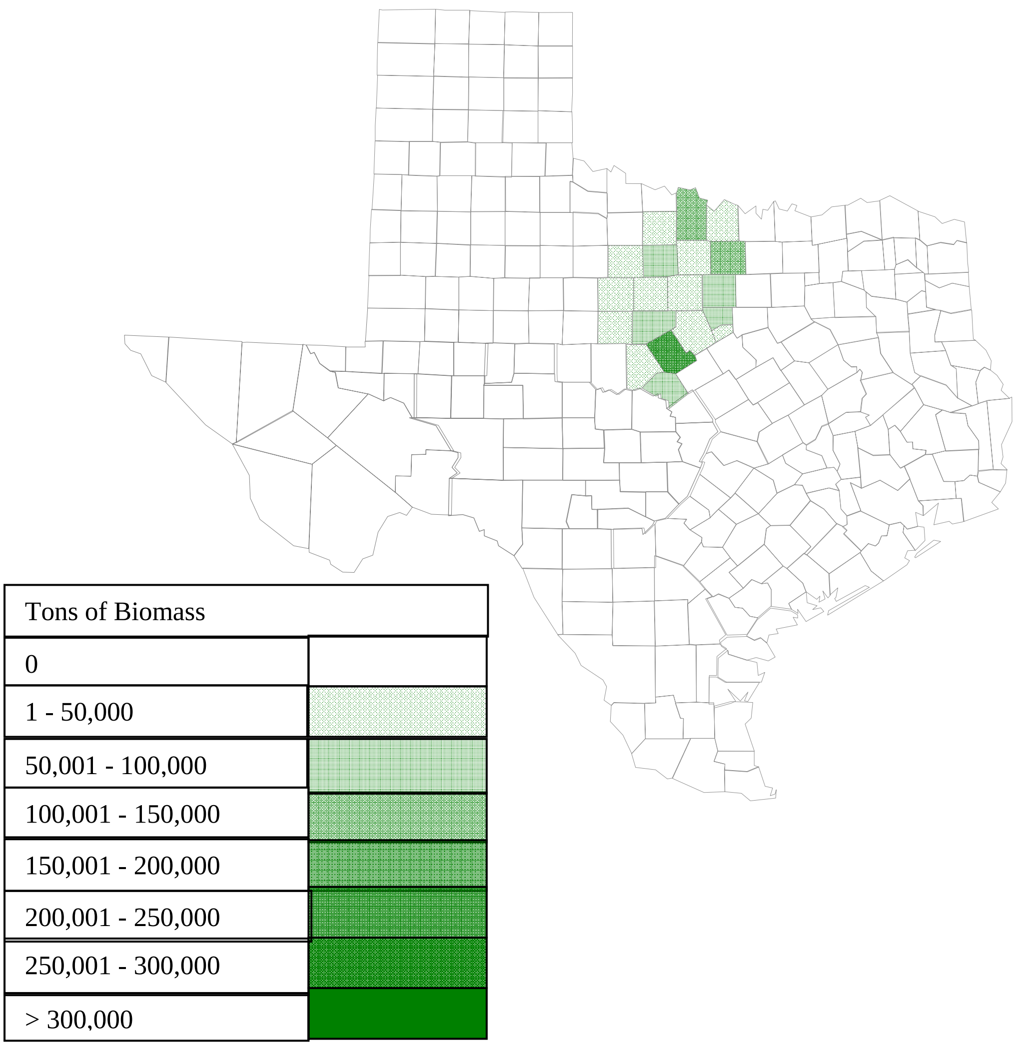

Figure 4. 9 Annual Residue Available from Commodities in the Crosstimbers

The main source of biomass for cellulosic ethanol production in this district comes from hay, sorghum residue, and wheat straw with some counties producing corn stover and cotton trash. As shown by both Figure 4.9 and Table 4.9 the top producing counties in the district are Comanche (202,654), Wise (110,087), and Clay (107,208). The range of biomass produced within the Crosstimbers ranges from roughly 650,000 dry tons to over 1.4 million dry tons per year (Figure 4.10).

Table 4. 9 Annual Biomass by County for the Crosstimbers

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Archer	10,434	10,267	2,885	28	4,411	17,719
Brown	24,104	25,991	9,193	35	8,523	46,717
Callahan	30,057	38,743	21,489	55	13,946	102,538
Clay	107,208	109,671	49,491	45	16,311	197,908
Comanche	202,654	196,497	70,565	36	77,678	349,597
Eastland	75,041	88,743	51,459	58	33,179	212,082
Erath	27,125	25,664	12,773	50	5,263	46,708
Hood	67,321	70,613	22,987	33	22,206	102,847
Jack	182	1,735	5,629	324	125	26,952
Mills	56,531	54,872	14,925	27	7,320	73,500
Montague	26,966	26,456	9,785	37	6,971	50,372
Palo Pinto	23,334	27,528	13,957	51	9,205	49,934
Parker	83,267	76,633	36,940	48	8,179	155,557
Shackelford	12,434	12,053	3,758	31	2,839	19,186
Somervell	43,479	43,097	13,141	30	17,738	67,238
Stephens	943	945	303	32	352	1,615
Throckmorton	14,846	24,711	27,480	111	4,625	145,996
Wise	110,087	114,229	38,130	33	47,759	191,834
Young	68,971	66,598	21,558	32	20,718	116,314
Total Dry Matter Biomass	984,984	1,015,047	122,345	12	649,631	1,418,908

Ninety percent of the time the amount of biomass that comes from the Crosstimbers is 850,000 dry tons. This amount of biomass can produce 50 mgpy of ethanol which can be obtained from either a one 50 mgpy plant or two 25 mgpy cellulosic ethanol plants (Table 4.10).

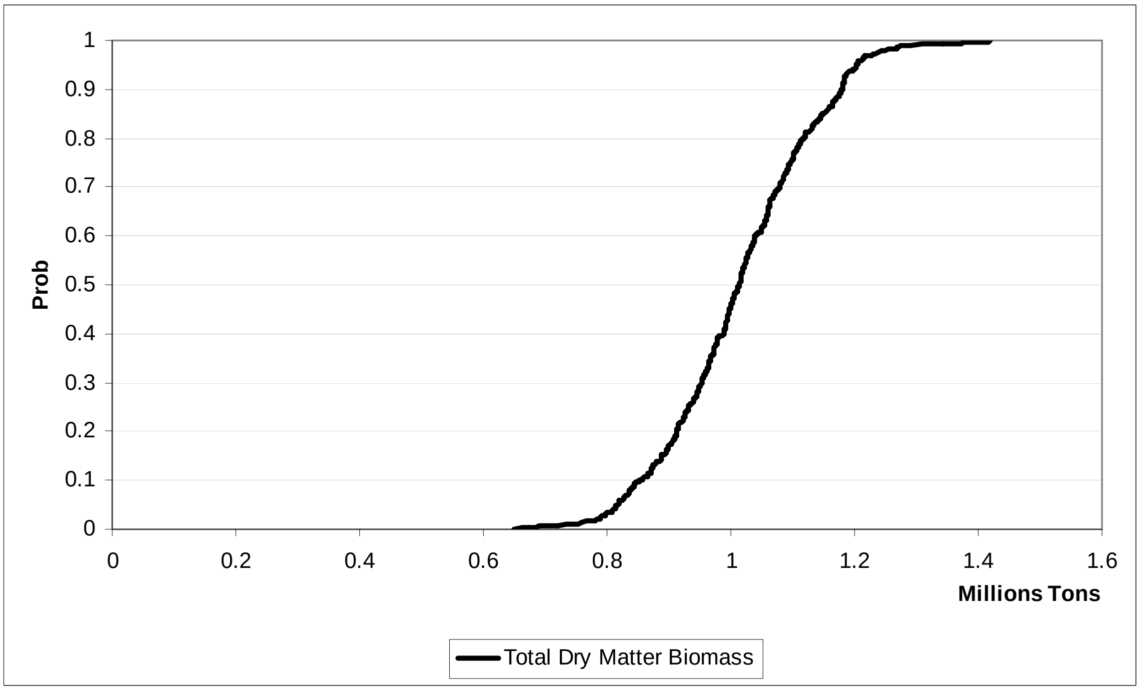

Figure 4. 10 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas Crosstimbers

Table 4. 10 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas Crosstimbers

Cellulosic Ethanol Plants	P(Sufficient Biomass)	Dry tons needed
25 Million Gallons	100.00%	347,223
50 Million Gallons	99.22%	694,445
75 Million Gallons	39.57%	1,041,667
100 Million Gallons	0.33%	1,388,889

Blacklands

The Blacklands district is located to the east of the Crosstimbers district and contains 25 counties (Figure 4.11).

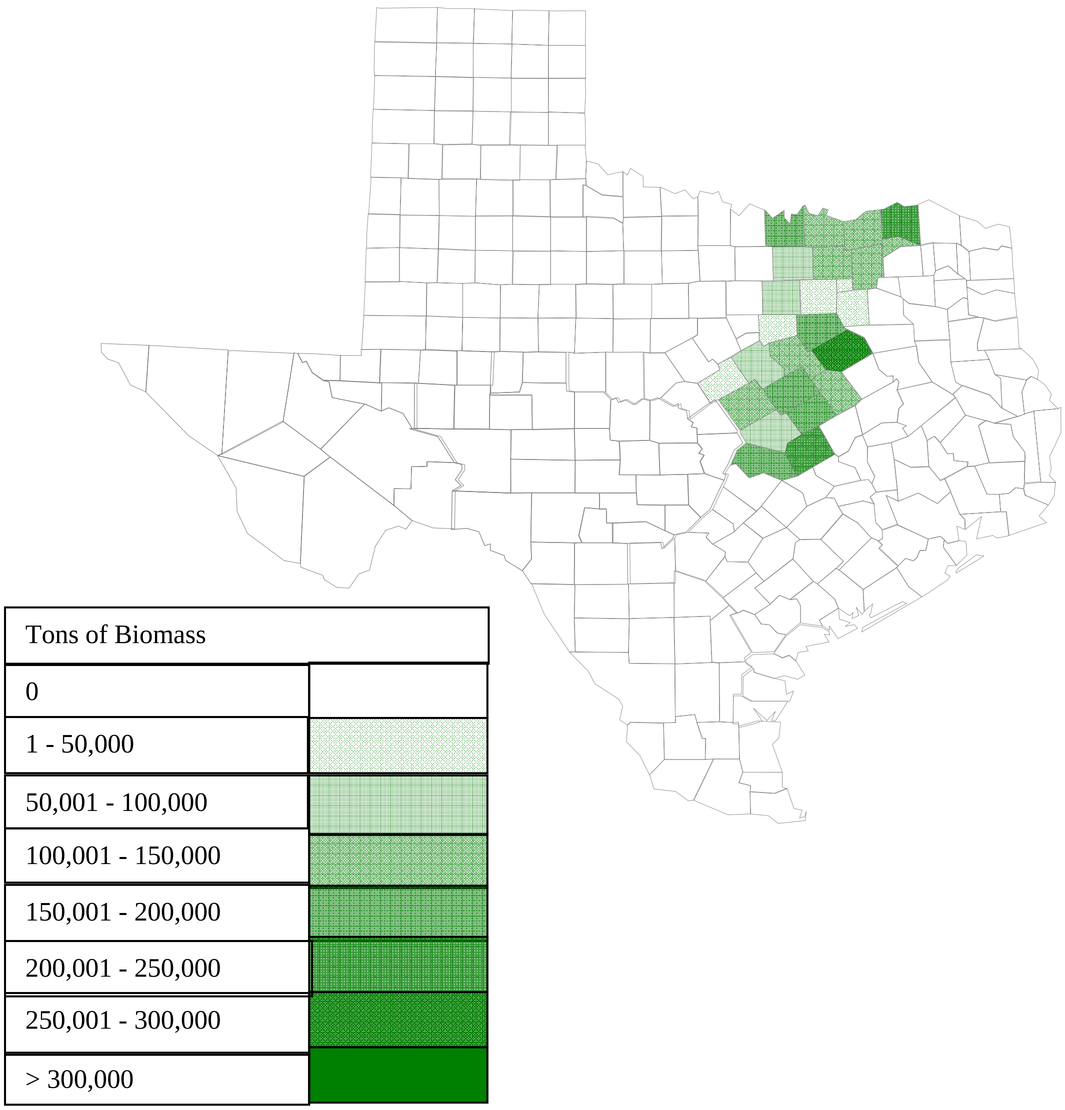

Figure 4. 11 Annual Residue Available from Commodities in the Blacklands

The main source of biomass comes from corn stover, cotton trash, hay, sorghum residue, and wheat straw. According to Figure 4.11 and Table 4.11 the top two producing counties in the district are Navarro (279,698), Lamar (242,777), and Milam (208,216). The rest of the counties produce less than 200,000 dry tons per year. The expected value for the total amount of biomass from the Blacklands is 2.9 million dry tons per year (Table 4.11).

Table 4. 11 Annual Biomass by County the Blacklands

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Bell	50,918	50,775	13,573	27	19,330	98,925
Bosque	89,317	97,459	49,762	51	17,485	192,317
Collin	154,816	160,630	37,193	23	52,281	249,222
Cookie	165,964	162,350	51,182	32	40,770	246,228
Coryell	113,244	116,295	37,634	32	30,745	186,418
Dallas	10,784	13,317	7,613	57	4,945	36,119
Delta	110,059	117,803	45,588	39	11,671	198,429
Denton	71,553	74,388	29,144	39	23,608	138,654
Ellis	152,579	162,479	48,048	30	57,894	288,808
Falls	185,083	218,093	125,104	57	36,280	522,043
Fannin	117,416	119,156	26,727	22	42,241	168,352
Grayson	139,677	145,824	46,521	32	35,433	246,769
Hamilton	31,800	35,702	16,614	47	10,662	68,519
Hill	137,436	138,385	32,390	23	47,520	205,353
Hunt	116,728	116,911	32,477	28	38,264	166,849
Johnson	8,339	8,466	1,679	20	4,322	12,989
Kaufman	5,344	8,234	10,460	127	3,320	55,295
Lamar	242,777	268,389	99,476	37	108,918	547,710
Limestone	122,556	124,536	41,536	33	53,367	212,341
McLennan	174,187	200,307	85,217	43	77,493	389,207
Milam	208,216	196,411	62,609	32	58,307	339,339
Navarro	279,698	274,170	119,356	44	56,983	540,535
Rockwall	5,234	5,163	812	16	2,935	7,041
Tarrant	58,085	58,383	24,021	41	14,690	115,131
Williamson	162,421	159,703	34,639	22	82,390	243,010
Total Dry Matter Biomass	2,914,231	3,033,327	269,226	9	2,305,292	3,921,588

Figure 4.12 shows that annual biomass production for the Blacklands district ranges from roughly 2.3 million dry tons to over 3.9 million dry tons. Ninety percent of the time the district produces around 2.6 million dry tons of biomass amounting to 175 mgpy of cellulosic ethanol. This production of ethanol can come from seven 25 mgpy plants, three 50 mgpy and one 25 mgpy plants, or one 100 mgpy and one 75 mgpy plants (Table 4.12).

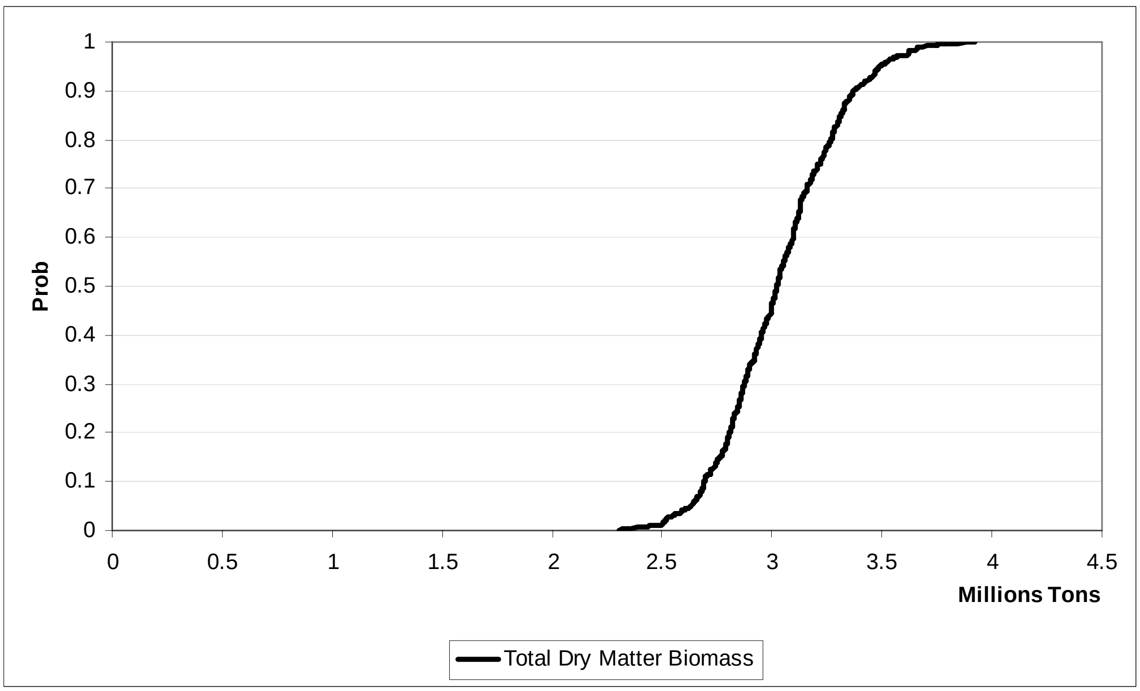

Figure 4. 12 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas Blacklands

Table 4. 12 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas Blacklands

Cellulosic Ethanol Plants	P(Sufficient Biomass)	Dry tons needed
25 Million Gallons	100.00%	347,223
50 Million Gallons	100.00%	694,445
75 Million Gallons	100.00%	1,041,667
100 Million Gallons	100.00%	1,388,889

North East

The North East district is located in the extreme north east of the state and has 24 counties (Figure 4.13).

Total Residue from Crops

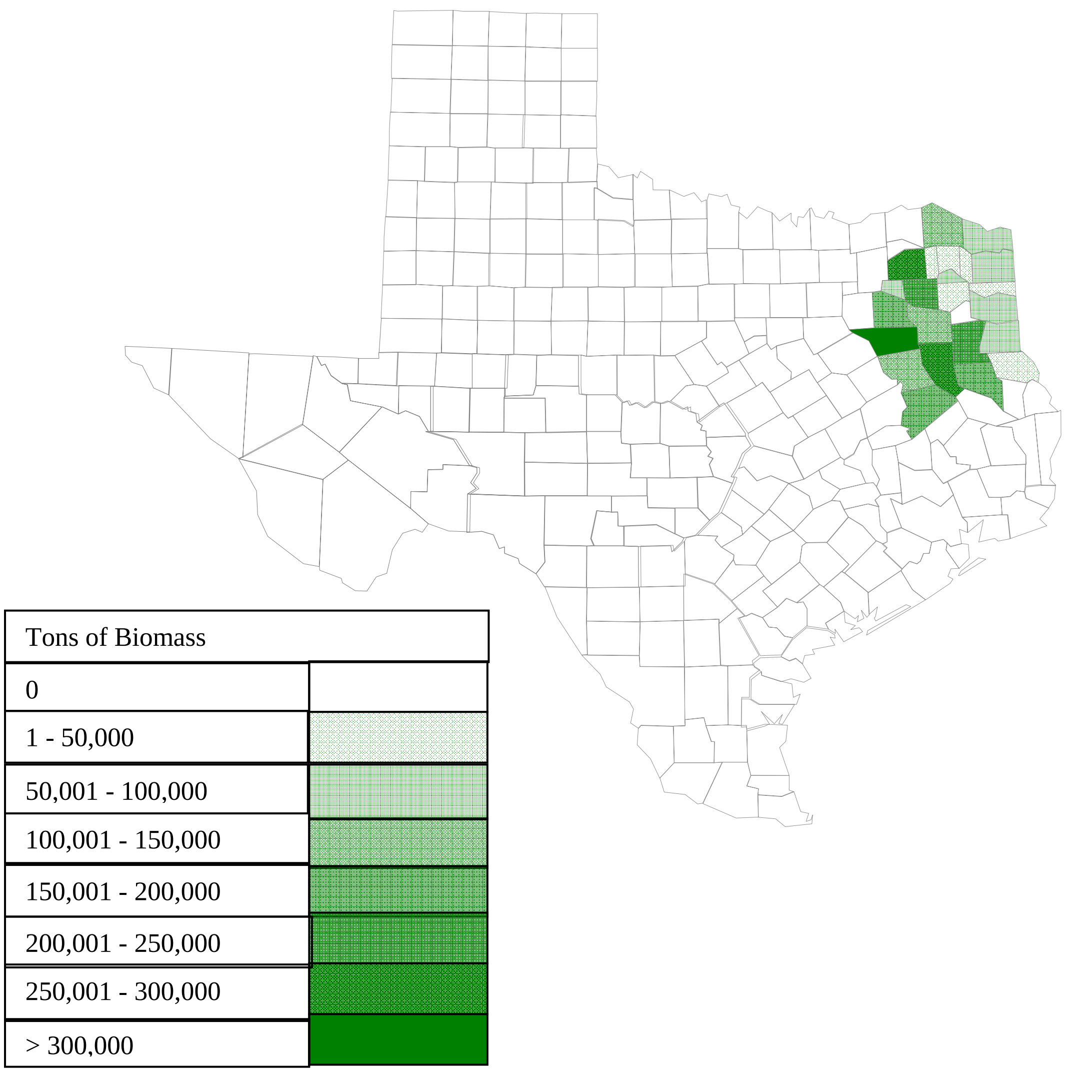

Figure 4. 13 Annual Residue Available from Commodities in the North East

The residue that comes from crops in this district comes mostly from hay with some counties producing corn stover, cotton trash, sorghum residue, and wheat straw.The concentration of crop residues is located in the southwest corner of the district (Figure 4.13). Table 4.13 indicates that the top three producing counties are Henderson, Cherokee, and Hopkins with 329,879 dt/y, 262,226 dt/y, and 253,779 dt/y, respectively, and the expected value of the total amount of residue produced by the North East district is 2,811,259 dt/y.

Table 4. 13 Annual Biomass from Commodities by County for the North East

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Anderson	118,134	134,210	66,197	49	50,052	351,850
Bowie	67,712	74,007	49,683	67	10,035	160,591
Camp	53,299	55,751	15,759	28	25,586	93,522
Cass	73,679	67,967	26,896	40	4,553	105,409
Cherokee	262,226	271,576	101,786	37	78,349	458,142
Franklin	43,124	44,399	12,693	29	15,098	80,768
Gregg	0	0	0	0	0	0
Harrison	76,509	104,300	75,665	73	11,093	399,714
Henderson	329,879	396,191	172,092	43	183,618	828,201
Hopkins	253,779	247,598	60,398	24	141,001	338,455
Houston	195,037	188,439	72,307	38	65,706	293,022
Marion	8,943	8,766	2,485	28	1,839	13,113
Morris	17,208	15,404	6,859	45	178	23,361
Nacogdoches	184,999	188,631	61,995	33	49,987	315,012
Panola	89,932	94,674	42,093	44	25,879	176,962
Rains	99,756	113,284	89,792	79	54	283,557
Red River	116,744	116,244	21,375	18	39,619	154,962
Rusk	203,448	201,196	91,338	45	62,319	348,224
Shelby	44,111	45,190	14,636	32	22,497	86,403
Smith	115,694	105,535	34,830	33	14,991	180,007
Titus	43,112	45,303	18,058	40	9,654	87,478
Upshur	43,333	59,507	55,202	93	22,033	304,187
Van Zandt	159,409	164,471	56,385	34	68,939	277,411
Wood	211,192	245,529	169,447	69	54,873	697,187
Total Biomass from Crops	2,811,259	2,988,174	352,128	12	2,064,203	4,040,140

This district also contains forestry wastes that can be used for cellulosic ethanol production. The forestry wastes are reported in Table 4.14 for total production by county. Figure 4.14 shows that the concentration of forestry wastes is located on the east side of the district.

Total Residue from Forestry

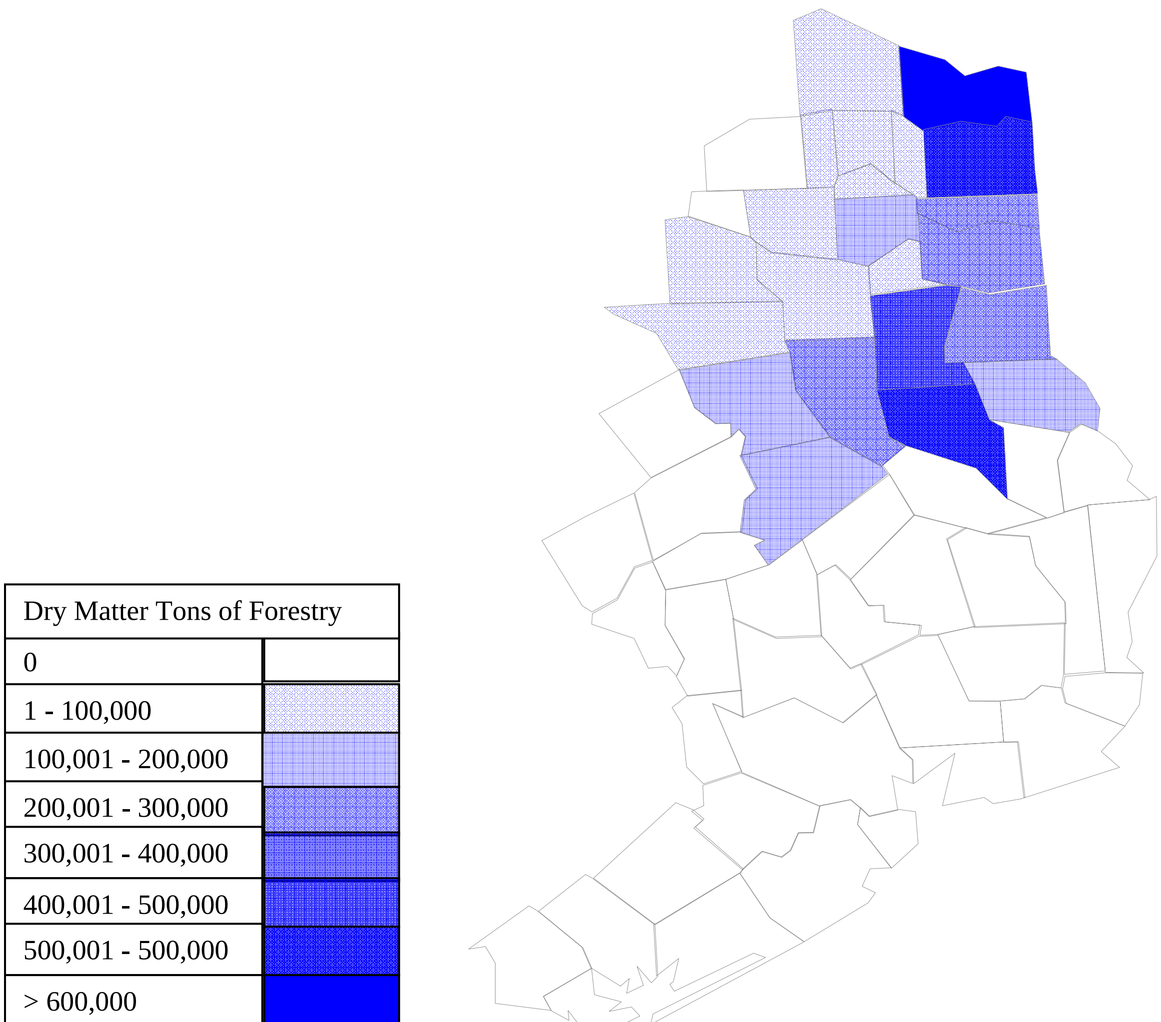

Figure 4. 14 Annual Residue from Forestry in the North East

Figure 4.15 shows that with crop residue alone the range of biomass for the district is from roughly 2 million dry tons to 4 million dry tons per year. The addition of forestry wastes shifts the CDF of total biomass production to the right, and the range starts at roughly 6.16 million dry tons and ends at about 8.14 million. The North East district can produce 6.6 million dry tons of biomass with 90 percent certainty. This amount of agricultural and forestry wastes can produce 475 mgpy of ethanol from either nineteen 25 mgpy plants or four 100 mgpy and one 75 mgpy cellulosic ethanol plants (Table 4.15).

Table 4. 14 Annual Residue Available from Forestry in the North East by County

Total Forestry			
Anderson	101492	Nacogdoches	561478
Bowie	715287	Panola	231645
Camp	13216	Rains	0
Cass	541773	Red River	89813
Cherokee	231972	Rusk	443530
Franklin	3713	Shelby	181809
Gregg	34076	Smith	73596
Harrison	259927	Titus	62618
Henderson	26460	Upshur	117033
Hopkins	0	Van Zandt	4239
Houston	115204	Wood	22215
Marion	236529	Total for Forestry	4101662
Morris	34037		

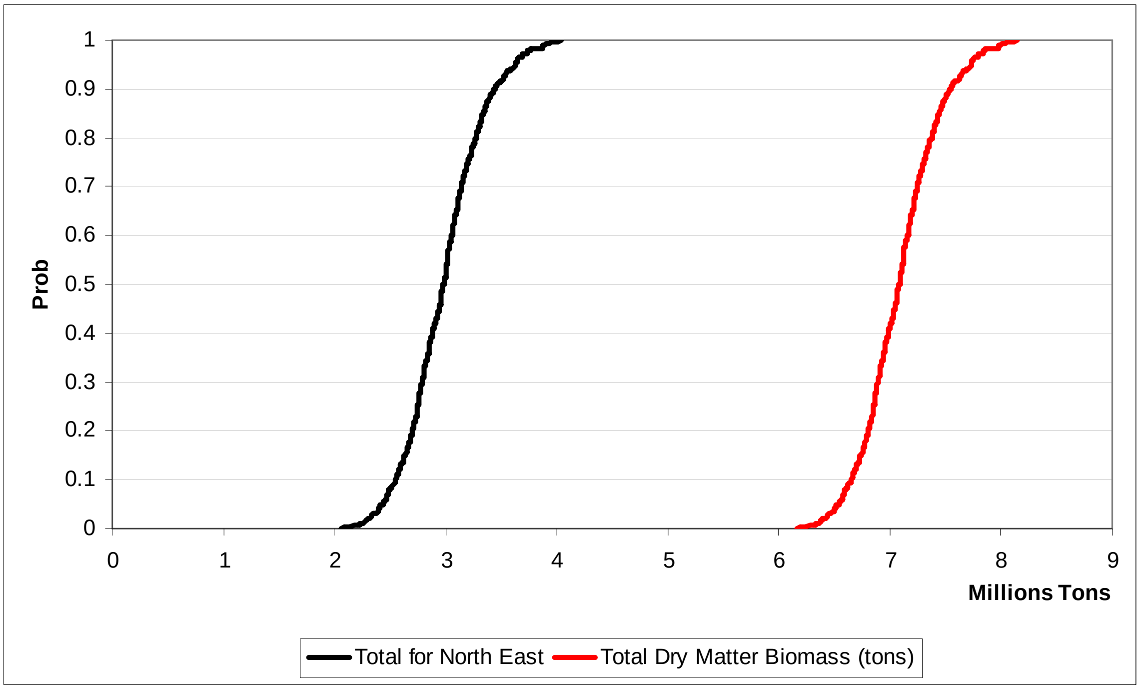

Figure 4. 15 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas North East

Table 4. 15 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas North East

Cellulosic Ethanol Plants	P(Sufficient Biomass from Crops)	P(Sufficient Biomass from Crops + Forestry)	Dry Tons Needed
25 Million Gallons	100.00%	100.00%	347,223
50 Million Gallons	100.00%	100.00%	694,445
75 Million Gallons	100.00%	100.00%	1,041,667
100 Million Gallons	100.00%	100.00%	1,388,889

South East

The South East district is located just south of the North East district and contains 19 counties. The district has three counties that have over 100,000 dry tons of residue crop production annually.

Total Residue from Crops

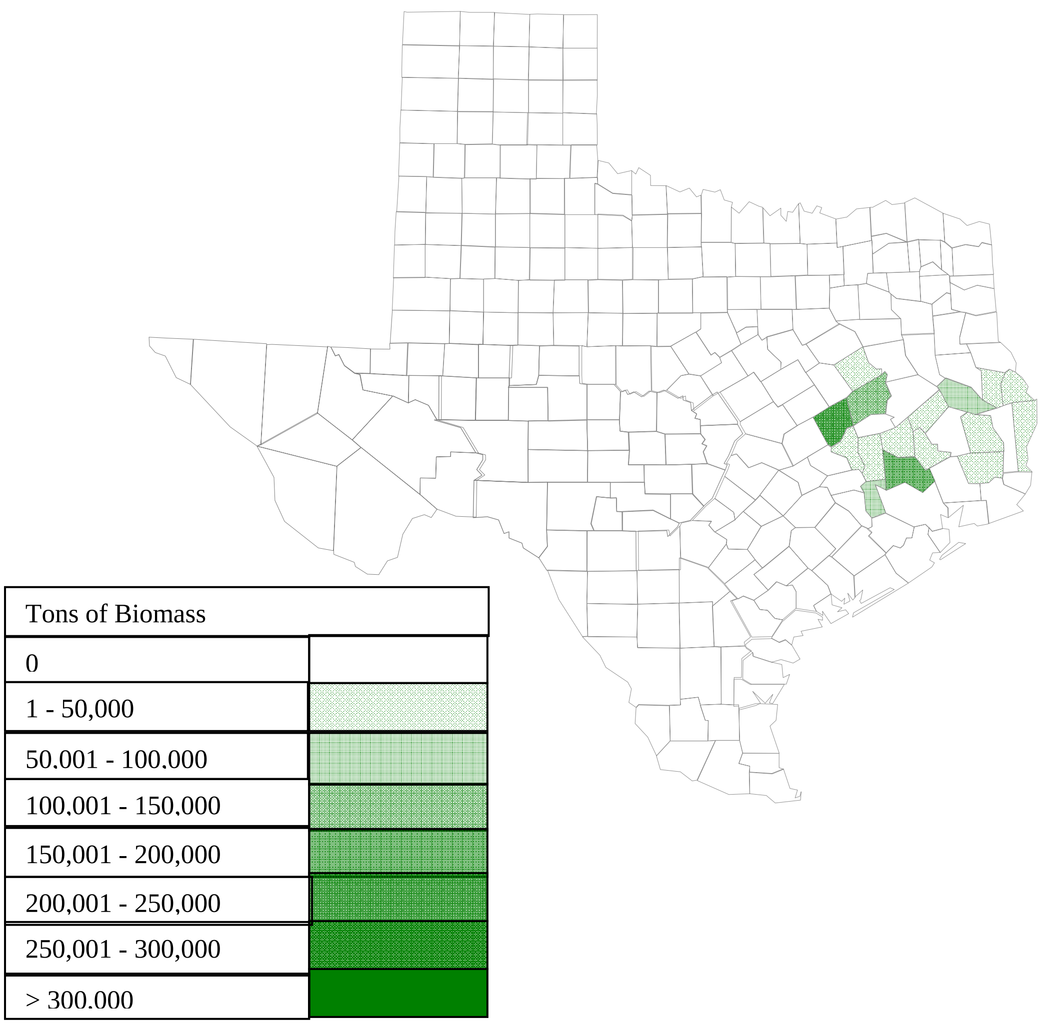

Figure 4. 16 Annual Residue Available from Commodities in the South East

They are Robertson, Montgomery, and Leon with 203,601 dt/y, 179,583 dt/y, and 117,026 dt/y respectively with the expected value from the total residue produced by the district is 0.85 million dt/y as presented in Figure 4.16 and Table 4.16. The majority of the crop residue comes from hay with the rest coming from corn stover, cotton trash, sorghum residue, and wheat straw. Forestry wastes are also present in the South East district. The total residue from forestry is reported in Figure 4.17 and in Table 4.18. The concentration within this district is located on the east side.

Table 4. 16 Annual Biomass from Commodities by County for the South East

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Angelina	65,728	63,335	24,543	39	20,495	120,005
Brazos	44,801	42,077	13,308	32	8,131	65,671
Freestone	41,255	39,131	16,723	43	11,588	69,597
Grimes	877	1,155	1,020	88	316	6,312
Hardin	1,738	1,872	1,382	74	178	5,927
Jasper	0	0	0	0	0	0
Leon	117,026	117,761	53,637	46	12,493	236,890
Madison	0	0	0	0	0	0
Montgomery	179,583	162,649	70,910	44	51,189	345,617
Newton	6,166	6,222	1,707	27	2,859	8,500
Plok	0	0	0	0	0	0
Robertson	203,601	196,809	38,823	20	119,163	278,985
Sabine	5,831	7,158	4,658	65	1,999	20,476
San Augustine	21,326	23,973	19,373	81	0	66,100
San Jacinto	19,967	19,521	5,227	27	10,999	36,001
Trinity	22,308	20,468	4,598	22	8,798	27,000
Tyler	27,500	27,226	9,457	35	9,998	62,878
Walker	959	3,593	10,629	296	458	55,666
Waller	93,058	133,910	108,616	81	1,145	490,540
Total Biomass from Crops	851,732	866,866	155,851	18	504,050	1,413,035

Total Residue from Forestry

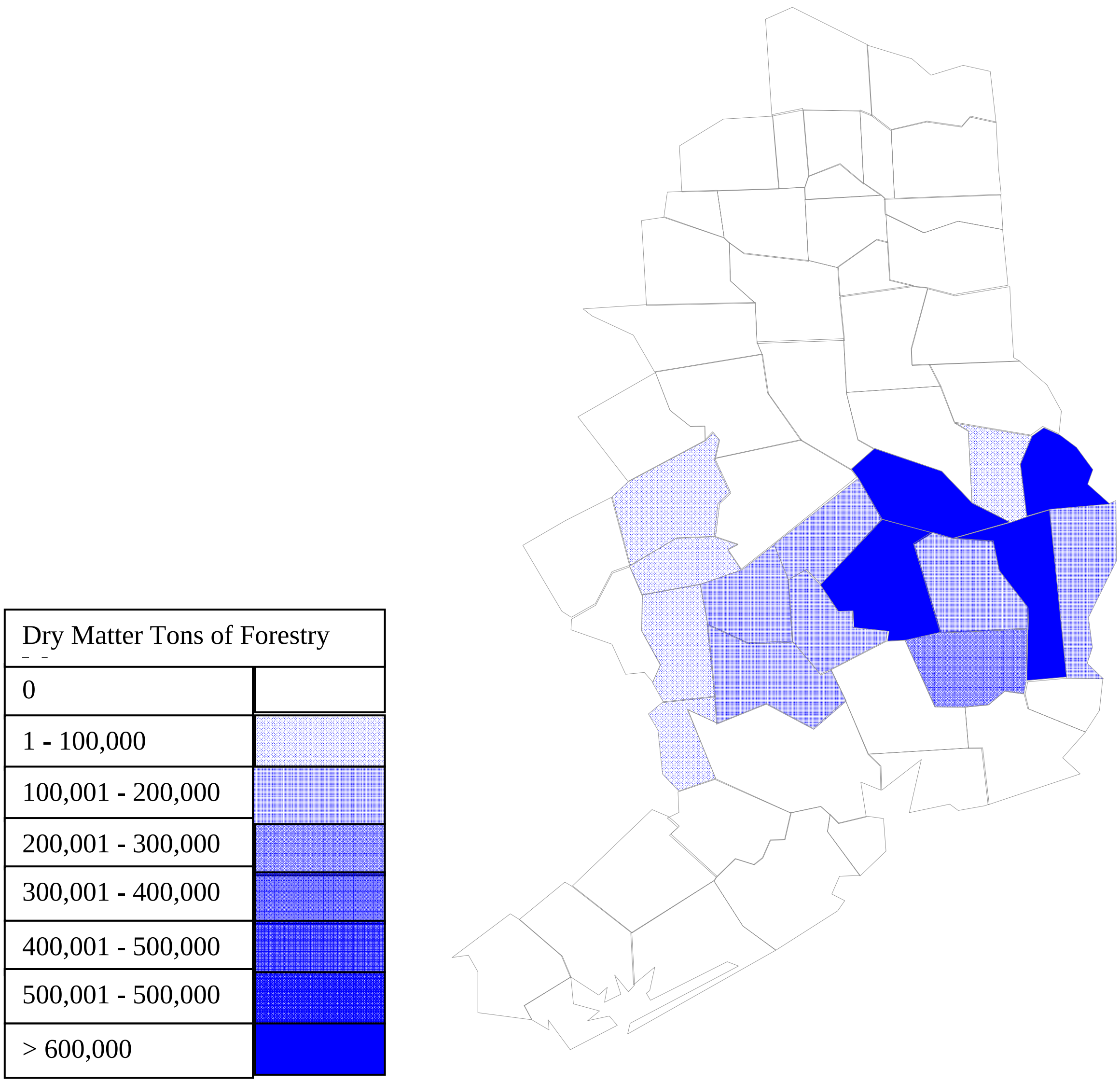

Figure 4. 17 Annual Residue Available from Forestry in the South East

The two CDFs in Figure 4.18 show that the range of annual biomass from commodities starts around 145,000 dry tons and ends roughly around 1.42 million dry tons. The expected value from forestry wastes is 4,665,256 dry tons annually (Table 4.17), which will shift the CDF over to the right, and then the range starts at roughly 5.4 million and ends at 6.7 million. The South East district can produce 5.9 million dry tons of biomass from agricultural and forestry wastes with 90% certainty. This amount of biomass can amount to 425 mgpy of ethanol which can be produced from either seventeen 25 mgpy plants or four 100 mgpy plants and one 25 mgpy plant (Table 4.18).

Table 4. 17 Annual Residue Available from Forestry in the South East by County

Total Forestry			
Angelina	832039	Plok	889162
Brazos	0	Robertson	0
Freestone	0	Sabine	826283
Grimes	13118	San Augustine	75437
Hardin	287423	San Jacinto	137432
Jasper	835500	Trinity	126341
Leon	4877	Tyler	154040
Madison	1144	Walker	176262
Montgomery	133717	Waller	1086
Newton	171395	Total For Forestry	4665256

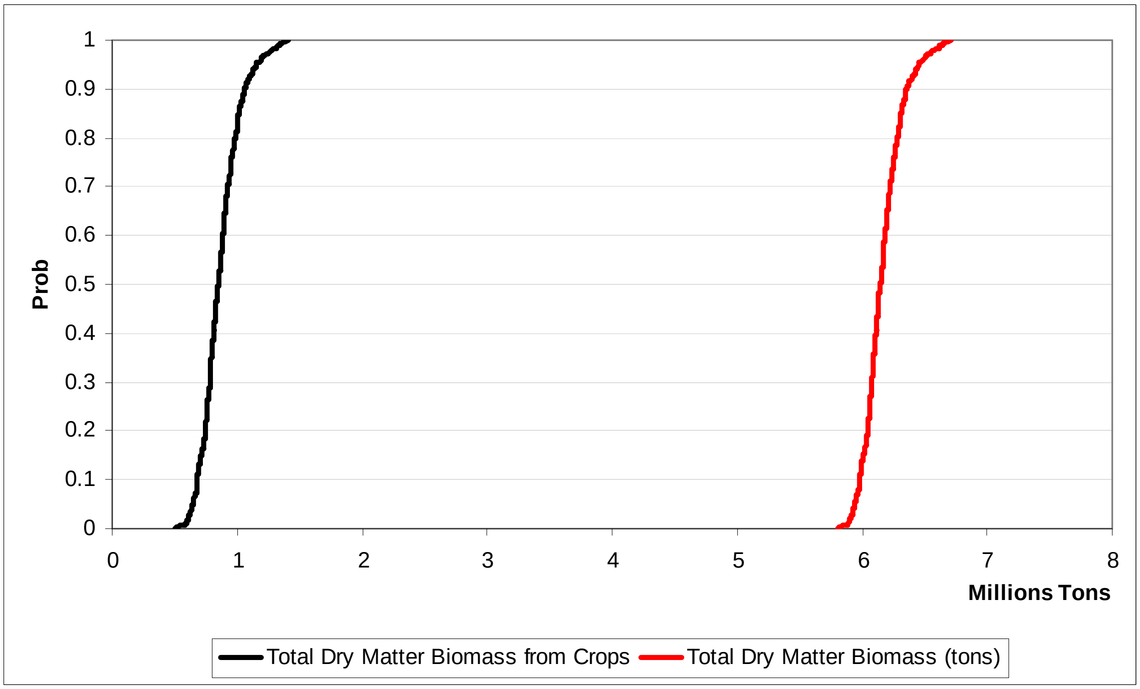

Figure 4. 18 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas South East

Table 4. 18 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas South East

Cellulosic Ethanol Plants	P(Sufficient Biomass from Crops)	P(Sufficient Biomass from Crops + Forestry)	Dry Tons Needed
25 Million Gallons	100.00%	100.00%	347,223
50 Million Gallons	87.65%	100.00%	694,445
75 Million Gallons	12.01%	100.00%	1,041,667
100 Million Gallons	0.11%	100.00%	1,388,889

Upper Coast

The Upper Coast district has thirteen counties and is located to the south of the South East district (Figure 4.19).

Total Residue from Crops

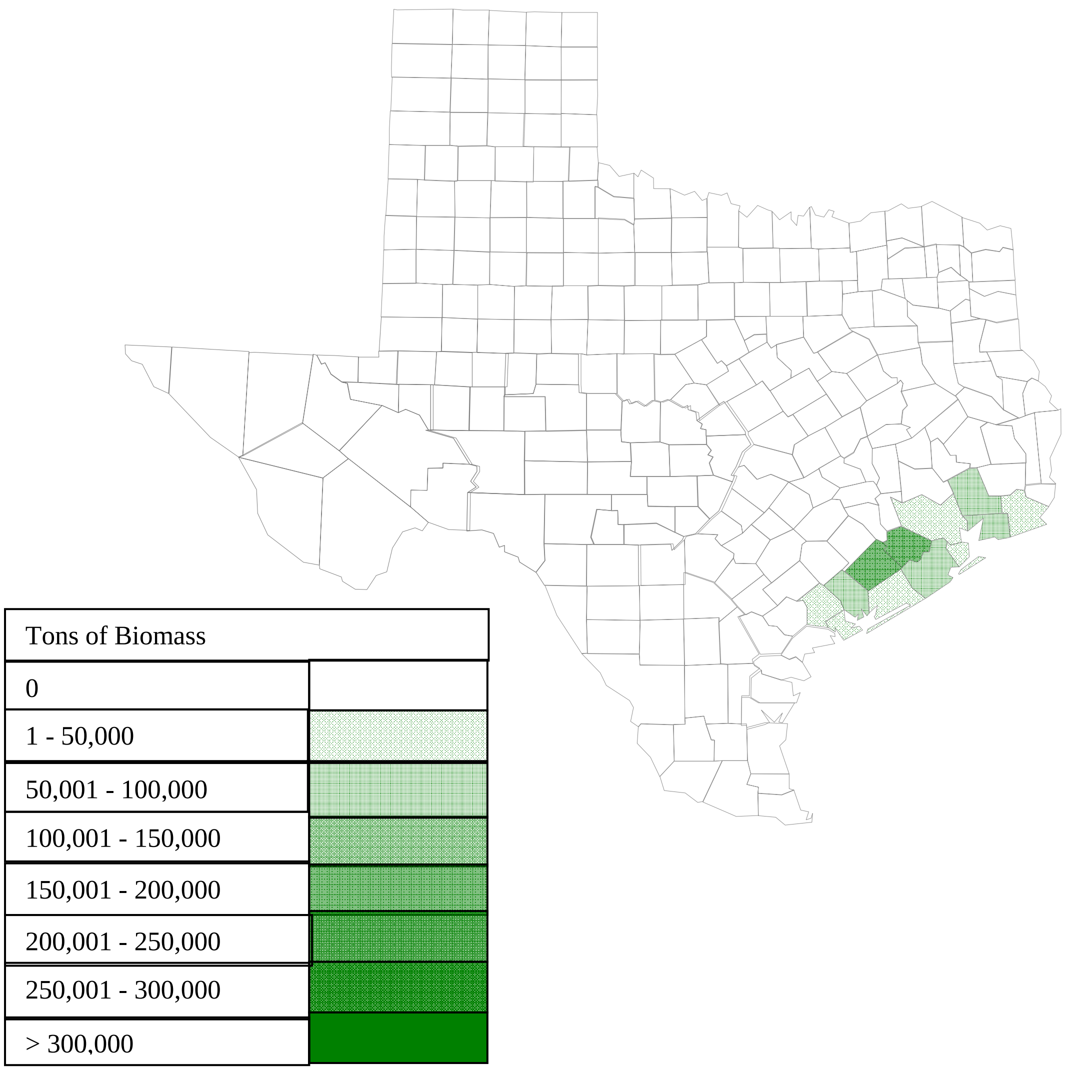

Figure 4. 19 Annual Residue Available from Commodities in the Upper Coast

The district only has two counties that produce more that 150,000 dry tons of biomass from crops (Wharton and Fort Bend). The remaining counties produce less than 100,000 dt/y of biomass from crops with the expected value for total biomass amounting to 0.8 million dt/y (Table 4.19). The crop residue within this district comes from corn stover, cotton trash, hay, and sorghum residue.

Table 4. 19 Annual Biomass from Commodities by County for the Upper Coast

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Brazoria	98,518	96,294	25,975	27	42,624	177,942
Calhoun	16,484	16,023	3,402	21	6,791	22,277
Chambers	57,305	54,807	16,829	31	30,284	89,000
Fort Bend	154,449	148,041	32,125	22	56,778	213,651
Galveston	28,517	28,559	9,155	32	9,238	45,586
Harris	33,166	33,297	10,103	30	19,817	77,180
Jackson	69,643	72,166	11,232	16	45,692	101,441
Jefferson	26,576	43,303	51,613	119	0	213,861
Liberty	80,110	103,291	75,337	73	31,703	342,869
Matagorda	24,875	24,872	4,454	18	14,902	33,237
Orange	0	0	0	0	0	0
Victoria	45,909	44,518	11,908	27	17,599	79,543
Wharton	165,445	150,737	29,662	20	79,777	218,215
Total Biomass from Crops	801,003	815,913	110,364	14	559,194	1,230,983

Total Residue from Forestry

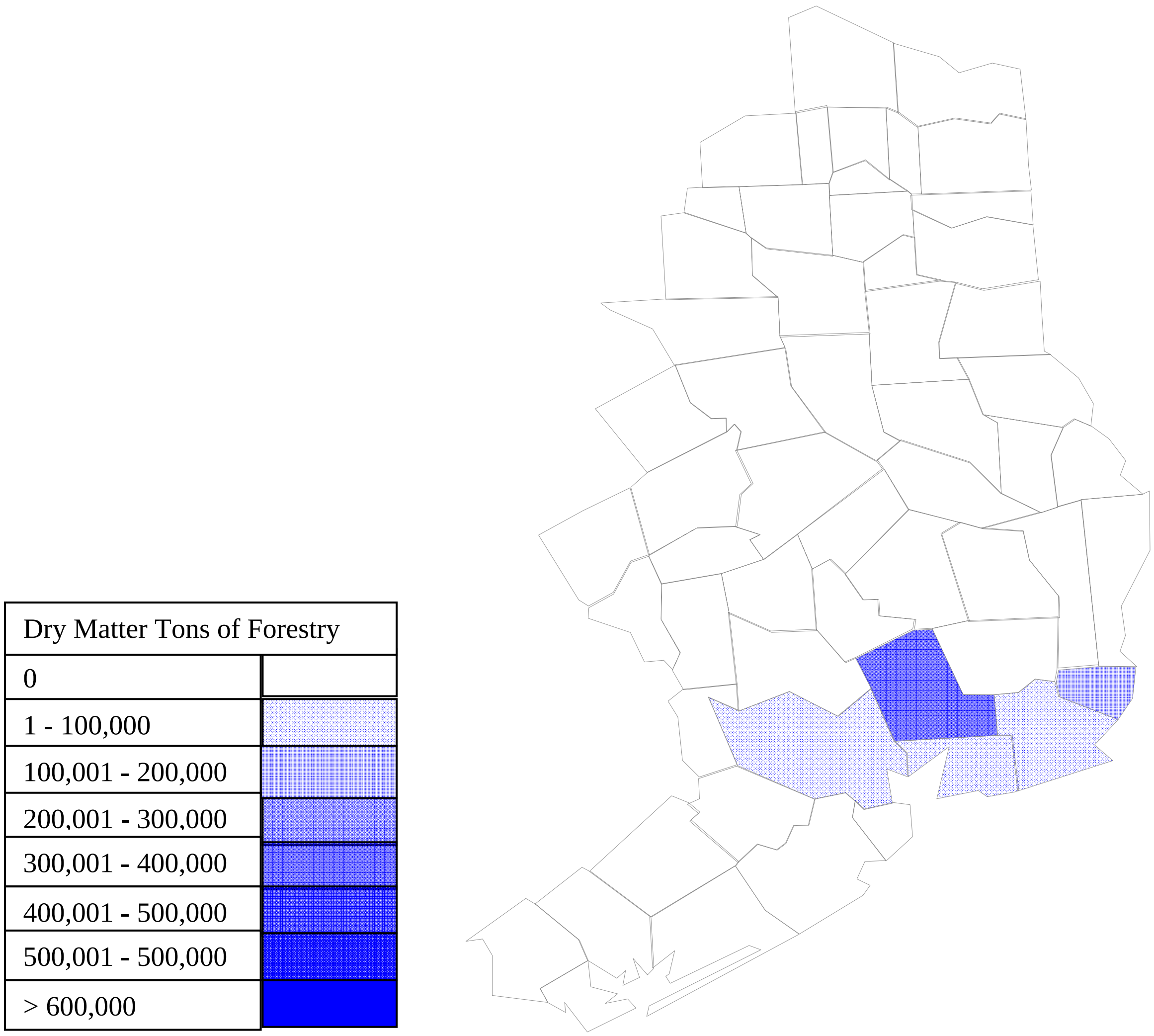

Figure 4. 20 Annual Residue Available from Forestry in the Upper Coast

Forestry wastes are also present in five of the thirteen counties, and these counties are located on the eastern side of the Upper Coast district (Figure 4.20). These counties produce 567,115 dry tons of forestry waste per year (Table 4.20). Figure 4.21 shows two CDF graphs. The first is for crops only and the second is crop residue with the addition of forestry wastes. This shows that the minimum amount of annual residue is roughly 1.2 million dt/y, while the maximum is about 1.9 million dt/y. The Upper Coast district has enough biomass to support five 25 mpgy or two 50 mgpy cellulosic ethanol plants 100 percent of the time, however, it only has enough to support a 100 million gallon plant 94.59 percent of the time (Table 4.21).

Table 4. 20 Annual Residue Available from Forestry in the Upper Coast by County

Total Forestry			
Brazoria	0	Jefferson	5389
Calhoun	0	Liberty	343364
Chambers	28034	Matagorda	0
Fort Bend	0	Orange	166937
Galveston	0	Victoria	0
Harris	23391	Wharton	0
Jackson	0	Total for Forestry	567115

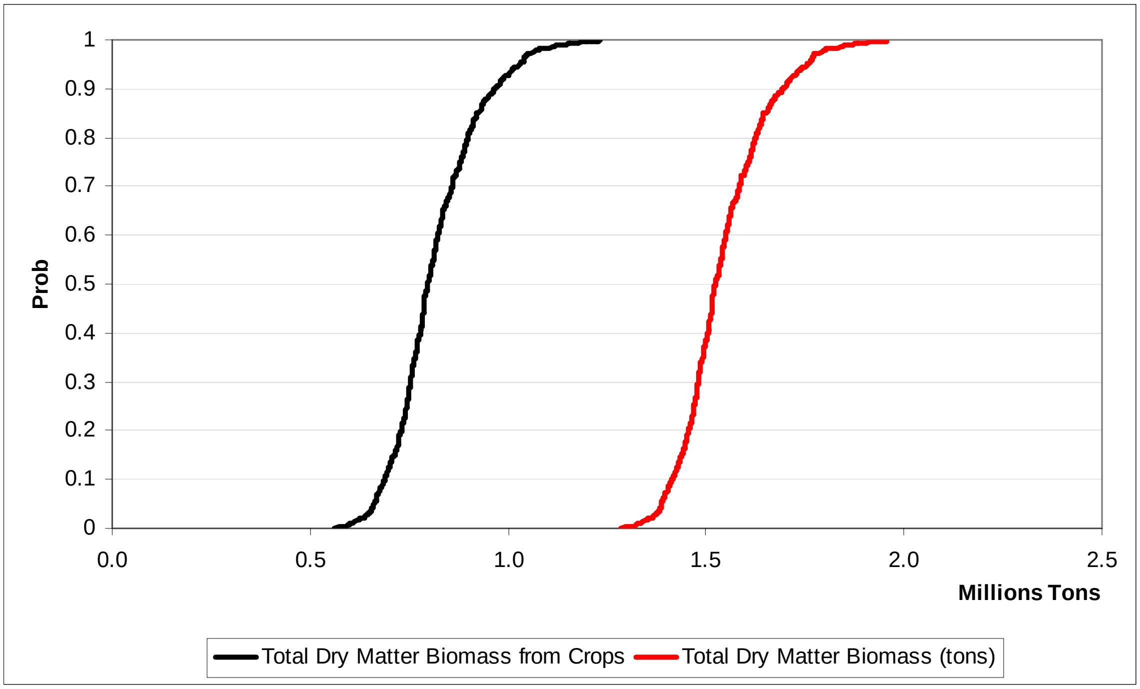

Figure 4. 21 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas Upper Coast

Table 4. 21 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas Upper Coast

Cellulosic Ethanol Plants	P(Sufficient Biomass From Crops	P(Sufficient Biomass from Crops + Forestry)	Dry Tons Needed
25 Million Gallons	100.00%	100.00%	347,223
50 Million Gallons	88.52%	100.00%	694,445
75 Million Gallons	3.76%	100.00%	1,041,667
100 Million Gallons	0.00%	94.59%	1,388,889

Trans-Pecos

The Trans-Pecos district is located in the extreme west region of the state and is comprised of fourteen counties (Figure 4.22).

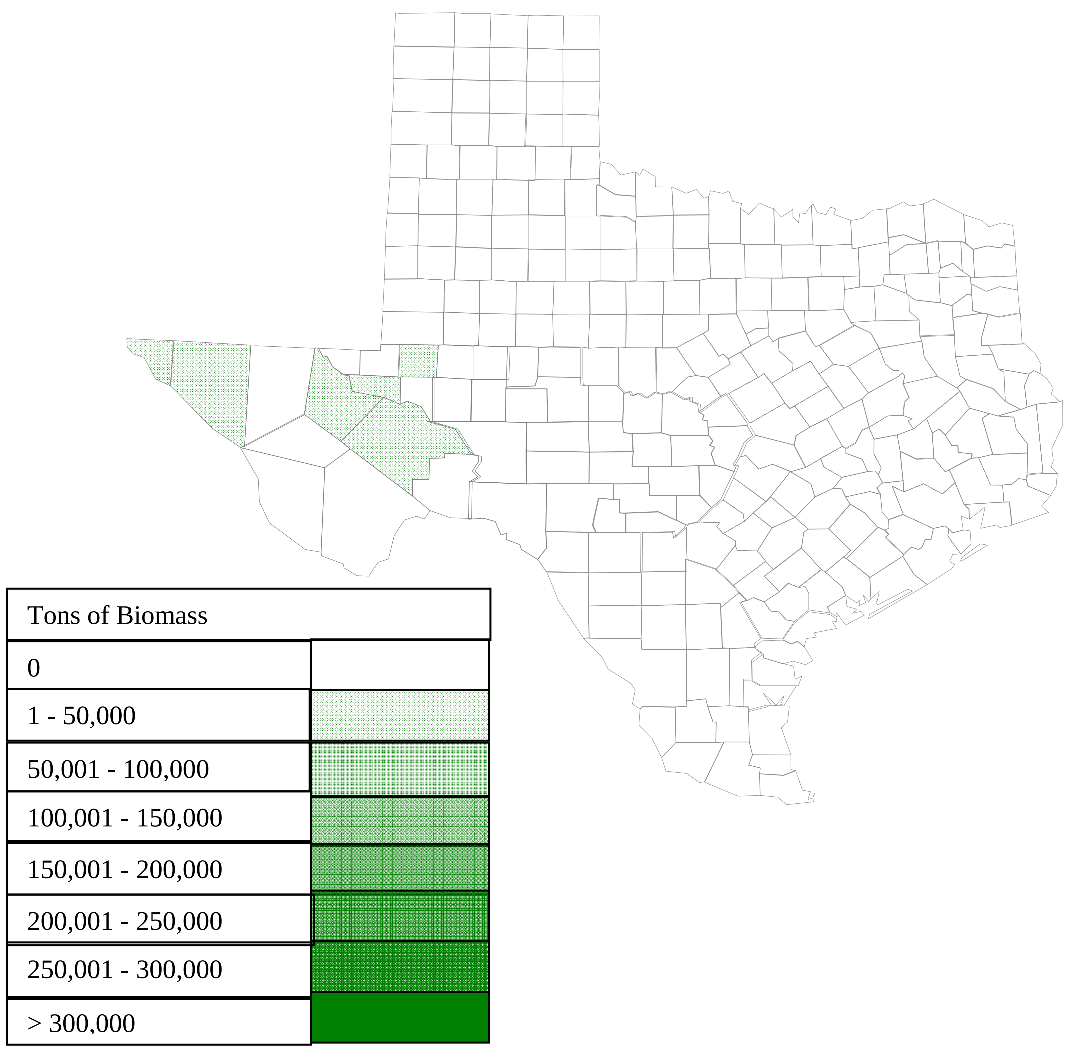

Figure 4. 22 Annual Residue Available from Commodities in the Trans-Pecos

Table 4. 22 Annual Biomass from Commodities by County for the Trans-Pecos

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Brewster	0	0	0	0	0	0
Crane	0	0	0	0	0	0
Culberson	0	0	0	0	0	0
Ector	2,749	2,696	787	29	1,799	4,500
El Paso	6,368	7,804	4,987	64	1,796	21,175
Hudspeth	1,629	11,012	31,914	290	616	161,356
Jeff Davis	0	0	0	0	0	0
Loving	0	0	0	0	0	0
Pecos	12,024	12,749	6,731	53	2,524	30,868
Presidio	0	0	0	0	0	0
Reeves	3,222	3,340	1,017	30	1,374	5,873
Terrell	0	0	0	0	0	0
Ward	207	222	161	73	9	600
Winkler	0	0	0	0	0	0
Total Dry Matter Biomass	26,202	37,826	33,694	89	12,151	212,567

The top producing county is Pecos, which can only produce 12,024 dry tons annually as presented in Table 4.22. Figure 4.23 shows that this district only produces 20,000 dry tons of biomass with 90 percent confidence which indicates that there is not enough biomass from crops to support even a 25 million gallon cellulosic ethanol plant as Table 4.23 presents.

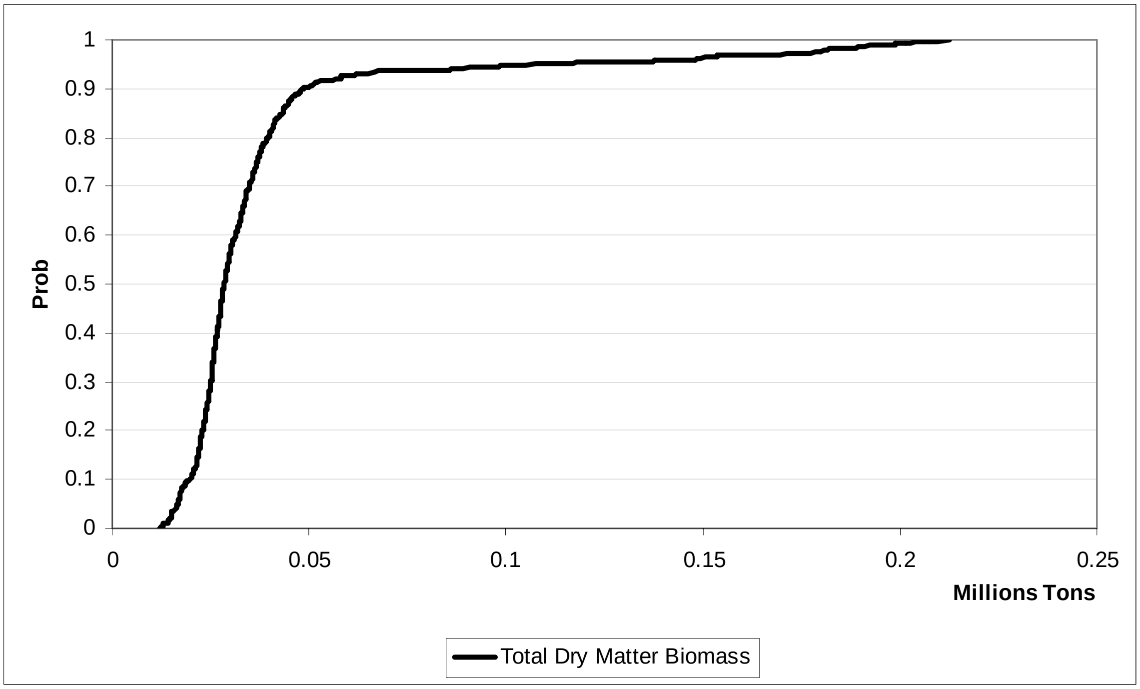

Figure 4. 23 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas Trans-Pecos

Table 4. 23 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas Trans-Pecos

Cellulosic Ethanol Plants	P(Sufficient Biomass)	Dry tons needed
25 Million Gallons	0.00%	347,223
50 Million Gallons	0.00%	694,445
75 Million Gallons	0.00%	1,041,667
100 Million Gallons	0.00%	1,388,889

Edwards Plateau

The Edwards Plateau district is comprised of twenty-nine counties each producing less than 50,000 dt/y of biomass from crops (Figure 4.24).

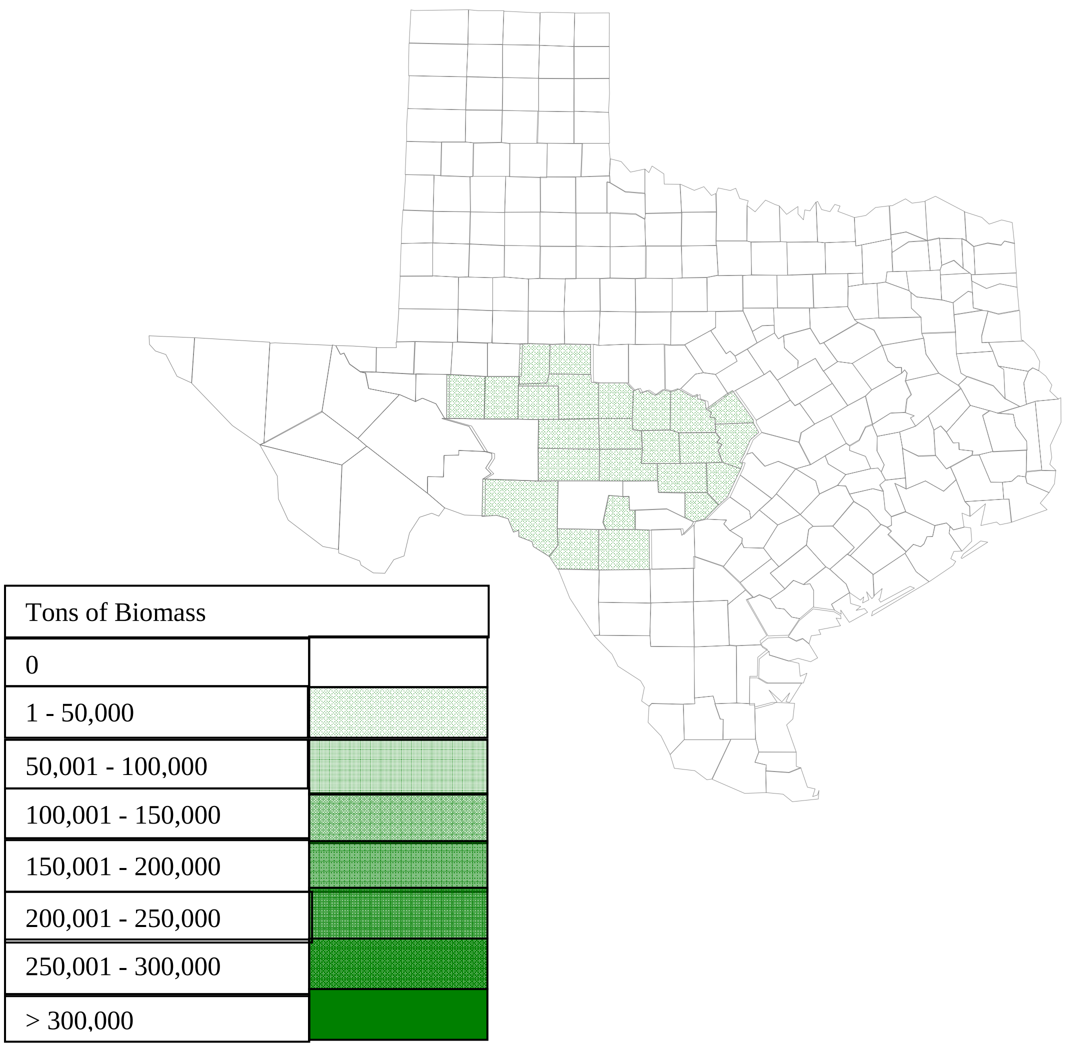

Figure 4. 24 Annual Residue Available from Commodities in the Edwards Plateau

Table 4. 24 Annual Biomass from Commodities by County for the Edwards Plateau

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Bandera	0	0	0	0	0	0
Blanco	8,590	9,706	3,726	38	5,084	17,797
Burnet	25,401	22,063	8,126	37	689	31,857
Coke	11,964	24,044	24,977	104	2,015	94,810
Concho	26,260	31,201	11,660	37	9,684	64,118
Crockett	0	0	0	0	0	0
Edwards	0	0	0	0	0	0
Gillespie	10,718	11,452	4,038	35	3,054	20,680
Irion	823	821	281	34	259	1,345
Kendall	24,440	25,454	7,649	30	10,943	40,864
Kerr	0	0	0	0	0	0
Kimble	162	169	74	44	54	325
Kinney	776	981	686	70	244	2,965
Lampasas	13,423	12,807	7,020	55	3,445	29,545
Llano	5,183	4,977	1,977	40	955	11,641
Mason	9,649	9,474	4,933	52	2,027	24,954
McCulloch	16,436	18,898	7,505	40	6,272	38,646
Menard	1,961	1,948	893	46	454	4,564
Reagan	6,491	7,075	2,838	40	3,263	19,803
Real	2,604	3,294	1,924	58	462	8,102
Rockwall	19,185	18,784	3,731	20	12,782	25,565
San Saba	11,182	21,161	18,139	86	1,175	82,574
Schleicher	2,719	2,771	530	19	1,159	4,216
Sterling	284	308	79	26	185	476
Sutton	100	107	34	32	57	166
Tom Green	27,802	30,481	8,790	29	18,227	73,325
Upton	3,176	3,838	1,719	45	1,599	9,963
Uvalde	42,219	41,246	6,412	16	21,522	59,889
Val Verde	1,127	2,538	2,370	93	618	10,132
Total Dry Matter Biomass	272,675	305,595	40,565	13	211,226	450,458

The largest producing county is Uvalde with 42,219 dt/y, however because of the large number of counties within this district the expected amount of biomass from crops is 272,675 dry tons per year (Table 4.24). The majority of the biomass comes from hay and wheat straw with some counties producing corn stover, cotton trash, and sorghum residue. As Figure 4.25 shows the minimum amount of biomass that this district can produce is about 210,000 dt/y and the maximum amount is roughly 450,000 dry tons per year. Agricultural wastes obtained from the Edwards Plateau can amount to 250,000 with 90 percent certainty, however, this is not enough biomass to support even a small 25 million gallon per year cellulosic ethanol plant (Table 4.25).

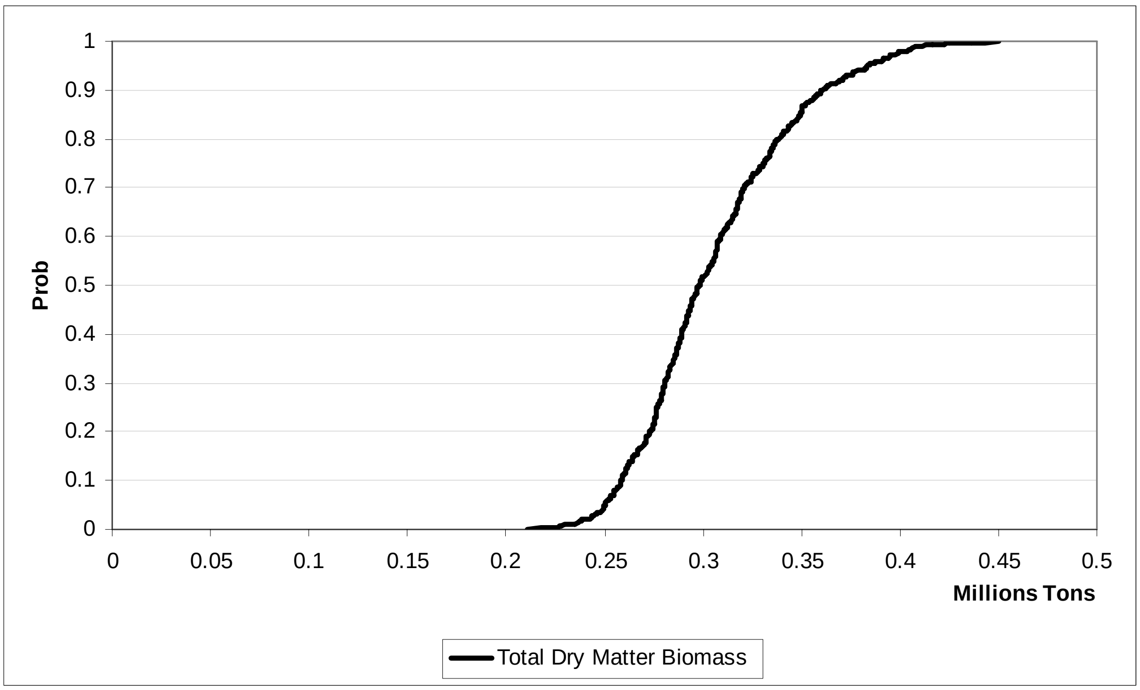

Figure 4. 25 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas Edwards Plateau

Table 4. 25 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas Edwards Plateau

Cellulosic Ethanol Plants	P(Sufficient Biomass)	Dry tons needed
25 Million Gallons	16.41%	347,223
50 Million Gallons	0.00%	694,445
75 Million Gallons	0.00%	1,041,667
100 Million Gallons	0.00%	1,388,889

South Central

The South Central district is located to the Northwest of the Upper Coast district and contains twenty-one counties (Figure 4.26).

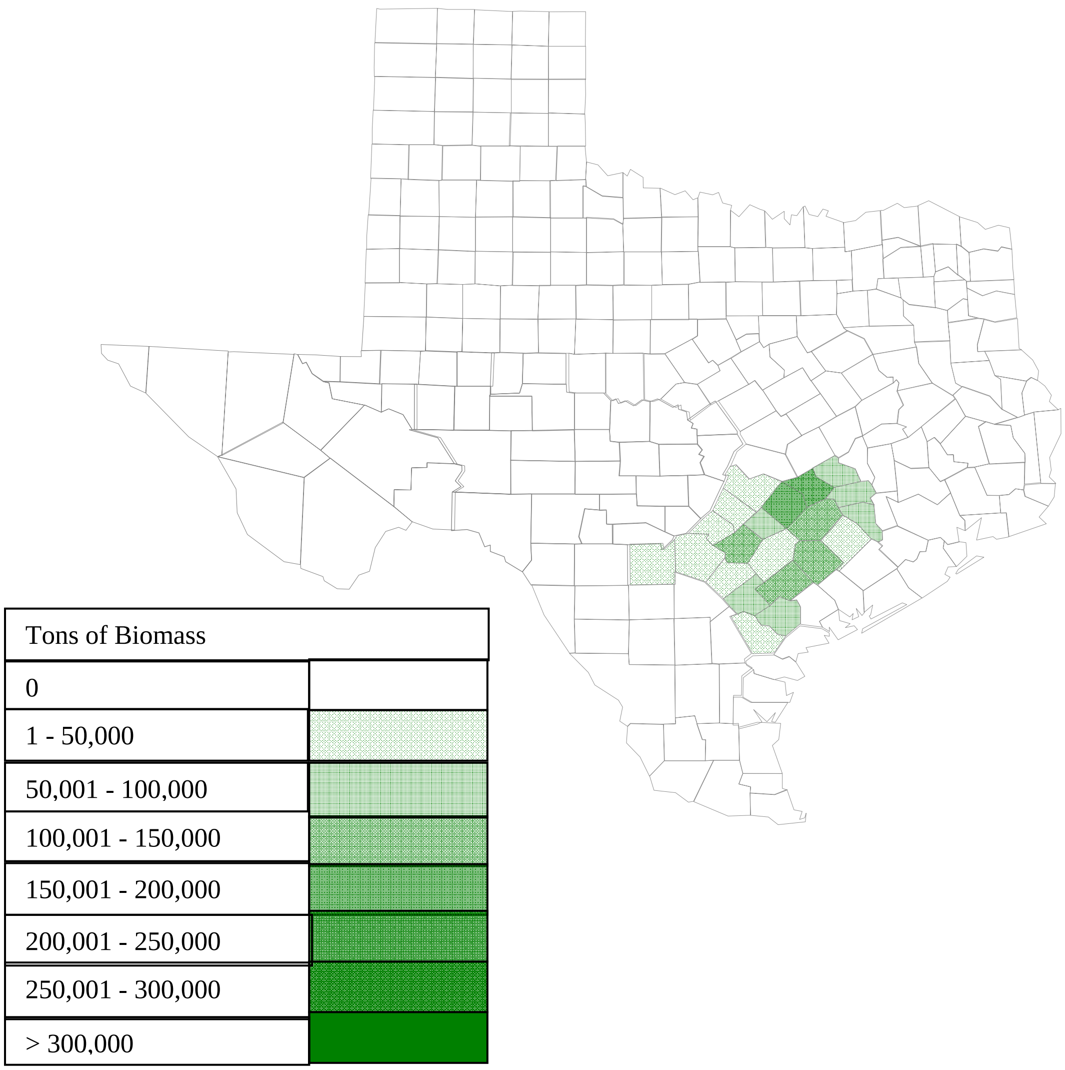

Figure 4. 26 Annual Residue Available from Commodities in the South Central

Table 4. 26 Annual Biomass from Commodities by County for the South Central

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Austin	89,442	88,295	19,482	22	45,047	142,710
Bastrop	183,606	200,633	138,222	69	29,063	576,840
Bee	50,699	66,979	48,735	73	6,173	220,529
Bexar	39,815	40,766	14,587	36	9,536	69,704
Burleson	92,857	85,950	25,944	30	31,642	133,594
Caldwell	84,560	77,685	24,857	32	25,270	123,339
Colorado	48,150	53,961	25,399	47	24,624	142,446
Comel	26,082	27,657	23,782	86	823	123,105
De Witt	145,666	168,812	136,726	81	1,348	635,971
Fayette	129,595	125,663	64,580	51	23,250	266,291
Goliad	55,526	51,837	33,096	64	4,951	138,546
Gonzales	39,455	47,987	25,417	53	20,567	128,129
Guadalupe	121,673	123,920	45,980	37	32,096	265,657
Hays	39,215	50,069	37,877	76	3,573	160,793
Karnes	55,304	56,218	27,936	50	13,016	126,300
Lavaca	147,524	150,588	56,702	38	59,117	240,229
Lee	173,282	197,117	84,575	43	44,953	371,734
Medina	47,434	47,904	8,169	17	31,053	79,112
Travis	9,971	9,987	2,158	22	4,900	14,244
Washington	73,429	73,864	16,024	22	29,494	98,876
Wilson	40,894	42,464	12,327	29	18,833	71,796
Total Dry Matter Biomass	1,694,189	1,788,363	258,174	14	1,143,790	2,807,722

The largest producing counties in this district are Bastrop, Lee, and Lavaca producing 183,606 dt/y, 173,282 dt/y, and 147,524 dt/y, respectively, with the total expected value for the biomass production of the South Central district being 1,694,189 dry tons per year (Table 4.26). The biomass for cellulosic ethanol in this district mainly comes from corn stover, cotton trash, hay, sorghum residue, and wheat straw.

Figure 4.27 shows that the range of biomass produced in the South Central district ranges from roughly 1.14 million dry tons per year to about 2.8 million dry tons per year. The South Central district can produce 1.5 million dry tons of agricultural wastes 90 percent of the time which can amount to 100 million gallons of ethanol. The production of this ethanol can come from either four 25 mgpy plants or one 100 mgpy plant (Table 4.27).

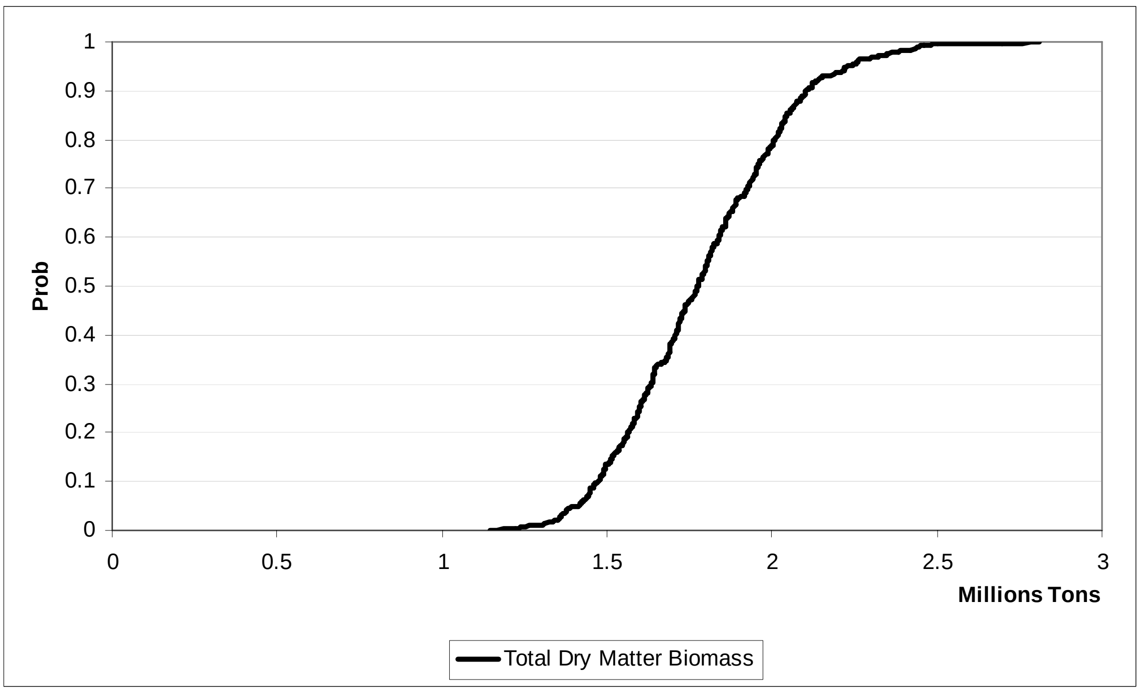

Figure 4. 27 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas South Central

Table 4. 27 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas South Central

Cellulosic Ethanol Plants	P(Sufficient Biomass)	Dry tons needed
25 Million Gallons	100.00%	347,223
50 Million Gallons	100.00%	694,445
75 Million Gallons	100.00%	1,041,667
100 Million Gallons	95.17%	1,388,889

Coastal Bend

The Coastal Bend district contains five counties and is located between the Upper Coast and the South Texas districts (Figure 4.28).

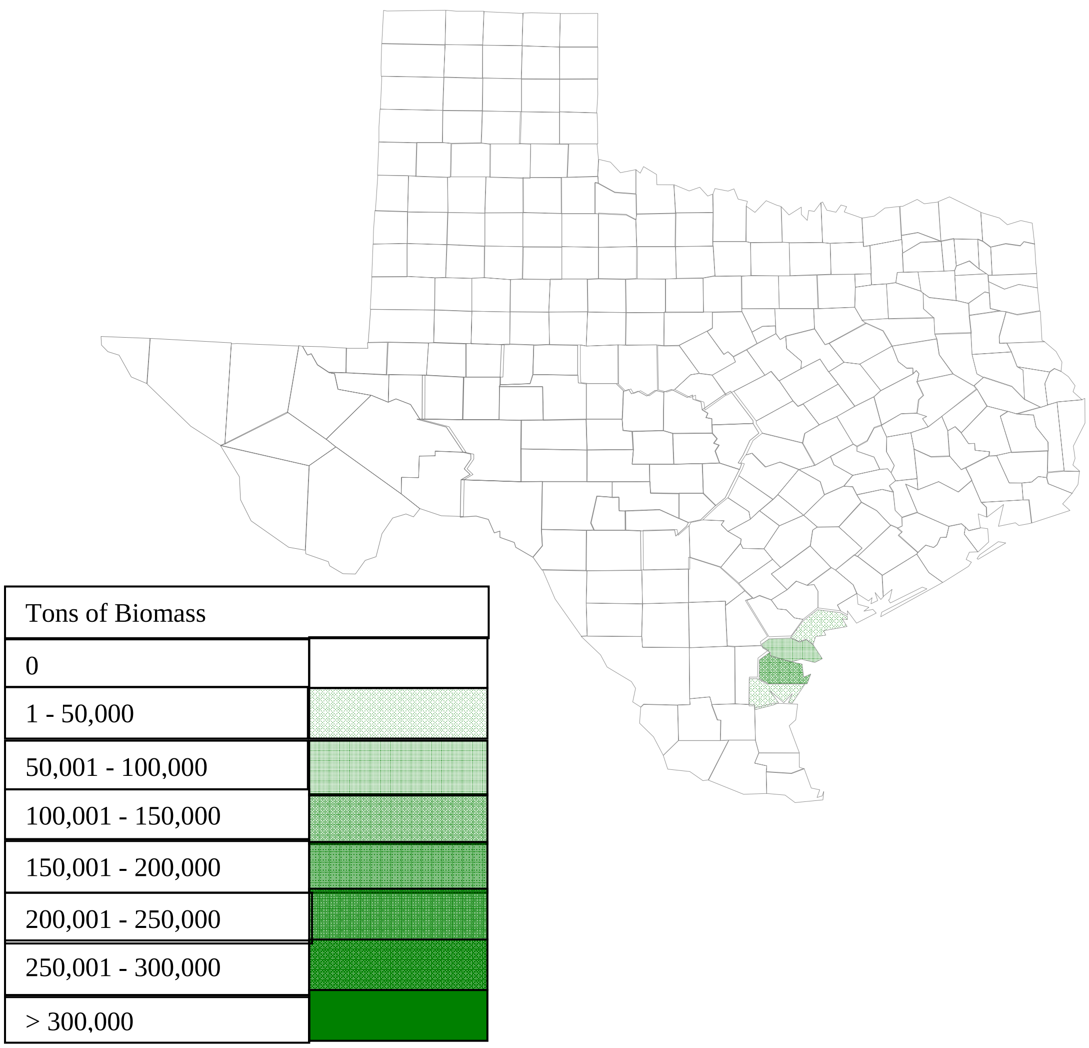

Figure 4. 28 Annual Residue Available from Commodities in the Coastal Bend

Table 4. 28 Annual Biomass from Commodities by County for the Coastal Bend

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Aransas	0	0	0	0	0	0
Kleberg	35,482	38,979	12,864	33	15,476	79,619
Nueces	102,099	106,878	21,724	20	59,361	182,956
Refugio	26,546	28,164	5,755	20	15,410	47,451
San Patrico	80,997	83,645	18,706	22	40,037	146,289
Total Dry Matter Biomass	245,124	257,667	30,145	12	185,623	348,787

The biomass in this district is produced by corn stover, cotton trash, hay, and sorghum residue. The majority of the 245,124 dry tons of biomass produced by this district each year comes from Nueces and San Patricio which provide 102,099 and 80,997 dry tons per year, respectively (Table 4.28).

As shown by Figure 4.29 total biomass produced by the Coastal Bend ranges from roughly 185,000 to 348,000 dry tons per year. There is a 90 percent chance that the agricultural wastes produced by the Coastal Bend will exceed 220,000 dry tons. However, this will not support even a small 25 mgpy cellulosic ethanol plant (Table 4.29).

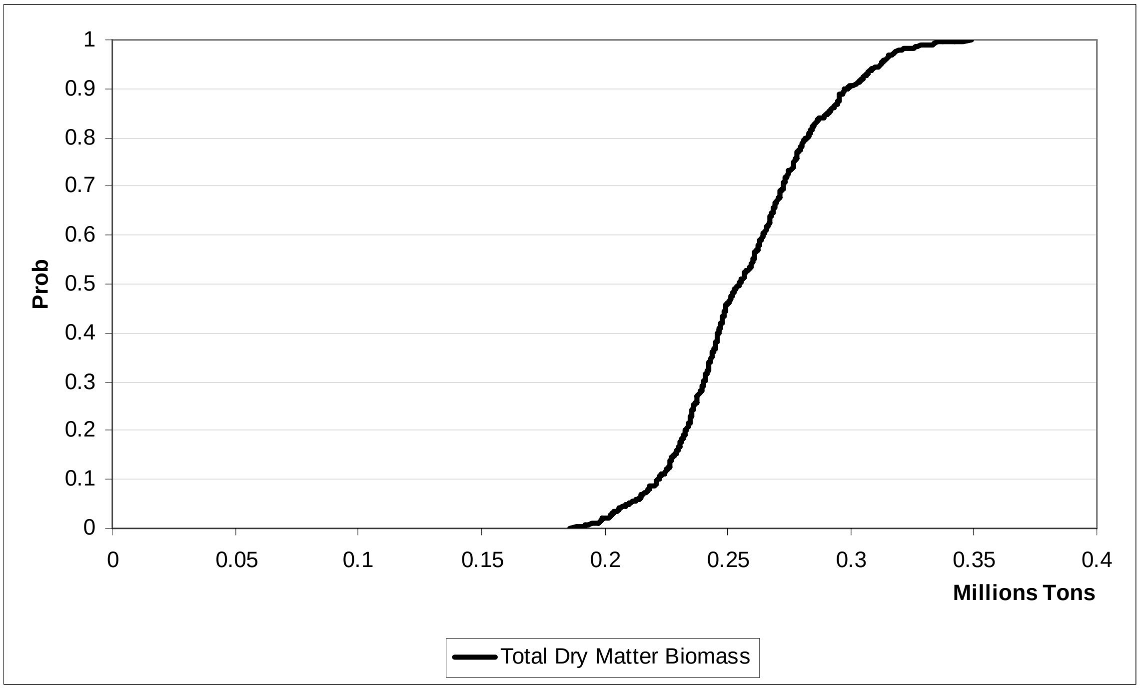

Figure 4. 29 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Texas Coastal Bend

Table 4. 29 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Texas Coastal Bend

Cellulosic Ethanol Plants	P(Sufficient Biomass)	Dry tons needed
25 Million Gallons	0.05%	347,223
50 Million Gallons	0.00%	694,445
75 Million Gallons	0.00%	1,041,667
100 Million Gallons	0.00%	1,388,889

South Texas

The South Texas district produces 86,000 to 255,000 tons of biomass annually (Table 4.30).

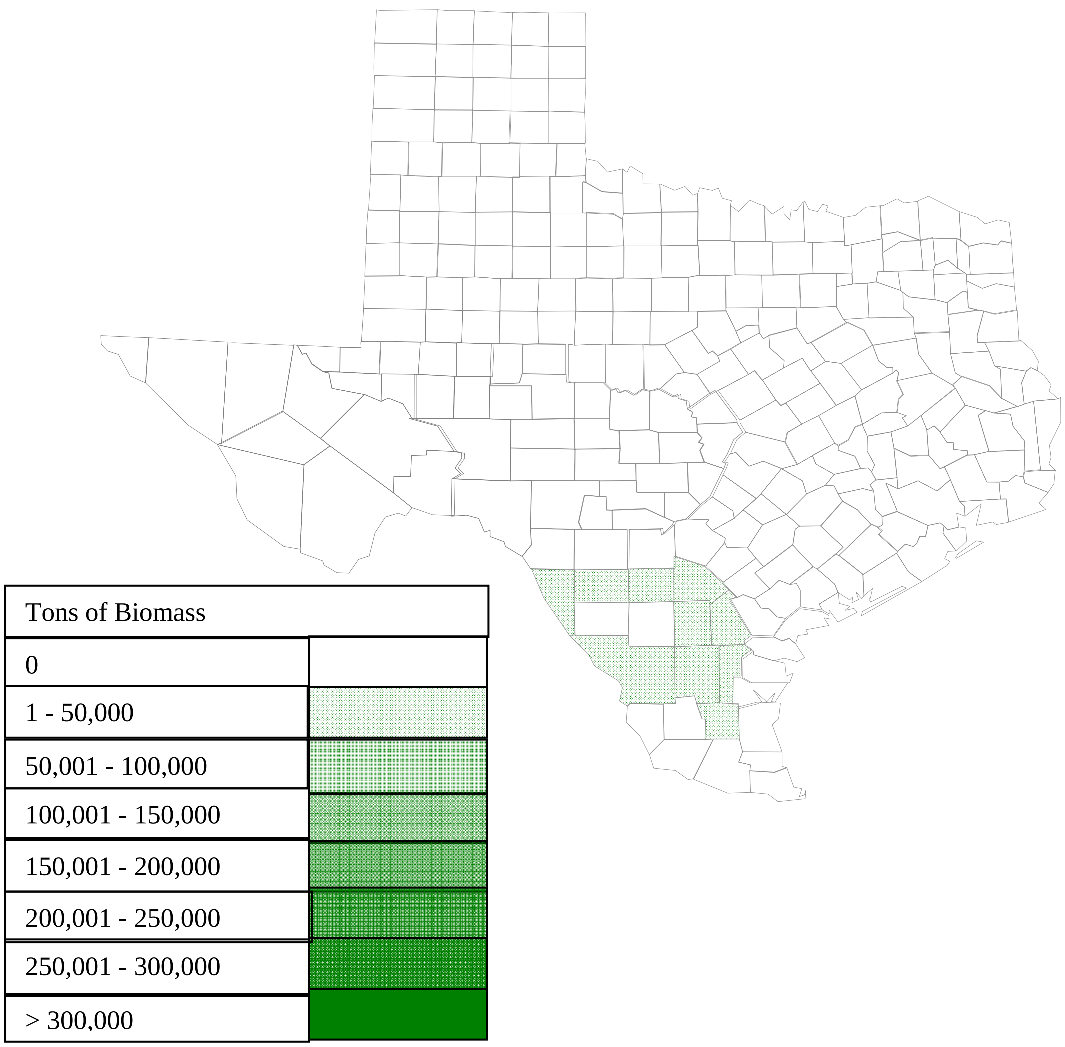

Figure 4. 30 Annual Residue Available from Commodities in South Texas

Table 4. 30 Annual Biomass from Commodities by County for South Texas

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Atascosa	44,195	45,208	16,968	38	9,135	94,519
Brooks	10,281	11,412	5,976	52	2,577	27,956
Dimmit	0	0	0	0	0	0
Duval	10,524	10,848	4,281	39	2,171	19,726
Frio	10,947	10,934	1,042	10	8,222	13,941
Jim Hogg	0	0	0	0	0	0
Jim Wells	16,030	16,072	4,575	28	7,592	27,844
Kenedy	0	0	0	0	0	0
La Salle	458	458	71	15	261	659
Live Oak	39,556	36,966	15,495	42	5,931	62,814
Maverick	38,447	38,022	16,906	44	5,665	64,255
McMullen	419	410	55	13	223	551
Webb	847	854	333	39	75	1,626
Zapata	0	0	0	0	0	0
Zavala	6,669	6,734	1,268	19	3,942	10,689
Total Dry Matter Biomass	178,378	177,923	29,642	17	86,374	256,585

The expected value of biomass produced annually is 178,378 dry tons as indicated by Table 4.30. There is a 90 percent chance that the district can obtain 4,000 dry tons of agricultural wastes annually as presented in Figure 4.31. This is not enough biomass to support even a small 25 mgpy plant (Table 4.31).

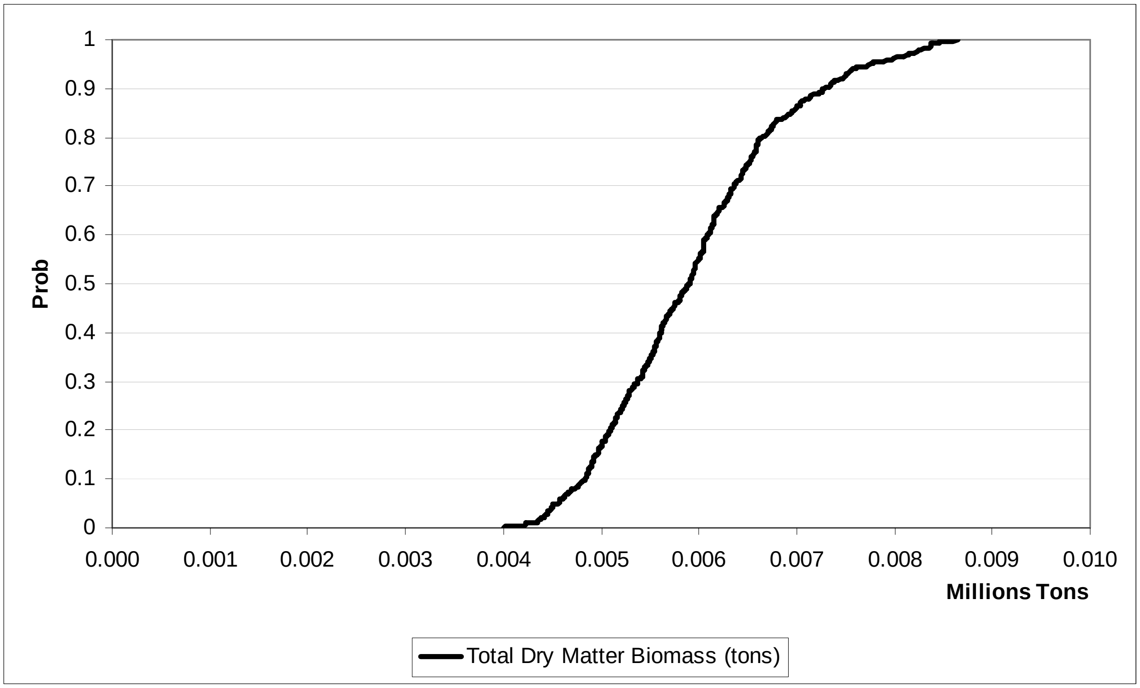

Figure 4. 31 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in South Texas

Table 4. 31 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the South Texas District

Cellulosic Ethanol Plants	P(Sufficient Biomass)	Dry tons needed
25 Million Gallons	0.00%	347,223
50 Million Gallons	0.00%	694,445
75 Million Gallons	0.00%	1,041,667
100 Million Gallons	0.00%	1,388,889

Lower Valley

The Lower Valley district produces 129,000 to 335,000 tons of biomass annually (Table 4.32). The expected value of biomass produced annually in the Lower Valley is 221,957 (Table 4.32).

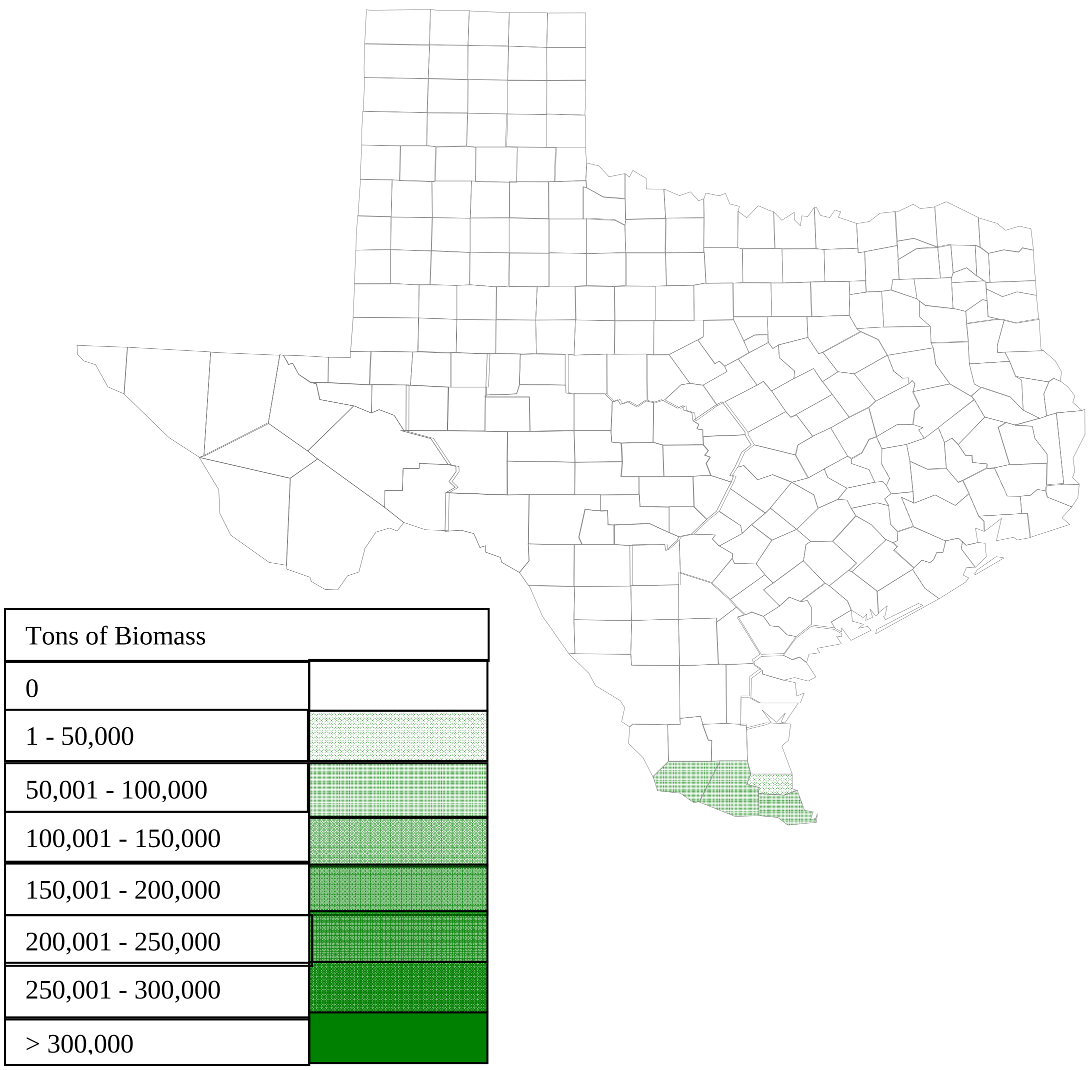

Figure 4. 32 Annual Residue Available from Commodities in the Lower Valley

Table 4. 32 Annual Biomass from Commodities by County for the Lower Valley

County	Total	Mean	StDev	CV	Min	Max
	(Tons)	(Tons)	(Tons)	(%)	(Tons)	(Tons)
Cameron	53,850	54,016	7,815	14	31,916	76,465
Hidalgo	58,936	57,374	10,070	18	32,545	85,757
Starr	69,757	70,267	35,573	51	10,008	145,756
Willacy	39,414	38,159	9,746	26	16,864	60,791
Total Dry Matter Biomass	221,957	219,817	39,344	18	129,164	335,529

There is a 90 percent chance that the agricultural wastes from the Lower Valley district will exceed 170,000 dry tons as shown by Figure 4.33 which is not enough biomass to support even a small 25 mgpy plant as indicated by Table 4.33.

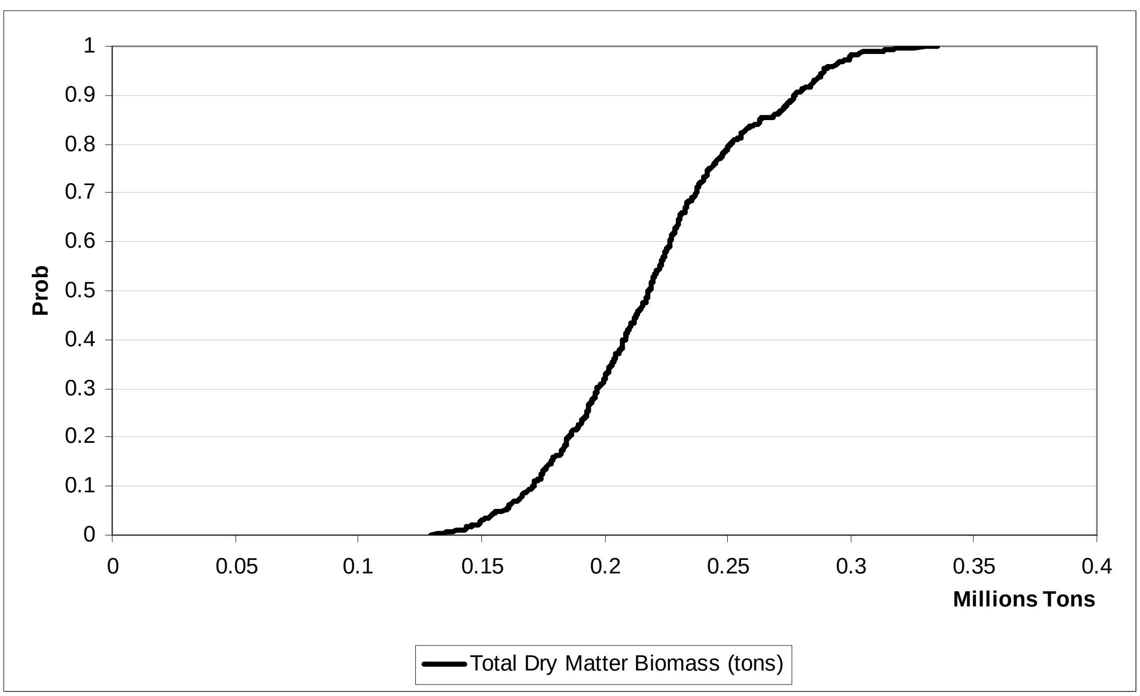

Figure 4. 33 Cumulative Distribution Function (CDF) for the Total Annual Biomass Available in the Lower Valley

Table 4. 33 Probability of Sufficient Annual Biomass for Four Different Sized Cellulosic Ethanol Plants in the Lower Valley

Cellulosic Ethanol Plants	P(Sufficient Biomass)	Dry tons needed
25 Million Gallons	0.00%	347,223
50 Million Gallons	0.00%	694,445
75 Million Gallons	0.00%	1,041,667
100 Million Gallons	0.00%	1,388,889

Summary

Potential biomass for cellulosic ethanol in Texas is concentrated in the Northern and Eastern regions of the state (Figure 4.34)

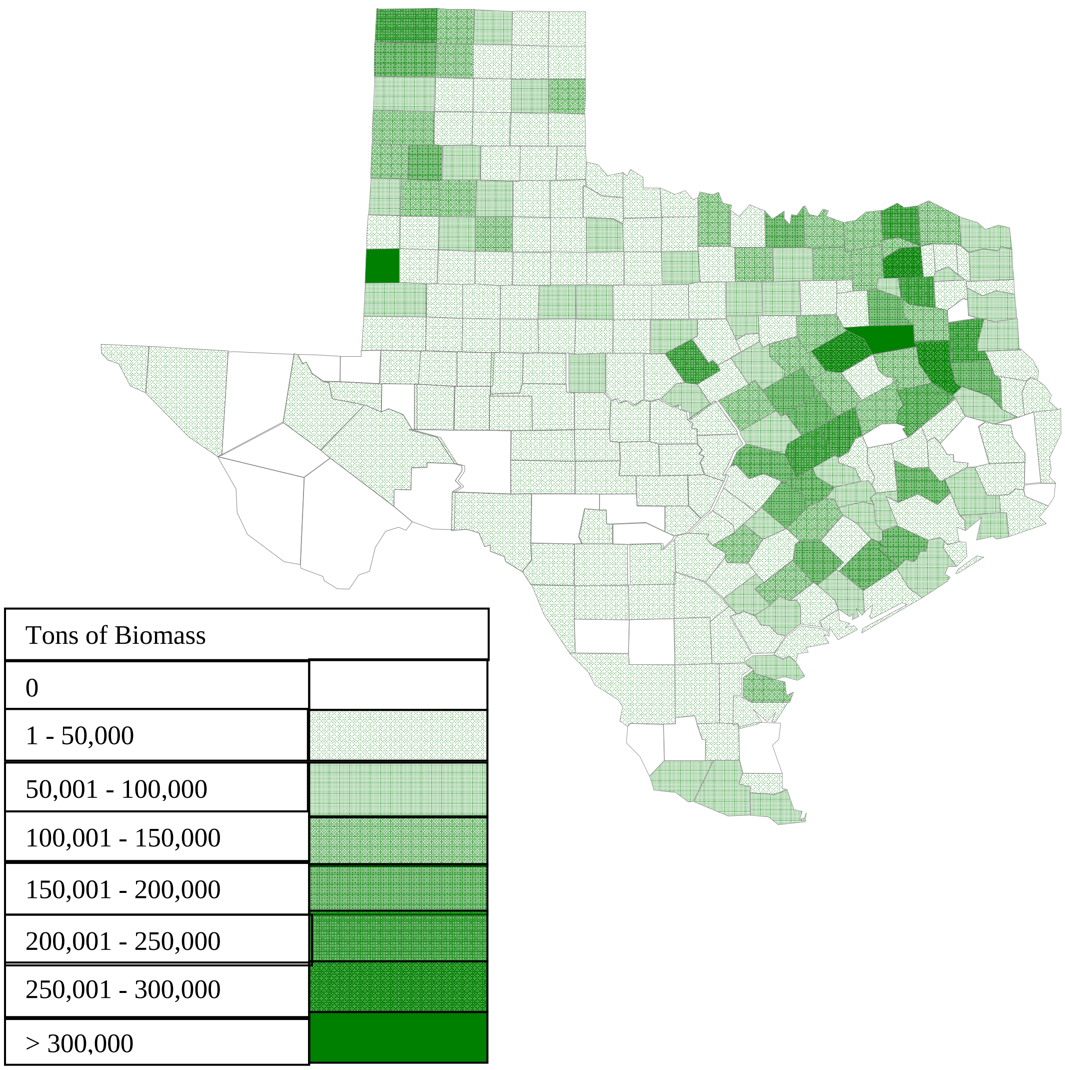

Figure 4. 34 Annual Residue Available from Commodities in Texas

The addition of forestry wastes to the districts of the North East, South East, and Upper Coast greatly increases the amount of potential biomass for cellulosic ethanol over agricultural wastes alone (Figure 4.35).

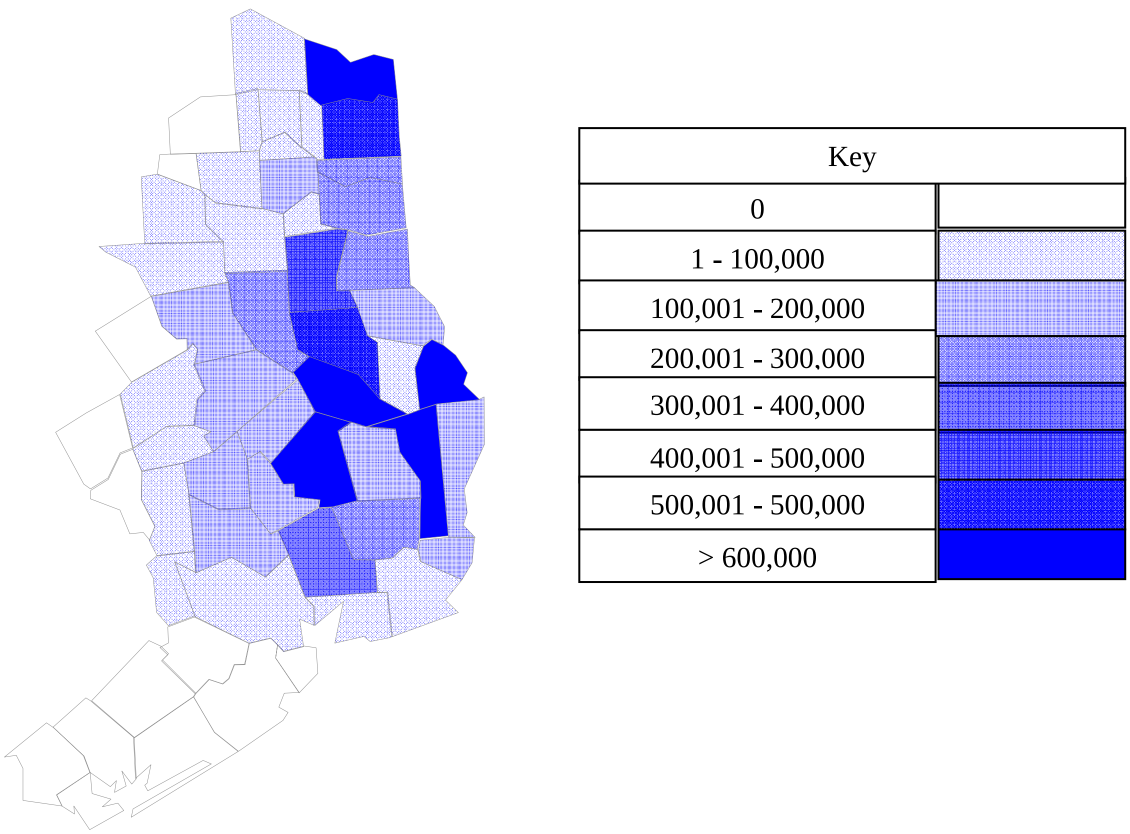

Figure 4. 35 Annual Residue from Forestry in Texas

As Table 4.34 indicates with 90 percent certainty, that Texas has the potential to produce 1.55 billion gallons of cellulosic ethanol which will come from nineteen different sized cellulosic ethanol plants (twelve 100 mgpy, three 75 mgpy, one 50 mgpy, and three 25 mgpy). Due to logistical problems of assembling biomass most cellulosic ethanol plants will be in the 25-50 million gallon range. This would reduce the number of large plants and expand the number of small plants to as many as 62 small plats of 25 million gallons per year.

Table 4. 34 Potential Number of Cellulosic Ethanol Plants in Texas Using Agricultural and Forestry Waste

Districts	**Total Potential Ethanol**	**Million Gallon Cellulosic Ethanol Plants**			
		25	**50**	**75**	**100**
	(Mgal)				
Northern High Plains	125	1	0	0	1
Southern High Plains	75	0	0	1	0
Northern Low Plains	0	0	0	0	0
Southern Low Plains	25	1	0	0	0
Crosstimbers	50	0	1	0	0
Blacklands	175	0	0	1	1
North East Texas	475	0	0	1	4
South East Texas	425	1	0	0	4
Upper Coast	100	0	0	0	1
Trans-Pecos	0	0	0	0	0
Edwards Plateau	0	0	0	0	0
South Central	100	0	0	0	1
Coastal Bend	0	0	0	0	0
South Texas	0	0	0	0	0
Lower Valley	0	0	0	0	0
Total	1550	3	1	3	12

Nine of the fifteen districts could produce cellulosic ethanol with the majority coming from the North East, South East, Blacklands, and Upper Coast districts. These districts could produce 475, 425, 125, and 100 million gallons of cellulosic ethanol, respectively (Table 4.34). These four districts are located in the Eastern region of Texas and account for over 70 percent of the state’s potential production for cellulosic ethanol.

CHAPTER V

SUMMARY AND CONCLUSION

This study was designed to assess the potential amount of agricultural wastes that each county and district in Texas could produce based on historical crop yields and the current crop mix. The resurgence of interest in alternative fuel sources has led to increased research into the use of biomass as a fuel source. Biomass has the potential to be burned for electricity production or to be anaerobically altered into ethanol. In either case the amount of biomass within a region needs to be known to evaluate the feasibility of cellulosic ethanol production in Texas.

Previous inventories of biomass only did a point estimate or they did not incorporate risk into their study. This research incorporates risk to produce a probabilistic forecast of available biomass. Incorporating risk into the inventory will allow decision makers to understand the potential risk associated with biomass production. This research also estimates the probability that there is enough biomass to support different sized ethanol plants for each district. Thus it will help prospective investors determine where and what size of plant to build so they will have a high probability of adequate biomass.

With the production technology to produce cellulosic ethanol nearing commercial availability, it is time to assess where and what is the concentration of biomass feedstock available in Texas? And what is the probability that adequate supplies of agricultural and forestry wastes would be available? The specific objective for this study is to inventory agriculture and forestry wastes for the state of Texas. This inventory will show how much biomass is available on a per county and district basis. A Monte-Carlo simulation model was used to develop a stochastic forecast for the amount of biomass in each county with a 90 percent level of confidence. The number of different size cellulosic ethanol plants that would have adequate feed stock with 90 percent confidence was estimated for each district.

The results from the analysis show that there is an abundance of agricultural waste produced in Texas that could be available for cellulosic ethanol. The majority of the biomass produced from crop residue is located in the districts to the North and East of the state with the top district being the North East. Districts to the far West and South such as the Trans-Pecos and South Texas do not have sufficient biomass production to be viable locations for cellulosic ethanol production, assuming historical crop yields and current crop mixes.

The addition of forestry biomass in the North East, South East, and Upper Coast districts would produce more ethanol than the rest of the state. There is a 90 percent chance that these three districts could produce more than half of the potential biomass for Texas. With the addition of the Blacklands district, which is also in the eastern region of the state, these four districts could potentially produce over 70 percent of the cellulosic ethanol for Texas. Other districts in Texas of notable interest are the Northern High Plains and the Southern High Plains. These two districts together have a 90 percent chance of supporting the production of 200 million gallons of cellulosic ethanol.

In summary this study shows that there is a large amount of biomass available for cellulosic ethanol production. Total gallons of ethanol from the cellulosic process could amount to 1.55 billion with more than 60 plants having a 25 mgpy capacity that have a 90 percent probability of an adequate supply of agricultural and forestry biomass. Assembling, transporting, and processing biomass will vary by region, residue type, haul distance, and plant locations.

Limitations

This study does not include municipal biomass wastes which could be used in the production of cellulosic ethanol. Also the mix of crops produced may change with new technology, for example high biomass or energy cane. Crop mixes also may change as crop prices adjust and/or contracts are offered to grow biomass crops.

Further Research

The addition of trash vegetation such as mesquite could be added to this study when there becomes a viable way to inventory and harvest this biomass. Municipal wastes could also be included.

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