Chapter 5

BIOMASS ENERGY

Introduction

Texas encompasses vast areas of land with significant potential for diverse biomass production and a measurable collection of bioenergy. Forest resources in East Texas, mesquite/cedar in the Hill Country and West Texas; municipal solid waste and urban waste; construction residue; dedicated energy crops such as energy cane, switchgrass, and sorghum; crop residue; oilseed crops; grain; and algae are important potential sources of energy. In 1995, the Texas Sustainable Energy Development Council produced a comprehensive assessment of renewable energy.[1] Chapter 6 of that report provides an excellent assessment of Texas' biomass potential. Also, in May 2008, the Comptroller of Public Accounts released a report on Texas energy resources that details the status and potential of 17 energy resources ranging from oil to hydrogen.[2] Ethanol, biodiesel, wood, feedlot waste, and municipal solid waste are characterized. This chapter on biomass will augment the information from these two reports regarding the biomass opportunities and challenges for Texas.

The establishment of bioenergy production capability in the United States (and Texas) can have significant positive economic and energy implications. Some optimistic projections indicate that up to 30 percent of our liquid fuel demand could be supplied by biomass. According to the U.S. Department of Energy, the nation has the potential to produce approximately 1.3 billion tons of biomass from forestry and agriculture for biofuels production, which would supply 30 percent or more of the U.S. transportation fuel requirements.[3] The U.S. DOE report anticipates that about 800 million tons per year of the U.S. biomass requirement will need to be supplied from crop residues and a new generation of dedicated bioenergy crops—which are sustainable and integrated with existing food, feed and fiber cropping systems—that are designed for biofuels production. Also, almost 400 million tons of forest resources will need to be utilized to meet the goal. The 25 × '25 organization anticipates that 25 percent of our energy supply could come from renewable resources such as solar, wind, and biomass by 2025.[4]

For Texas, the 25 × '25 estimate, prepared by the University of Tennessee, projects that by 2025, Texas' wind, solar and biomass resources will have the potential to produce 3.79 billion gallons of biofuels and 145.7 billion kilowatt-hours of renewable electricity. For biomass, this would result in the demand of nearly 44.2 million dry tons of crop residues, waste biomass, and dedicated energy crops and 4.8 million dry tons of wood. It should be noted that the 25 × '25 report for biomass also represents an optimistic projection; however, biomass still has significant potential, especially for non-grain bioenergy production. If biomass could account for 10 to 15 percent of our liquid fuel supply, this would be a significant benchmark because Texas imports roughly that amount of oil, much of which comes from the currently unstable Middle East.[5]

Below is a listing of biomass feedstocks of varying implementation potential for Texas.

Texas Biomass Feedstocks

- Animal wastes
- Crop residues
- Forest products/mesquite/cedar
- Grain
- High-tonnage sorghums
- Microalgae
- Municipal solid waste/urban waste
- Oilseed crops
- Sugar cane/energy cane
- Sweet sorghum
- Switch grass

Regarding grain-based production of ethanol, Texas is a grain deficit state and would require significant increases in production and/or importation to increase grain-based ethanol production. As such, Texas is at a disadvantage in competing in the grain-based ethanol market currently dominated by the Midwest. Animal agriculture, which is Texas' largest agricultural sector, has been stressed by the recent market situation for feed grains. Currently, three ethanol plants are in operation in Texas and another is under construction. These four plants would represent about 355 million gallons of ethanol production, about 50 percent of current MTBE replacement demand in Texas. A spring 2008 report by Texas A&M analyzed the dynamics of grain-based ethanol production in Texas.[6] The report concluded that:

1. $100+ per barrel oil is driving food/feed prices

2. Energy and fertilizer costs are major factors impacting crop production

3. Corn price increases have little to do with food price increases

4. Speculative fund activities are a significant contributor to high oil and grain prices

Regardless of the actual potential, biomass resources must be produced, harvested/collected, transported, stored, and processed based on new paradigms associated with input costs, production schedules, capacities and capabilities. The challenge for researchers, producers, equipment manufacturers, and end users will be to incorporate production systems that are sustainable and efficient, using existing systems when appropriate. In addition, improvements in the conversion—biochemical, physico-chemical, and thermal-chemical—of ligno-cellulosic biomass to biofuels must rapidly progress within the next five to seven years to meet U.S. biofuels production goals. A critical element in the ultimate success of this country's biofuels production will be the linkage between biomass feedstock development, production, harvesting, transporting, storing, and processing into biofuels/bioproducts and/or energy.

For Texas-derived biomass, a number of questions must be addressed to determine the initial viability and long-term sustainability of a biofuels sector in Texas. Some questions are:

- What is the realistic, feasible, economically affordable level of production?
- What are the leading viable feedstocks?
- What conversion technologies might persist or emerge?
- How will biomass production affect the food vs. fuel issue?
- What are the impacts on water usage and soil erosion?
- What are the carbon impacts?
- What are the impacts on animal agriculture?
- How can bioenergy crops be produced in a sustainable manner?
- Is there available land?
- How far can bulky biomass be affordably hauled?

Although each of these questions is critically important, this chapter is limited to alternative feedstocks and outlook. Further, issues related to conversion technologies, input and consumption issues, sustainability, and environmental/policy issues must be thoroughly vetted to assure a firm foundation for the potential of biomass to bioenergy (where it is economically feasible).

Resources

Texas contains one of the most diverse and most accommodating growing environments in the United States, and boasts a plethora of potential biomass-based renewable energy sources. From the seemingly endless stands of pine in East Texas to brackish water algae farms in West Texas, statewide agriculture incorporates a wide variety of crops in between. Be it the energy potential of mesquite brush found in the extensive rangelands of the south and west or the sucrose content of hybrid sugarcane varieties grown along the coast and the south, the following information related to Texas' biomass sources will show that Texas' biomass inputs are as varied and diverse as the regions in which they grow.

Dedicated Energy Crop Production

Classification of Energy Crops—Dedicated energy crops can be divided into three subgroups based on the utilization of the plant materials in the conversion process to bioenegy/biofuel: 1) sources of sugar and starches (non-structural carbohydrates); 2) ligno-cellulosic feedstocks; and 3) sources of vegetable oils. Later in this report, an estimate of the energy potential and liquid fuel potential from Texas biomass will be given. The variation in available land, rainfall, competing crops, producer interest, economic incentives, and infrastructure will determine actual production. As mentioned above, several studies have attempted to estimate the production potential, but they are speculative.

The most important potential sources of ligno-cellulosic feedstock for Texas are high biomass sorghum, energy cane, and switchgrass.

High biomass sorghums—have promise as a dedicated bioenergy crop due to their high yield potential and growth habit, which allows more flexible management of the crop. McBee et al. described the efforts to combine characteristics of both grain and sweet sorghums into a new class designated as high energy sorghums. These sorghums produced biomass yields in excess of 36 tons per acre (fresh weight) and 9 tons per acre (dry weight). They reported that expected improvements could extend the potential of these types of hybrids to a wide range of environments.[7]

Energy cane—is a vegetatively propagated perennial grass. Unlike sugar cane, energy cane is selected not for high sucrose content in the stalk, but for high biomass production. The climatic requirement of energy cane will restrict its cultivation to South Texas and the state's coastal regions.

Sweet Sorghum and Sugar Cane—The two most important potential sources of dedicated energy crops for non-structural carbohydrates from Texas are sweet sorghum and sugar cane (corn is an important source both in Texas and nationally, but is not considered a dedicated energy crop). Currently, 40,500 acres of sugarcane are grown in the lower Rio Grande Valley of Texas. Although all sugar derived from cane is currently converted to refined sugar for human consumption, fermentation of sugar cane and molasses to ethanol is feasible, but there are questions of economic viability. Sweet sorghums produce high levels of sugar in the stalk and these cultivars can also be milled and fermented to ethanol using the same methods employed by sugarcane processors. Sweet sorghum is being used for ethanol conversion in India and Brazil and its efficacy is also being tested in other countries such as China, Uruguay, and Colombia. Sweet sorghums have the advantage over sugarcane of being applicable over a much wider area of Texas.

Switchgrass—A native warm-season perennial grass that can be grown throughout Texas. Yield potential will be determined by the amount and timing of precipitation.[8] Average yield in Texas was estimated by scientists at the Texas Agrilife's Blacklands Research Center to be 6.25 tons per acre.[9]

Miscanthus—A tall perennial grass having been developed for biofuel usage in Europe over the past decade. Some of the beneficial characteristics noted in European trials thus far include: relatively high yields (three to six tons/acre dry weight), tolerance to cold weather, low moisture content (as low as 15 to 20 percent depending on time frame), low mineral content, and an annual harvest pattern providing yearly income to growers. However, there is very little experience with commercial production of Miscanthus in the U.S.[10]

Giant Reed—*Arundo donax* grows in many parts of Texas, but it is classified as a noxious invasive plant. Along the Rio Grande, it has demonstrated growth rates of as much as four inches per day and reaches six to eight meters (20 to 25 feet) in height. It consumes large quantities of water and creates serious issues in and around the banks of rivers that can disrupt the flow line of water ways. The implications of cultivating Arundo as a dedicated energy crop have not been studied, but there are issues related to getting a permit from the Texas Department of Agriculture and then assuring that it can be controlled within the cropped area.

Leauceana Lucacephala—This plant has the potential to both fix its own nitrogen and to accumulate high biomass. It is a perennial crop, but currently has the winterhardiness for only small portions of Texas. Other related species are being investigated for their cold hardiness, and the potential for future genetic crosses.

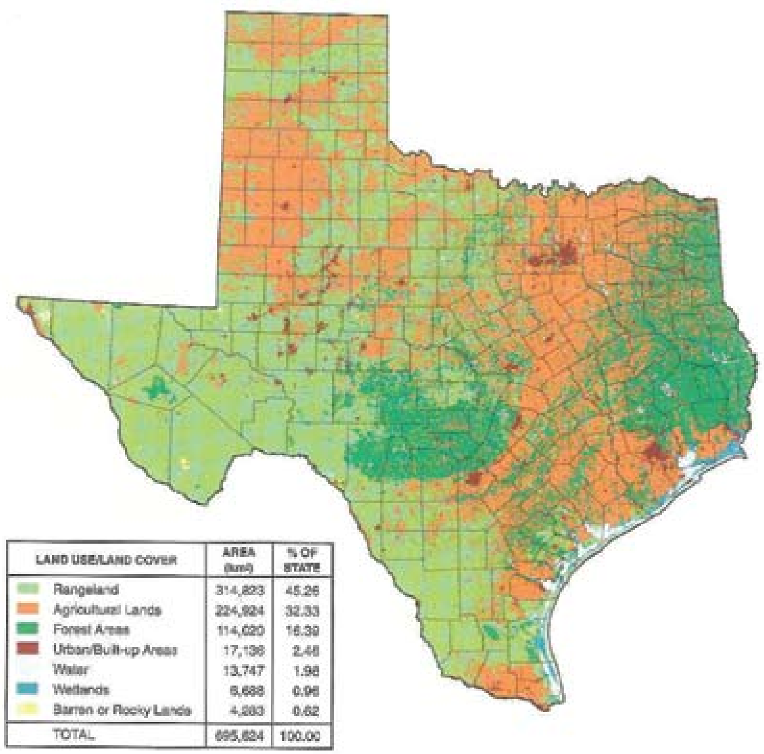
Production systems, logistics, and mass delivery systems are important elements to be taken into consideration in relation to biofuels. In the case of biofuels, production systems can be divided into perennial systems (switchgrass, sugar and energy cane, leauceana, jatropha, Chinese tallow and others) and annual systems for all the other crops. Sugar and energy cane stands are maintained for three to seven years. The crop is harvested annually. As yields decline over time, stands will be terminated (destroyed) and land can be rotated into another crop. After an establishment year, switchgrass can be in production for as long as 20 years. As a perennial crop, a switchgrass stand's productivity and its useful lifespan are mostly a function of the crop's ability to persist and stay free of weeds. Both production of cane and switchgrass will tie up the land resource for several years. All annuals can readily fit into existing cropping systems in Texas.

Logistics—The logistics of sugar cane and sweet sorghum production are complex. Once harvested, the sucrose must be extracted within 24 to 48 hours because sucrose starts to break down almost immediately after harvest. With sugar cane, one harvest per year is performed. Harvest requirements of sweet sorghum vary by location: one harvest in West Texas, two harvests in Central and East Texas, and as many as three harvests in the lower Rio Grande Valley.

The ligno-cellulosic feedstocks (biomass sorghum, energy cane, switchgrass, and similar crops) are generally harvested once a year. Two harvests may be economical with biomass sorghum grown in favorable environments. The harvested biomass can be handled fresh (moisture content 70 percent to 80 percent) and stored as silage/haylage (preserved green biomass, a fermented high moisture fodder that can be used as a biofuel feedstock in anaerobic digesters). Alternatively, it might be attractive to field dry the crop, thereby reducing its moisture, and allow for storage as hay. By varying planting and harvesting schedules, it may be possible to supply a cellulosic bioenergy plant in Central and East Texas with fresh harvested biomass from early to mid June through the end of November.

The logistics of producing vegetable oil for biodiesel are rather simple. The oil is contained in the seeds of crops. The seeds are harvested when ripe with conventional agricultural machinery or, in the case of perennial oilseeds, with modifications to existing equipment and can then be easily transported.

Exhibit 5-1 Growing Regions of Texas



Source: Faidley, Richard. Energy From Biomass, 1995

Biomass Delivery—A key aspect in the development of biorefineries will be the ability to provide low cost biomass to operate the facility 24 hours per day, seven days per week, 365 days per year. This paradigm is significantly different than for other agricultural commodity processors which tend to be seasonal in nature. For example, cotton gins and country grain elevators only receive farm produced commodities for a few months during the year. Thus, when a production region is evaluated for a biorefinery the following factors need to be considered:

- Biomass production capacity (dry tons per acre)
- Biomass production duration (months per year)
- Additional available biomass resources (to provide year round supply)
- Consistency of production (rainfall, soil quality)
- Compact production region (to reduce hauling distance)
- Willingness of producers to participate in long-term contracts (~10 years)
- Infrastructure to support a biorefinery (personnel, water, utilities, roads, trucks, harvest equipment)
- Storage for seasonally produced biomass that is affordable and minimizes biomass loss/deterioration
- Buffering storage to possibly supply needs on nights, weekends, and holidays

In Texas, the preferred areas will be those areas that have adequate rainfall, high quality available land, a long growing season, ability to provide just-in-time delivery, and strong producer networks. Specifically, areas along the Gulf Coast and Northeast Texas have strong potential to provide this infrastructure. Other areas of Texas also have noteworthy potential, but greater developed input factors of production logistics will be required to support a year-round supply. In these areas, just-in-time delivery of dedicated energy crops, regimented delivery of crop residue, and feedstock stockpiling/storing will be necessary. **Exhibit 5-1** shows the diversity of growing regions in Texas that vary from forest lands to range lands.

Oilseed Crops — Worldwide, oilseed crops are the largest source of commercially available fats and oils. Oilseed crops can be classified as major, minor or potential. Based on their growth habits, oilseed crops are also classified as cool-season or warm-season and perennial or annual. The major oilseed crop in Texas is cotton; however, soybeans far exceed cotton as an oilseed crop on a nationwide level. Neither has been developed solely as an oilseed crop, but oil has traditionally been a valued co-product with lower historical value than the fiber or protein. Worldwide, palm oil and rapeseed (canola) oil are of strategic importance as well, but in the U.S., the only other crops with major acreage (greater than 3 million acres) are soybeans and cotton. Minor crops include sunflower, rapeseed, peanut, flax, safflower and sesame. Potential oilseed crops not currently produced commercially in Texas include jatropha, Chinese tallow, and castor.

Exhibit 5-2 U.S. Oilseed Crop Acreage, 2007

Additional Significant Energy Crops	Acreage
Major	
Soybeans	63,600,000
Cotton	10,800,000
Minor	
Sunflower	2,100,000
Rapeseed	1,200,000
Peanut	1,200,000
Flax	400,000
Safflower	200,000
Sesame	100,000

Cool-season oilseed crops have the potential to be planted in the fall or late winter (similar to winter wheat or spring wheat) and be harvested in time to also grow a summer crop (double cropping). Texas AgriLife Research is exploring several cool-season oilseed crops to potentially fit into double crop systems. Research is being conducted to improve stand establishment, winter survival and either heat tolerance or avoidance through early maturity.

Warm-season crops are responsive to the late spring and early summer climate in Texas. They are frost susceptible both as seedlings and near maturity, so they must be produced during the frost-free period.

Perennial oilseed crops have the advantage of not needing to be reestablished each year, but many have yet to be well adapted to mechanical harvest. Once established, they have much higher oil production potential per year than annual crops. Conversely, annual crops fit into rotations with other major crops and increase the producer's flexibility to: establish more productive varieties as they are developed, rotate crops, and respond to market demands.

Exhibit 5-3 Oilseed Crops

Crop	Major, Minor or Potential (World)	Cool or Warm Season	Perennial or Annual	Oil Percentage
Cotton	Major	Warm	Annual	17
Soybean	Major	Warm	Annual	18
Peanut	Minor	Warm	Annual	45
Canola	Major	Cool	Annual	40
Flax	Minor	Cool	Annual	35
Sunflower	Major	Warm	Annual	42
Safflower	Minor	Warm (and cool)	Annual	42
Sesame	Minor	Warm	Annual	50
Tung	Potential	Warm/ Subtropical	Perennial	35
Palm	Major	Warm/ Tropical	Perennial	35
Camelina	Potential	Cool	Annual	40
Brown Mustard	Potential	Cool	Annual	40
Castor	Potential	Warm	Annual	50
Chinese Tallow	Potential	Warm	Perennial	31
Jatropha	Potential	Warm/ Subtropical	Perennial	35

Source: Dr. David Baltensperger, Texas A&M University, Soil and Crop Sciences

Cotton—Texas ranks first in cottonseed production in the U.S. and produces nearly half of all U.S. cotton seed, with annual production near 5 million acres. Most cottonseed is used as food grade oil or fed whole to dairy cattle. Currently, food and feed uses exceed the value as biofuel.

Soybean—Soybean has been produced on limited acreage in Texas due to the less than favorable climate. Texas ranked 25th in production in 2005 and 2006; however, the potential acreage is significantly higher given a stable market demand.

Peanut—Texas is second in peanut production nationally, but the food quality peanut market demands production inputs at a level that make the oil production less economical than other crops. As such, current research is focused on the development of a high oil non-food peanut and the development of alternative production techniques that would maximize oil yields.

Canola—It has become recognized as a high quality biofuel crop in Europe and Canada. It has seen a rapid increase in production in the northern U.S. Farmers in Texas, Oklahoma and Kansas are evaluating canola in wheat, sorghum and cotton rotations.

Camelina—A relatively under-exploited crop with a shorter growing season than canola or brown mustard that may have potential for double crop systems in the drier climatic regions of Texas.

Brown Mustard—Very similar to canola and another of the rapeseed complex like canola, but with limited adaptation work for Texas. Brown mustard does not have a food or feed grade oil or meal.

Flax—Historically, flax has been grown as a cool season oilseed in Texas, but the state is not yet a low cost producer of flax oil. Research is identifying flax genetics and production systems to make this crop competitive with currently produced crops.

Sunflower—Acreage has increased rapidly over the past few years, but biofuels are in direct competition with the food oil market, where sunflower oil carries a premium. Its yield potential and drought/heat tolerance make it a strong candidate for expanded Texas production.

Safflower—Grown for several years in Texas due to its exceptional drought tolerance; unfortunately, has seen limited acceptance as high-yielding varieties have not been developed. Both cool season and warm season types of safflower may have adaptation to Texas conditions.

Castor—Contains a highly toxic compound, ricin, but low ricin types are being developed that may open this crop species to wide-scale bioenergy production. Its drought, heat and salinity tolerance as well as high oil yield make it a promising oilseed candidate.

Jatropha—Dry subtropical species with adaptation potential for marginal lands in southern Texas.

Chinese tallow—Weedy species with wide adaptation in coastal regions of Texas. This under-utilized species has great potential for oil production if management, harvesting and high oil types can be developed and implemented.

Crop Residues

Tyson reviewed agricultural crop and orchard residues generated in the Western U.S. in a 1990 study.[11] Her results were based on 1987-88 production numbers of the following crops: wheat, corn, sorghum, sunflower, barley, oats, rye, cotton, and orchard trimmings. The numbers for collectable residues were based on the following assumptions: a minimum of 1 ton per acre must be left behind for soil conservation, 20 percent of the residues will be lost in collection, and a yield of less than 0.5 ton per acre after allowing for soil conservation and collection losses was assumed to be uneconomic. In Tyson's report, the highest concentration of collectable residues in Texas was found to be in the Gulf Coast counties of Wharton, Jackson, and Matagorda. Wharton County's total of 490,000 tons ranked eighth. Statewide, agricultural residues sum to over 5.3 million tons. This amounts to an energy potential of 0.085 EJ, or about 7.1 billion kWh of electricity (given 30 percent conversion efficiency). More recent crop residue figures, as shown in **Exhibit 5-5**, point to the High Plains region of Texas as the greatest source of collectible crop residue.

While the Tyson (1991) study gives some indication about the potential use of residue as a source of bioenergy, the underlying assumptions also reveal the limits of our knowledge. In traditional agriculture, residues are returned to the soil where they play an important role in maintaining a stable and sustainable agroecosystem. Returning residue to the soil is important to maintain soil organic matter, soil structure, productivity, and soil carbon content. Data on the impact of repeated residue removal on Texas' soils is lacking, and thresholds for sustainably doing so have not been established.[11]

Cotton gin trash has a potential as a cellulosic biofuel. Much of the logistical problem associated with energy crops is not an issue with gin trash, as it is accumulated at a cotton gin as a co-product from cotton lint harvest. Gin trash is comprised of the leaves, burs, stems, and soil stuck to the cotton fiber after harvest, and it is separated at the gin. Texas leads the nation in production of gin trash with about one million tons created per year. This has been estimated to produce 1.7 billion kWh of electricity.[12] Cotton hulls could be added, but hulls are traditionally consumed as an animal feed. Currently, the return of nutrients to the land is the only value assigned to gin trash.

While much has been suggested about crop residue, the complexity of crop harvest is such that few have been interested in further complication by harvesting residue at the same time. This leads to a secondary harvest of the residue adding significantly to cost, especially in marginal yield situations. Even in high yield corn production, it is estimated that more than half the residue needs to be left in the field to avoid soil degradation, and systems designed to collect a specific amount of residues while leaving an alternative desired amount in the field are not as efficient as primary collection strategies. Furthermore, crop residues are generally a highly seasonal source of input, and are thus considered a short term source or a source requiring a significant storage effort.

The total energy potential from the agricultural residue (leaves and stalks) left in the fields after harvesting corn, wheat, and sorghum is significant. However, these feedstocks present significant collection, transportation, and storage challenges for a large energy producer depending on such inputs for a significant amount of energy production.

Uses—If the agricultural residues were collected and stored for use on a large scale, the use could be for cellulosic ethanol, or electricity production. Cellulosic biofuels companies view large concentrations of row crop residue as prime feedstock and, therefore, prime locations for an ethanol facility. It is unlikely that a power producer would be able to compete with cellulosic biofuels for the feedstock because of the current subsidized nature of cellulosic ethanol.[13] However, power producer competition with cellulosic ethanol could be contingent upon a greenhouse gas offset price, a carbon cap and trade policy, or a sorted carbon output tax that would substantially alter the aforementioned situation.

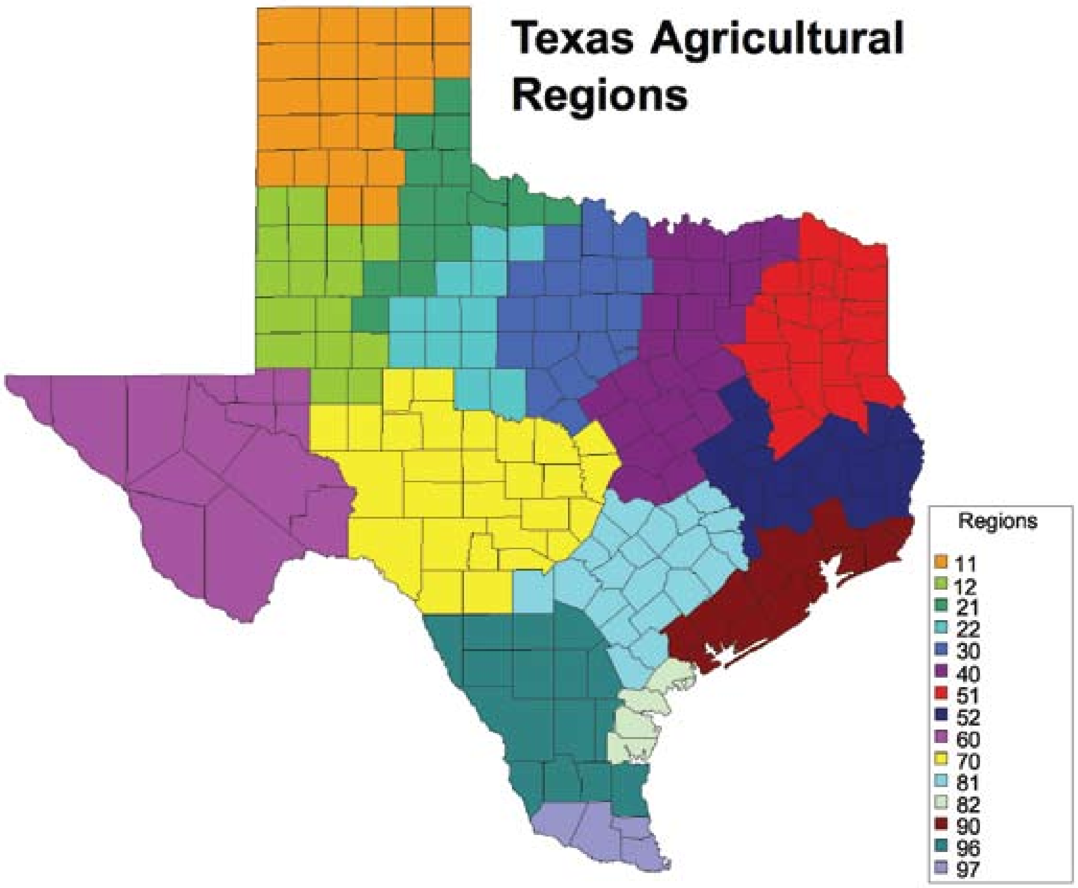
Challenges include:

- Non-perennial nature of the feedstock – In most regions of Texas, crop residues will only be available in the field for a 6 to 12 week window. During this time, all of the material must be harvested, used, or put into protected storage to maintain its usefulness.
- Diffuse Nature of the Feedstock – The amount of stover or wheat straw collected is small, perhaps one to two tons per acre can be collected off of the land in a sustainable fashion. This means that while the total amount of row crop residue available is large, the amount available in any one place is relatively small and the cost of collection and delivery are relatively large.
- Cost of Collection and Storage – The diffuse nature of the feedstock also means that it is expensive to gather and store in large quantities in a central location. U.S. Department of Energy and State Agriculture Extension Service reports forecasted expected gathering, delivery and storage costs for very large quantities of agricultural residue to be in the $60/delivered ton range. This is much more expensive than delivered costs for broiler litter (commercially reared chicken waste) and logging waste.

A 2002 Oak Ridge National Laboratory report analyzed the costs associated with short-range transportation and intermediate storage of corn stover, a crop residue that is abundant in today's high-priced corn markets.[14] In order to estimate a cost range associated with corn stover transportation and storage, the authors analyzed field shredding, raking, baling, short-range hauling (five miles with farm equipment), and covered storage. In 2002, given the variability inherent in all farming operations, the costs were determined to range from $23/dry ton up to $45/dry ton. In today's marketplace, one would expect the baseline and upper-range costs to be greater given recent increases in farm grade dyed diesel (red-fuel), machinery (steel, copper, etc.), and labor. This is evident in the difference between projected costs in the Oak Ridge study and the predictions provided by the DOE and State Agriculture Extension Service.

Texas is divided into a number of reporting districts which provide agriculture production statistics (**Exhibits 5-4** and **5-5**)

EXHIBIT 5-4 – Texas Agricultural Regions



Source: United States Department of Agriculture, NASS

EXHIBIT 5-5 Total Energy Potential of all Crop Residues

	Tons of Biomass	BTU/Year (Millions)
Northern High Plains	3,404,400,000	25,533,000
Southern High Plains	388,600,000	2,914,500
Northern Low Plains	363,200,000	2,724,000
Southern Low Plains	430,200,000	3,226,500
Cross Timbers	180,600,000	1,354,500
Blacklands	2,254,500,000	16,908,750
East Texas North	80,600,00	604,500
East Texas South	78,600,000	589,500
Trans-Pecos	9,800,000	73,500
Edwards Plateau	229,200,000	1,719,000
South Central	412,600,000	3,094,500
Coastal Bend	424,200,000	3,181,500
Upper Coast	850,800,000	6,381,000
South Texas	79,000,000	592,500
Lower Valley	560,400,000	4,203,000
Combined Districts	5,100,000	38,250
STATE	9,751,800,000	73,138,500

Source: Cornwell, Bret, David Sandhop, Lauralee Shanks, Lauralee Phillips, and Deborah Webb

Texas Woody Biomass Sources

Forest Sources—The forestry sector is important to the Texas economy. In 2005, timber ranked sixth in agricultural cash receipts with cattle/calves, cotton, broilers, greenhouse/nurseries, and milk ranking from one to five respectively. In East Texas, timber ranks even higher and is the number one agricultural crop in several rural counties. The direct economic impact of the Texas forest sector in 2004 was $17.5 billion of total industry output, $5.5 billion of which was value-added. It employed almost 76,000 workers and paid $2.7 billion in wages, salaries, and benefits. The total economic impact the same year was $30.6 billion, of which $12.4 billion was value-added, and generated more than 173,000 jobs and paid $7.6 billion in labor income.16

Of the 21.4 million acres in the 43 East Texas counties, 11.9 million acres (56 percent) are covered by forests.[15] Historically, family forest owners held nearly 2/3 of the East Texas forests, forest industry owned nearly 1/3, and a small percentage was publicly owned. However, since 2000, ownership patterns have changed rapidly with forest industry lands being sold to investment groups (**Exhibit 5-6**).

Although the number of forest products manufacturing facilities has declined during the last few years, demand for the higher value timber products continues to be elevated. Conversely, demand for lower value woody biomass is depressed. Sources of lower value woody biomass include logging residues, thinnings for improving forest productivity and health, and biomass damaged or killed by insects, diseases, fire, storms, and others. Utilizing these resources for an array of bioenergy and bio-based products has several advantages including: year-round supply; complements with existing sustainable forest management practices (reducing site preparation costs and fire risk, mitigating disturbances, etc.); and low energy and water input. H.B.1090, Agricultural Biomass and Landfill Diversion Incentive, was passed by both the Texas House and Senate in 2007 to encourage the construction of facilities that generate electrical energy using logging residue and urban woody biomass.

Exhibit 5-6 Dry Tons of Logging Residue in East Texas, 2005

Region	Species Group	Stump	Top/ Limbs	Unused Cull	Total Residue	Available Residue
Northeast	Softwood	6,891	274,068	99,693	460,652	373,761
	Hardwood	65,292	210,513	101,056	376,860	311,569
	All	152,183	484,581	200,749	837,512	685,330
Southeast	Softwood	156,155	495,141	182,572	833,868	677,713
	Hardwood	44,584	141,794	64,305	250,683	206,099
	All	200,739	636,935	246,877	1,084,550	883,811
East Texas	Softwood	243,046	769,209	282,265	1,294,520	1,051,474
	Hardwood	109,876	352,307	165,360	627,543	517,667
	All	352,922	1,121,516	447,625	1,922,062	1,569,141

Source: Texas Forest Service

Standing Biomass—The total above-ground biomass of the East Texas forests is estimated at 472 million dry tons.[16] The energy content of this immense resource is nearly 8.7 EJ (8.2 quads, or quadrillion BTUs). Commercial and residential thinnings are the residue/waste resulting from forest/tree management practices. Both are presently considered premerchantable because of the small diameter of the trees, and provide excellent potential for use as bioenergy feedstock due to the small existing markets for those fiber sources. Inventories of those resources are currently being conducted by the Texas Forest Service (TFS) and will be posted to the http://texasforestservice.tamu.edu website by early fall 2008. Although catastrophic losses from insects, storms, fire, etc. are unpredictable, they frequently regenerate large volumes of woody biomass and should, therefore, be factored into the biomass supply chain.

Outside of East Texas, substantial woody biomass in the form of brush species occupies much of the remainder of the state. An inventory of 25 major brush species compiled by the United States Department of Agriculture's Soil Conservation Service (Natural Resource Conservation Service now) in 1982 revealed that: (1) "dense" brush infestations (greater than 30 percent canopy cover) occurred on over 33.7 million Texas acres, or about 20 percent of the state's land area, and (2) that some degree of brush canopy is present in nearly 60 percent of the state.[17] Mesquite is the most common brush species and occupies over 51 million acres, of which 19 million is moderate to high cover (greater than 10

Exhibit 5-7 Dry Tons of Mill Residue in East Texas, 2005

Region	Species Group	Chips	Sawdust	Shavings	Bark	Total
Northeast	Softwood	441,210	67,204	64,282	271,457	844,153
	Hardwood	88,597	54,779	8,775	163,917	316,068
	All	529,807	121,983	73,057	724,847	1,160,221
Southeast	Softwood	1,071,737	119,415	114,223	517,268	1,822,643
	Hardwood	36,745	23,149	3,708	109,503	173,105
	All	1,108,482	142,564	117,931	626,771	1,995,748
East Texas	Softwood	151,2947	186,619	178,505	788,725	2,666,796
	Hardwood	125,342	77,928	12,483	273,420	489,173
	All	1,638,289	264,547	190,988	1,062,144	3,155,969

Source: Texas Forest Service

percent). These values are much greater today than they were in 1982. Recent data indicate dense mesquite (300 trees/acre) in North Texas have a standing dry mass of 5 to 15 tons/acre. Required time after harvest for regrowth to attain 10 tons/acre is 10 years, or 1 ton/acre/year.[18] This production rate is below the 5 tons/acre/year yields of short rotation woody crop systems in the slightly wetter site of the upper Midwest.[19] Thus, management of brush in Texas for bioenergy may need to encompass more land area to allow for the longer regrowth interval as compared to short rotation woody crop systems. There are issues related to the costs and efficiency levels of harvesting brush on rangelands.

Logging Residues—Logging residues are the unused portions of harvested trees left in the woods. Types of logging residue include stumps, tops, limbs and unutilized cull trees. In East Texas, this biomass represents a significant energy resource. The amount of unused forest biomass in East Texas is significant. For 2006, the Texas Forest Service estimated these residues at 1.1 and 0.8 million dry tons for Texas pines and hardwoods, respectively.[20] However, this resource is for the most part not utilized, perhaps due to issues of harvest and transportation.

Mill Residues—The forest products industry produces considerable volumes of mill residue in their manufacturing process. However, these facilities utilize 97 percent of the residues to produce steam, electricity, and for other uses.[21] The forest products industry leads all other industries in the use of biomass energy. The 2004 data indicate that 77 percent of the fuel used at wood products facilities and 60 percent of the fuel used at pulp and paper mills are biomass fuels.[22] The Texas Forest Service estimates that total mill residue, including chips, sawdust, shavings, and bark in primary mills such as sawmills, panel mills and chip mills in 2006 was 3.3 million short tons; softwood and hardwood mill residue generation was at 2.7 and 0.5 million dry tons, respectively.[23] The annual survey of mills by the Texas Forest Service illustrates the distribution of the industry and mill residues (**Exhibit 5-7**).

Urban Woody Biomass—Although reliable, local estimates regarding the volume of urban biomass are generally unavailable, the National Renewable Energy Laboratory estimated the annual per capita generation of urban wood resources to be 0.17 dry tons.[24] Using that estimate, 22 million Texans produce nearly 3.7 million tons of woody biomass each year. A significant volume of this resource is currently being sent to landfills (**Exhibit 5-8**).

Exhibit 5-8 Available Woody Biomass in Texas

Source	Dry Tons/Year
Logging residues	1,569,141
Mill residues	3,155,969
Forest Thinnings	Estimate available fall 2008, [TFS website]
Insect & Disease	46,800
Mesquite	19,000,000
Urban Woody Biomass	3,663,000

Sources: Xu, W. and B. Carraway
Pye, J.M., T.S. Price, S.R. Clarks, and R.J. Huggett, Jr.
Ansley, R.J.
Wiltsee, G.

Exhibit 5-9 Available Tons of Animal Waste Biomass per Year and Energy Potential

	Tons of Dry Solids/Year	Energy potential, HHV, BTU/Year (Millions)
Beef Feedlots	2,302,000	32,230,000
Dairies	1,140,000	16,180,000
Swine	34,000	1,070,000
Poultry	1,649,000	15,260,000
STATE	5,125,000	64,740,000

Animal Wastes

Environmental quality and natural resources management issues are important drivers of industry structure and location, production practices, and growth opportunities for concentrated animal feeding operations (CAFOs). Key issues include: energy efficiency, bioenergy/biofuel opportunities, and mortality disposal/utilization, along with more traditional issues such as adequate water supply, protecting water and air quality, efficient manure/nutrient utilization, and holistic environmental management. Livestock retain less than 25 percent of the nutrients they consume; resulting in harvestable manure, which can be managed as a valuable fertilizer (traditional use) or as a biomass/biofuel resource.

Feedlot Biomass—Texas feedlot operations define where the feedlot biomass is available in large quantities and available for little to no cost at the source; however, recent dramatic increases in fertilizer costs have created an emerging market for animal wastes. These feedlot operations are concentrated in the Texas Panhandle. Most beef cattle on the High Plains are fed in open pens with native soil surfaces. Manure is normally scraped from the pens after each lot of cattle is finished (120 to 200 days). The quantity and quality of manure produced is highly dependent upon the diet the cattle are fed.[25] Most feedyard rations are highly digestible, so the feces excreted is comprised mostly of undigested fiber and minerals, metabolic excretions, sloughed cells, and microbial biomass. When the grain portion of the diet is not highly processed, appreciable quantities of starch may also be excreted.[26]

Each year, the nearly 5.5 million cattle finished at feedyards in the Panhandle and South Plains excrete about 2.3 million tons of manure on a dry basis.[27] The main use of feedlot manure is fertilizer. Nearly all of this manure is harvested for use as organic fertilizer for crop or pasture lands. About half of the feedlots keep their manure and apply it to their own fields. The majority of the remaining manure is given to manure haulers at a price ranging from a tipping fee of $1/ton to a price as high as $3 to $5/ton with some upward pressure on the price of manure. Feedlots have traditionally made their manure available at no cost to a manure hauler. The manure haulers then transport the manure for land application elsewhere and charge a transportation and/or spreading fee, typically averaging about $2.25 per ton plus $0.15/ton-mile one-way.[28] The fertilizer value of manure may preclude its availability as a feedstock for energy.

The quantity and chemical content of as-excreted manure changes on the feedlot surface due to many factors, such as decomposition and potential soil incorporation. On an "as removed" wet basis, nearly 7 million tons of manure at 33 ± 28 percent moisture, or 4-5 million dry tons/yr, is scraped from these feedyards annually. The nutrient value of this manure is estimated at 82,000 tons of N, 79,000 tons of P_2O_5 and 87,000 tons of K_2O.[29] Sweeten et al. determined that the higher heating value (HHV) of as-harvested cattle feedlot manure ranged from approximately 2,500 to 6,000 BTU/lb, primarily due to variations in (a) moisture content and (b) ash content, which includes entrained soil.[30] However, the HHV averages 8,500 BTUs per pound of dry/ash-free basis. Using this as a reference value, the total energy content of as-excreted feedlot manure in Texas is about 30×10^{12} BTUs.

Dairy—Nearly 40 percent of the 333,000 milking cows in Texas are now reared in the Panhandle with proportions increasing annually. On average, these herds excrete nearly 440,000 tons of dry manure with an approximate N, P_2O_5 and K_2O content of 2,800 tons, 1,140 tons, and 1,640 tons per year, respectively. Total energy from excreted dairy manure in the Panhandle is estimated (assuming a HHV of 8,500 BTUs per pound of dry/ash-free dairy manure) to be 6×10^{12} BTUs.[31] Assuming 80 percent of the cows in the Panhandle are raised in open lots, nearly 1.5 million tons of manure is scraped from earthen lots annually. The corresponding nutrient value of as-scraped manure is estimated at 10,482 tons, 8,576 tons and 12,040 tons of N, P_2O_5 and K_2O, respectively.[32]

Swine—The Panhandle also finishes nearly all (92 percent) of the estimated 565,000 pigs in Texas each year. The resulting manure is generally produced in liquid or slurry form. This manure is highly diluted when flushed to a lagoon or other storage facility. Flushed manure from finishing barns is stored in manure treatment lagoons, evaporation ponds, or slurry tanks, and is ultimately irrigated as a fertilizer, contributing both nutrients and moisture for row crops (mostly corn) in the area. On a dry basis, about 34,000 tons of manure is excreted by finishing pigs annually.[33] It is estimated that each year, nearly 1.2 million tons of diluted manure having a nutrient value of 2,387 tons of N, 1,913 tons of P2O5 and 2,434 tons of K2O may be available for irrigation from these swine finishing facilities.[34]

Poultry Litter—Based on data provided in the USDA National Agricultural Statistics Service Census, nearly 72 percent of all commercial broiler production in Texas originates in the state's 24-county northeast region designated as District 5-North by the USDA. Nearly 450,000,000 of the state's 628,300,000 broilers come from this region. Poultry litter has two primary market applications in the region, a substitute for commercial fertilizer and cattle feed. Poultry producers first spread litter on adjacent lands and crops as fertilizer. It is an easy decision for poultry operators if they have additional land and crops. According to the EPA, approximately 90 percent of all poultry litter is hauled away and used in the external marketplace, so the internal uses of poultry litter have only a nominal effect on market availability. Taking into account that roughly 10 percent of production is used internally and not available on the fertilizer market, the available poultry litter for sale on the open market in Texas is approximately 1,200,000 tons.

Mortality Disposal—Beginning with federal regulations restricting the use of rendered bovine by-product as animal feed in 1997, the cost of rendering has increased, and rendering companies now charge a sizeable pick-up fee for carcasses, causing producers to look for practical, on-farm alternatives. Studies have shown that on-farm management of cattle and swine mortalities by carcass composting is a viable and economical method, and the end product can be utilized as a plant nutrient and organic soil amendment material.[35] Several large, commercial feedyards have successfully incorporated carcass composting with feedlot manure guided by ongoing applied research and outreach efforts by TAMU's agricultural engineers.[36] An extension of this technology would be to manage composted mortality, whether for cattle feedlots, dairies, swine or poultry, as a biofuel resource for thermochemical processing, where the composted residue contributes to higher heating values and provides for environmentally-secure disposal.[37] Greater research is needed in this area.

Municipal Solid Waste (MSW)

MSW is solid waste resulting from or incidental to municipal, community, commercial, institutional, and recreational activities. MSW includes garbage, rubbish, ashes, street cleanings, dead animals, abandoned automobiles, and all other solid waste not deemed industrial solid waste. Except for glass and metal, MSW is an excellent source of biomass for energy recovery. Solid waste management has been a practice in the United States for well over a century and there are currently two main methods that are likely to be employed to utilize the energy content of municipal solid waste in the United States: landfill gas (methane) capture and municipal solid waste combustion. In the case of landfill gas capture, the methane released at the landfill sites (having half of the energy content of natural gas) is collected and burned to reduce air pollution and harness the inherent energy by generating electricity or powering boilers.[38] Municipal waste combustion began with the sole intention of reducing the volume of waste, but current practices harness the heat being generated for operations such as heating, steam generation, and electricity production.[39] It is neither the intention of this report to demarcate between the two most widely utilized MSW energy generation processes nor to identify a dominant process, as situational circumstances including budgetary and pollution constraints play a significant role in process selection.

In classifying MSW, Texas considers the source, rather than the constituents or properties of the waste. Distributors, retailers, repair services and the general public are considered municipal generators. Texas also considers construction and demolition (C&D) debris and municipal sludge to be a part of the aggregate MSW figures. Conversely, manufacturers are not considered MSW contributors, but rather industrial solid waste generators. As Texas includes construction and demolition

(C&D) debris and municipal sludge, the per capita MSW disposal and generation rates appear significantly higher than those of other states in the nation.[40] MSW is demarcated into hazardous or non-hazardous. In Texas, industrial solid waste may similarly be defined as hazardous or non-hazardous with non-hazardous defined by classification.[41]

- Class 1 non-hazardous includes waste that may pose a danger to human health or environment if not properly managed (based on its constituents and properties, i.e., solidified industrial sludges contaminated with metals or organics).
- Class 2 is for industrial solid waste that cannot be described as hazardous, class1, or class 3. Examples include waste activated sludge from industrial biological wastewater treatment and regular trash from plant offices.
- Class 3 wastes are inert and essentially insoluble industrial solid wastes not readily decomposed: demolition debris and bricks that are insoluble, do not react with other materials, and do not decompose.

Quantity—For 2006, total disposal in the state was 30.45 million tons.[42] This represents 365 trillion BTUs, assuming an average BTU content of 6,000 per pound. Of course, only a fraction of this might be suitable for practical application. At a consumption rate of ten percent (36.5 trillion BTUs) this would be the equivalent of 6,293,105.5 barrels of oil.[43] Utilizing the EPA definition of MSW (which excludes C&D debris and treatment plant sludge), the per capita disposal rate in Texas was 5.8 pounds per person per day, which is above the U.S. EPA national average for 2005 of 4.5 pounds per person per day. The per-capita landfill disposal rate for Texas for 2006 was 7.1 pounds per person per day. The total remaining landfill capacity in Texas at the end of 2006 was 2.11 billion cubic yards.

Classification—The largest single type of waste disposed of in MSW landfills in Texas in 2006 was residential waste, comprising 35 percent of the total waste stream, followed by commercial waste with 33 percent of the waste stream, and C&D with 19 percent. These three types compose the vast majority of the waste stream, 87 percent of all the waste disposed of in the state.

Exhibit 5-10 A breakdown of waste types in 2008 in Texas:

Residential	35%
Commercial	33%
C&D	19%
Class 2/3	5%
Sludge	2%
Brush	2%
Soil	1%
All Others	3%

Algae

Algae have great potential as a feedstock for biofuels and bioproducts. Microalgae can regenerate in 48 to 72 hours. Cyanobacteria can regenerate in 5 to 20 hours. These short generation times (compared to seed crops such as soybean, jatropha, and castor) lead to the high potential for biodiesel production from algae.

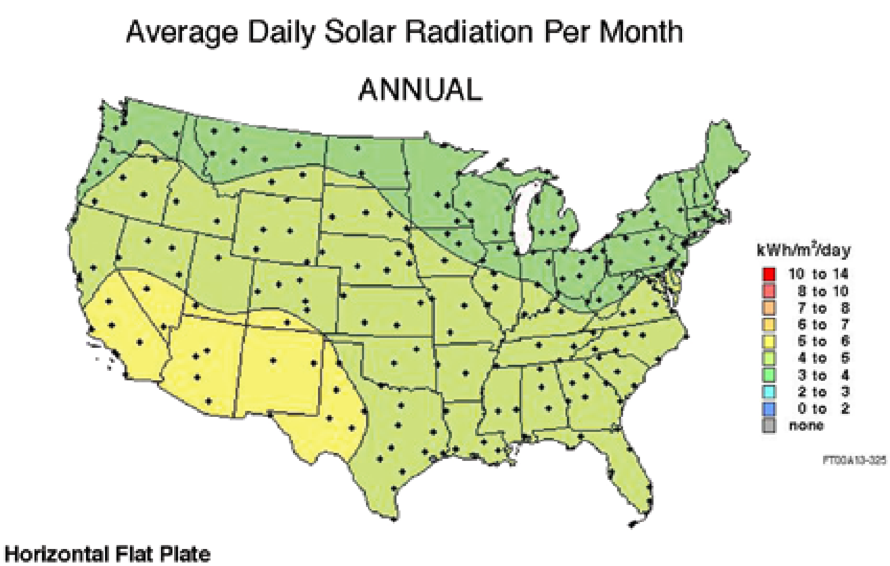
Exhibit 5-11 Production potential of biodiesel from dedicated fuel crops

Dedicated Fuel Crop	Biodiesel Production Potential (gallons/acre/year)
Algae	5,000
Palm	560
Jatropha	250
Castor	140
Canola	90
Sunflower	90
Soybean	57

The theoretical potential biodiesel production from algae is 15,000 gallons/acre each year, assuming optimal growth conditions. For large-scale production of algae in outdoor ponds (raceways), actual production may be 3,000-5,000 gallons/acre per year. Even so, the potential for algae biodiesel production would be close to ten times the potential of palm oil and 100 times that of soy oil, the two most commonly used feedstocks for biodiesel production today.

Some algae strains have been identified that produce especially high levels, 25 to 55 percent by weight, of lipids, the precursor to oil.[44] Environmental conditions and nutrient availability affect the growth of algae and production of lipids. Algae require three ingredients to grow: 1) high solar radiation (sunlight), 2) carbon dioxide (CO_2), and 3) brackish water, or water high in salt content (up to 30,000 ppm). The logical location for growing algae under high levels of solar radiation would be the desert southwest.

Exhibit 5-12 Annual average daily solar radiation for the U.S.



Source: National Renewable Energy Laboratory

In Texas, large parts of West Texas and along the Gulf Coast represent excellent sites for algae production. An ideal match may be to couple Gulf Coast petrochemical facilities and power plants with algae production, in order to capture CO_2 and produce biofuels/bioproducts feedstocks.

Temperature control is also important, as algae grow optimally in steady temperatures with little fluctuation. Temperature extremes in the water, such as seen in winter and summer, may require heating or chilling of the water for continuous production. Circulation of water is required to keep the algae water mixed and assure there is no occurrence of flocculation, the formation of clumps or masses that would likely sink to the bottom of the raceways.

Two possible system approaches to algae production are: (1) raceway ponds; and (2) photo bioreactors (PBRs). Raceway ponds allow for high production of algae and typically cost less per acre to construct; however, because they are open to the environment, they require control of contaminants and management of evaporation. PBRs on the other hand are more costly to build per acre but can operate year round because they are enclosed, typically in glass or film tubes.

After generation and production of lipids, algae must be harvested, concentrated, and forced to lysis (a disintegration of the cell wall) to release lipids. Harvesting processes include processes such as pumping the algae to settling tanks and using rakes or skimmers. Algae cell walls can be made to lysis by the application of ultrasound.

The lipid/algae carcass/water slurry must go through an oil separation and purification process. Chemical extraction and mechanical extraction are the primary methods for oil separation. Hexane is used successfully in separation applications, but may be cost prohibitive. Centrifuge processes have also been successful, but require high energy inputs for large-scale production. Research is underway to develop high capacity separation technologies.

Algae production as a dedicated biodiesel feedstock provides for an area of extensive research. Academia, private industry, and governmental agencies are ramping up investigation into these topics. Theoretically, algae could supply the entire U.S. diesel demand on only 2.7 million acres of land. In comparison, 970 million acres are utilized for crops and grazing.[45] Algae are not a food crop and would likely be farmed with high saline ground water sources where traditional field crops cannot be sustained, and would not, therefore, compete for the same land.

Currently, the only commercial algae production is for high value products such as cosmetics and nutritional items. In Texas, several entities are developing pre-commercial demonstration projects for biofuels and bioproducts. General Atomics and Texas AgriLife Research have received major funding from the Governor's Emerging Technology Fund and the Department of Defense to build and operate an algae research and demonstration facility at Pecos, Texas. Several other projects are in various stages of development.

Utilization

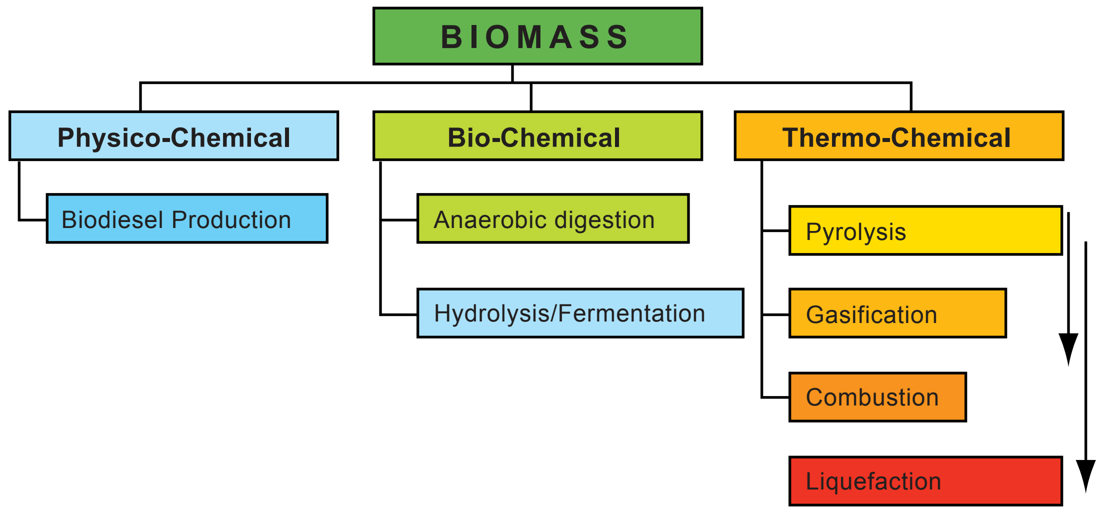
The generation of vast quantities of biomass is just one part of the effort in developing sustainable energy. Issues of conversion, available resources, infrastructure, and logistics must additionally be addressed as related to developing energy.

Conversion Technologies

There are three general pathways to produce energy from biomass. Thermo-chemical biomass conversion processes involve the treatment of biomass under high heat with or without an oxidant. Included in this category are: pyrolysis, gasification, and combustion. Biochemical conversion processes make use of specific microbial populations to convert biomass resources into high energy liquid (e.g. ethanol) or gaseous compounds (methane). Processes under this category include: anaerobic digestion for biogas production and fermentation into ethanol. An example of a physico-chemical process is a simple oil extraction from plant or animal sources for biodiesel production (**Exhibit 5-13**).

There are inherent limitations in each of the processes. Two key factors in thermal conversions are moisture content and ash, to prevent slagging and fouling.[46] For bio-chemical conversion processes, such as ethanol production, sterility of the process needs to be ensured so that only the selected microbes are retained. Contamination with other unwanted microbes is to be avoided at all times. This will make the reaction proceed with the highest efficiency. The different processes will be discussed in more detail in the following sections.

Exhibit 5-13 Biomass Resource Conversion Processes



Source: Capareda, Sergio

Physico-Chemical Conversion Technologies—The simplest process of producing liquid transportation fuel from biomass is through trans-esterification of fats and oils. This is made by mixing refined, bleached, and deodorized vegetable oil or animal fats with an alcohol (methanol is the most common), in the presence of base or acid catalysts (e.g. sodium methoxide) this exposure would yield esters of oil (biodiesel). The theoretical rate of conversion is about 100 pounds of biodiesel (B100) with about 10 pounds of unpurified glycerin produced from every 100 pounds of oil and 10 pounds of methanol.[47] Vegetable oils and fats are never alike. There are different levels of saturated and unsaturated fatty acids and the yields per acre are highly varied. In addition, the use of biodiesel as fuel for engines will generate different emissions as a result of the burning efficiencies of the biodiesel components.

Bio-Chemical Conversion Technologies—There are two important biochemical conversion processes: (1) anaerobic digestion for biogas ($CH_4 + CO_2$) production; and (2) ethanol (C_2H_5OH) fermentation. These biochemical conversion processes require substrates that are well suited to the type of microbial population used.[48] Ethanol production from sugary compounds requires the use of yeast, while those coming from starchy materials need enzymes (e.g. amylases from different microbial groups) to convert starch into sugar. The production of methane from anaerobic digestion of biomass requires the use of acid producing and methane producing microbes.

Anaerobic Digestion—The anaerobic digestion process begins with the breaking down of cellulosic biomass compounds into organic acids by enzymes from acid producing microbes. This is followed by conversion into methane by the methane producing microbial population.[49] The reactor must be free of oxygen to ensure that anaerobic microbes will be kept alive. In addition, methane producing microbes are very sensitive to low pH and thus, conversion efficiency will diminish when the microbe population is decreased due to low pH. Two types of anaerobic digesters are used commercially: the low rate (conventional) and the high rate digesters. Conventional anaerobic digesters have retention times of several days or weeks, making the digester volume large; while high rate digesters offer a smaller reactor footprint and shorter retention times of a few days or hours.[50]

Ethanol Fermentation—Conversion of ethanol from biomass resources differs based on the form of substrate used. Sugar compounds, such as sweet sorghum or sugarcane juices, only need ethanol-producing yeasts for conversion. However, starchy materials need amylase-producing microbes to convert the starch into sugar, followed by the use of yeast to convert the resulting sugar into ethanol. Cellulosic biomass needs an additional step to convert the cellulosic materials into organic acids, sugars, and ethanol. There are numerous ways to replicate the process. Some methods use steam explosion to break cellulose down into simpler organics, while others use high strength acid for the same purpose.[51] More recently, thermal conversion systems have been designed to convert cellulosic biomass into liquid fuel via a thermal catalytic process, a combination of the thermal and biochemical conversion processes.

Thermo-Chemical Conversion Technologies—There are three major thermo-chemical conversion processes: pyrolysis, gasification, and combustion. While combustion is the most mature of the thermal conversion processes, it is likely not the best candidate for biomass conversion processes due to the high ash content of most biomass resources. These inorganic ash materials found in most biomass resources have a very low eutectic point (melting point), and these inorganic materials may solidify and attach to thermal conversion surfaces. Such incidences may lead to slagging and fouling problems after several hours of operation.

Pyrolysis—Pyrolysis, or destructive distillation, is the thermal conversion process of biomass in complete absence of oxygen or an oxidant. Products of this process include medium calorific value gas (MCV), liquid condensates (bio-oil, water and tar), and char (carbonaceous solid products with greater than 2 percent carbon). There are different variations of the pyrolysis process (depending upon the rate of heating, temperature, and pressure used). Flash, or fast pyrolysis, is known for the production of high yields of bio-oil and is done under medium temperatures, 400 to 500°C (750 to 930°F), in a very short period of time (milliseconds). Generally, low temperatures and slow heating result in high yields of char, whereas rapid heating and high temperatures produce high yields of gaseous compounds.[52] The gaseous products are primarily CO and H_2 (also termed synthesis gas, syngas, or producers gas), char, and organic liquids (bio-oils).

Gasification—Gasification is thermal conversion with limited amounts of oxidant. Products of the process are very similar to those of the pyrolysis process. Gasification is an endothermic reaction and, thus, would not need supplemental fuels or heating once the process had begun. There are two general types of gasifiers: the fixed bed (downdraft or updraft) and the moving bed gasifier (fluidized bed). When wood is used as fuel, with air as an oxidizing medium, the typical gas composition is as follows: CO_2 (10 percent); CO (20-22 percent); H_2 (12-15 percent); CH_4 (2-3 percent), N_2 (50-53 percent) with a heat content of about 5,500 kJ/m3.[53]

Combustion—Direct biomass combustion systems are now technically and economically viable for some biomass resources (specifically wood). There are numerous biomass-fueled power plants currently installed in the U.S. for this purpose. Most biomass power plants are wood-based due to the low ash content of most wood residues. Some biomass, particularly those with low ash content (e.g. sugarcane bagasse) have been proven viable for combustion systems and in boiler applications. The total heat produced during the combustion process is similar to the heating value of the fuel.[54]

Thermo-Catalytic Conversion to Bio-fuels—A number of thermo-chemical processes exist for converting biomass into liquid fuels. The synthesized gas (CO and H_2) produced from either pyrolysis or gasification processes could be reformed either catalytically or with the use of steam to produce synthetic gasoline or diesel-like liquid fuels. The majority of these processes were originally developed for the conversion of natural gas into liquid fuels. Examples of these biomass liquefaction processes include the Fischer-Tropsch (F-T) process and the Mobil processes.[55] The F-T process was developed in the 1920s and was used extensively in Germany during World War II to produce synthetic fuels. It is currently being used in South Africa for coal conversion.[56]

Infrastructure Considerations

Availability of land for dedicated energy crops—Texas consists of approximately 171 million acres of land area, including fresh water bodies. More than 55 percent of Texas land area is currently rangeland (see **Exhibit 5-1**), which occupy land that is marginal for agriculture due to soil or climate limitations. Cropland occupies approximately 15 percent of the area (20 percent of cropland is under irrigation), and pastureland occupies approximately 10 percent of the area.[57]

There are three main avenues by which acreage devoted to dedicated biomass production will expand. The first course of action involves incorporating new dedicated energy crops into the traditional crop rotation pattern with the underlying goal of intensifying overall production in the cropland area. Secondly, converting agriculturally suitable pastureland to cropland would potentially increase the overall supply of biofuel feedstocks. Finally, the goal of production expansion could be achieved by incorporating perennial crop production in areas deemed marginal for agriculture and currently under pastureland or rangeland. The latter option is only feasible in areas with relatively high rainfall (greater than 31.5 inches/year) and is, thereby, restricted to the eastern part of the state. In that area (Blackland Prairie, Oak Woods and Prairie, Piney Woods, and Gulf Coast and Prairies), there are approximately 8 million acres of pastureland and 20 million acres of rangeland, of which a fraction could be converted to biofuel production. Likewise, the prime farmland is already dedicated to cropland, or is being developed. Recently, much talk has been centered on devoting USDA Conservation Reserve Program (CRP) land to biofuel production. In Texas, there are an estimated 4 million acres under CRP.[58] This area is located primarily in West Texas, where annual precipitation is low, and it is unlikely that irrigation for high tonnage biomass production would be economically viable.[59]

The development of a significant biomass-based energy industry requires a reliable supply of cellulosic biomass with consistent energy content, physical properties, and chemical makeup. A bio-energy conversion plant producing 100 million gallons of cellulose-based ethanol would require approximately 1.1 million dry matter tons annually. If high yielding dedicated crops are used (assuming a yield of 10 dry matter tons/acre), 172 square miles of production will be required to produce 100 million gallons of ethanol. Removing non-productive lands from consideration, and accounting for crop rotation and partial participation by landowners, the total region size to supply the plant could be in excess of 2,000 square miles. If the biomass is delivered by fully loaded semi-trailers, a truck will have to be unloaded at the plant every 14 minutes or less. No existing agricultural supply chain system currently meets this level of intensity year round. While using diverse feedstock sources can mitigate supply risk, differences in the machine systems required, achievable yield levels, and energy content will complicate supply chain logistics.

Production Systems—Existing agricultural production systems are capable of producing biomass for energy from both annual and perennial crops. The development of a profitable bio-energy industry will generate refinements in production practices and equipment, but dramatic improvements will not be required. Studies by DOE on the feasibility of biomass energy have frequently been based on an assumption of using "no-till" production systems.[60] However, these have proven unsuccessful for crops and soils in some parts of Texas, with problems of maintaining long term productivity.

Harvest Systems—Forage harvesting systems have limitations for biomass harvest under Texas conditions. The direct relationship between available moisture and high yields will require that biomass for energy production be located in regions of the state with higher humidity. The larger stems found in higher yielding crops such as energy cane, miscanthus and biomass sorghum require more time to field dry in order to prevent storage and transport problems: storage with excessive moisture contents can present serious problems with material quality, and transporting high-moisture material is more expensive than transporting low-moisture material. Field drying of the stems to 20 percent moisture or less will result in greater levels of dry matter loss, particularly leaves and smaller diameter plant parts. Silage chopping is an alternative harvesting approach that can accommodate high moisture crops, but handling of chopped materials results in additional requirements for storage and additional expense for harvest and hauling.

Most studies of biomass harvesting systems have emphasized baling, in either the large square or round form, resulting in packages of 1,000 to 1,500 lbs. Bales can be formed at moistures above 20 percent, but wrapping in plastic is then required to avoid degradation. Baling of high-tonnage field mass may be less effective because five to seven days of field exposure might be required prior to baling. Existing mower/conditioners are marginally acceptable for the tall (12 to 16 feet) thick-stemmed biomass crops that would be grown. If field conditions are less than optimal, existing mower/conditioner designs will result in excessive harvest losses and soil accumulations in the harvested material. New machine designs and modifications will be required to enable crop moisture loss to be accelerated, to handle crop matter stuck in the machinery, to minimize the amount of soil mixed into the crop and to maintain the high throughput rate of current designs.

Storage and Transport Systems—Harvest periods of six to seven months are potentially available in most regions of Texas. This extended period will enable approximately half of the biomass to be processed without incurring the cost of storage depending on the moisture content and the method by which it is removed.

This longer harvest season makes Texas more competitive than many other states. However, if biomass from dedicated energy crops is needed year round, storage will be needed (both for the portion of the year when the crop is growing to an economically justifiable harvest size and to provide a buffer at the processing plant for delays in delivery).

Harvest systems that rely on baling have the disadvantage of requiring the handling of large numbers of small packages. Systems are needed that can load and unload trucks with minimal labor and time. The harvest storage and transport model used by the cotton industry could be emulated to obtain needed efficiencies. Knowledge of the system and the existence of support industries in the state provide an additional advantage for Texas. However, the direct adaptation of existing cotton module builders as a means of preparing loose biomass for transportation and storage is not likely to be successful. Compressed biomass will have significantly higher density, resulting in illegal truck weights if current module specifications are used. Higher compressive stresses that will likely be required with biomass mean that heavier module builders will be necessary. The economic need to maximize load size will mean that the tilt bed trucks used with cotton will not be optimum, and alternative means of loading the modules on, for example, the more common and less expensive flat-bed trailer, will likely be required.

Finally, Texas has a large number of rural bridges that are weight limited, making certain areas inaccessible to fully loaded semi-trailers. The development of an extensive biomass energy system will likely place demands on the state for improvements to bridge and road capacity.

Water Supply—Water is a limited resource in much of Texas, and it is potentially one of the more limiting inputs of a biomass energy production system; if irrigation is required.

Texas consumes approximately 18 million acre-feet of water per year, and water use is projected to increase steadily through 2060, particularly for municipal use in the Dallas-Fort Worth, Houston, Austin, and San Antonio areas.[61] Currently, an estimated 60 percent of water use is for agricultural irrigation, but the trend (in both relative and absolute terms) is for agriculture to consume a decreasing amount. The state has devised a plan to develop water supplies that is aimed at matching the increasing demand. The cost of the plan is $30.7 billion. In addition, water shortages are projected to cost the state $9.1 billion by 2010. In these projections, no specific allowance has been made for irrigation for biomass production, nor to attend industrial demands for bioenergy production.

Availability of water for crop growth will be a key issue. In seasons of drought, irrigation will be required to maintain expected yield levels and ultimately the availability of the crop. This is further complicated by the potential implication of global climate change.

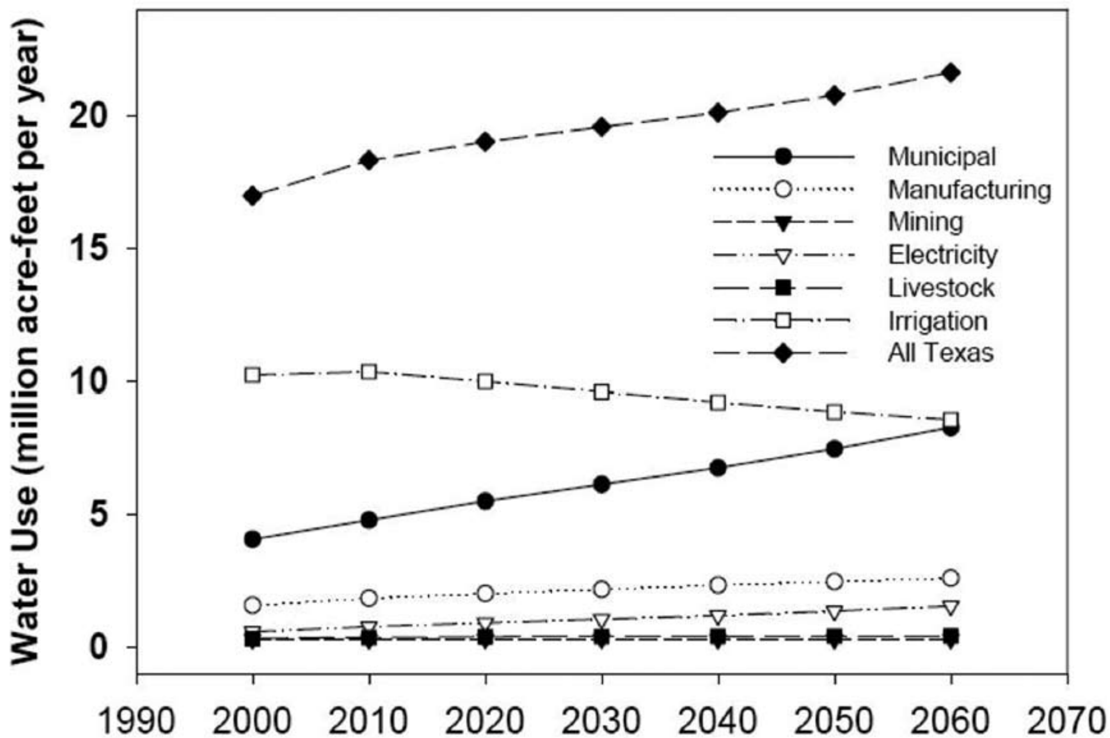
Water supplies for bioenergy may be available in regions with a projected surplus of water (precipitation or new reservoirs). These regions exclude most of West Texas and include areas north and east of Houston, and particular locations within the Brazos River watershed and Colorado River watershed. All of these areas are projected to have large increases in population, and competition with municipal water use can be expected. Irrigation is possibly feasible in the rice belt of Texas where water supplies are available and bioenergy crops may play a role in annual crop rotation. Ethanol production (distillation process) from corn consumes approximately 4 gallons of water per gallon of ethanol produced. Further, if one considers the amount of water required to grow corn in Texas, the quantity per gallon of ethanol skyrockets to cases as much as one thousand gallons of water per gallon of ethanol. If these same consumption trends were continued for renewable fuels, and the amount of renewable fuels production/demand increases at a significant rate, it is highly likely that water-use conflicts will arise. **Exhibit 5-14** shows competing water uses for Texas.

Economics

Biofuel production can be an important force in the economy. Forms of ethanol are expected to be produced for less than petroleum based fuels, with crude oil prices in excess of $100 per barrel. At the same time, the opportunities for ethanol production place pressure on commodity markets. In the spring of 2008, the combination of a number of factors including bioenergy production, energy costs, inputs, world demand, and market speculation contributed to a significant rise in commodity prices; however, by the end of 2008 commodity prices had significantly retreated because market forces and a slowing economy. Higher commodity prices benefit crop farmers but place economic stress on animal agriculture. Furthermore, high commodity and energy prices have caused substantial increases in the prices and costs of agricultural inputs. For example, recent land values in certain areas have doubled, and fertilizer and fuel prices have risen roughly 40 percent, with labor and machinery costs also steadily increasing.

The rise in commodity prices has made some biofuel production less desirable, slowing the extraordinarily rapid industry expansion. For example, in late April 2008 soybean oil prices hovered near 60 cents per pound (with a gallon weighing 7.6 pounds), driving the oil cost to about $4.50 per gallon. Soaring prices combined

Exhibit 5-14 Projected water use by economic activity for Texas



Source: Texas Water Development Board

with a transformation cost of $0.50 per gallon, and a similar conveyance cost, result in a production cost of about $5.50 per gallon for a product selling at the pump for around $4.00 per gallon. Even with the $1.00 per gallon subsidy discussed below, this has led to an industry currently operating with more than 50 percent of its capacity idle. Furthermore, the 2008 Farm Bill did not extend the biodiesel subsidy and it is due to expire in December of 2008.

Biofuels have been encouraged by federal government policies. Originally, the ethanol subsidy reduced the federal excise tax on gasoline by 5.2¢ per gallon for any gallon containing at least 10 percent ethanol meaning a gallon of ethanol could earn the subsidy 10 times by blending into 10 gallons of product; thereby creating a 52¢ per gallon ethanol subsidy. In 2004, the subsidy was simplified to a 51¢ per gallon tax credit for the ethanol content in all blends. In 2008, the Farm Bill reduced this to 45¢ per gallon. Biodiesel producers also receive a tax credit first established in the American Jobs Creation Act and extended through 2008 by the 2005 Energy Policy Act. Under these acts, the tax credit amounts to one dollar per gallon of biodiesel created from virgin oil and 50¢ per gallon for biodiesel created from animal fats, oilseeds, or recycled cooking oil. Numerous states have followed suit in providing additional subsidies for the production of biofuels.[62]

Biofuels are encouraged by the oxygenate provisions of the Clean Air Act and the Renewable Fuels Standard (RFS) as instituted under the 2005 Energy Bill and the 2007 bill.[63] Oxygenates are gasoline additives used to reduce carbon monoxide. The oxygenate provision requires an amount of renewable fuels in blends in air pollution non-compliance areas. The 2005 renewable fuel standard mandates a level of ethanol in gasoline blends, however, industry expansion has surpassed these requirements.

The 2007 Energy Bill requires significantly higher levels of blending, mandating 9 billion gallons of "conventional biofuel" (grain-based ethanol) in 2008, and rising to 13.2 billion gallons by 2012 (with increased minimum usage quotas from 5 and 7.5 billion gallons in the 2005 RFS). Furthermore, these provisions are specific to energy types and do not allow biodiesel or other biofuel forms to apply under the older, more flexible RFS.

Ultimately, the Renewable Fuels Standard will require a total of 36 billion gallons of biofuels or ethanol by 2022 with corn ethanol capped at 15 billion gallons per year starting in 2015. The remaining ethanol is to be provided by "advanced biofuels" defined as:

- Ethanol produced from cellulose, hemicelluloses, and lignin;
- Ethanol derived from sugar other than from corn starch;
- Ethanol derived from waste materials, including crop residue;
- Butanol or other alcohols produced via conversion of organic materials;
- Biomass-based diesel;
- Biogas (including landfill gas and sewage waste treatment gas) produced through the conversion of organic matter from renewable biomass; and
- Other fuels derived from cellulosic biomass.

The 2007 Energy bill also requires minimum greenhouse gas (GHG) emission reductions beginning at 20 percent; biomass-based diesel must deliver a 50 percent reduction in GHG, and cellulosic biofuels must deliver a 60 percent improvement in lifecycle GHG emissions.

Texas Biofuel Production Potential

This section has discussed the numerous biomass resources available in Texas and how they might be converted into useable energy. Because of the diversity of biomass feedstocks and the variation in availability across Texas, it is difficult to estimate total production of biofuels from the various sources. Several studies have projected biofuels production possibilities and each utilizes different assumptions and resource assessments. In an attempt to provide a conservative, base-line projection for Texas, the following estimates were made to reflect a realistic and conservative total number of energy and petroleum product gallon equivalents that could be produced using current feedstock, land, and other input factor availability. Furthermore, it was assumed that all technological innovations are more or less fixed at the current rate, and that near term crop production in Texas will closely mirror the 2007 figures used for the calculations (one or more variable inputs must be fixed in the short-run).

Currently, technological innovations, input availability, and economic feasibility qualify ten potentially significant sources of biomass for liquid fuel production. Crop residue, forest resources (woody biomass), grain ethanol, high-tonnage sorghum, oilseed crops, algae, municipal solid waste, energy cane, sweet sorghum, and switchgrass comprise the feedstocks for short-run petroleum replacement. Energy estimations were reported in terms of Btu's and in gallons as a reference point for comparison between total renewable energy and the equivalent energy in the form of traditional petroleum fuel products. Current conversion technologies can range from 60-120 gallons per dry ton of input depending upon the type of feedstock.[64] For the purpose of the provided estimations, the conversion rate of 75 gallons per dry ton was applied for the final estimation. Other inputs, such as oilseed crops, algae, and sweet sorghum were calculated at a more specific measure of the given feedstock's energy potential per acre. **Exhibit 5-15** estimates that nearly 2 billion gallons of biofuels from all sources of biomass could be produced in Texas, almost immediately.

Btu, or British Thermal Unit is the measure of thermal energy most commonly employed in the United States. From a technical standpoint, a Btu is the energy required to increase the temperature of a pound of water by one degree Fahrenheit. As applied to biofuels, Btu's are a means of comparison. According to the United States Energy Information Administration, the only means by which to make meaningful comparisons of energy commodities is to convert the listed units (including weight or volume) into similar units; thus, Btu's are essential in comparing the various types of biofuel sources in Texas. As a means of comparison between biofuels sources and traditional fuels, the relative Btu levels are as follows:[65]

- 1 barrel of crude (42 gallons) – 5,800,000 Btu
- 1 gallon of gasoline – 124,000 Btu
- 1 gallon of diesel fuel – 139,000 Btu
- 1 cubic foot of natural gas – 1,026 Btu
- 1 gallon of propane – 91,000 Btu
- 1 short ton of coal – 20,681,000 Btu
- 1 kilowatthour of electricity – 3,412 Btu

Exhibit 5-16 provides an estimate of the Btu content of some of the biomass sources provided in **Exhibit 5-15** (adjusted for availability) which might be converted to heat energy. However, it should be noted that each source could not be converted to both direct heat energy and liquid fuel.

Crop residue, as applied to Texas, is mainly a function of wheat, corn, grain sorghum, soybeans, rice, and cotton production. Of the 3.8 million acres of wheat production in the state, it was assumed that ten percent would be utilized for crop residue harvest at a rate of one dry ton per acre. Corn and grain sorghum were also calculated at a ten percent acreage allotment. However, total corn acreage was comprised of the High Plains production only, and corn residue was calculated at a rate of two dry tons per acre. Soybeans, while a crop of interest, are not a significant portion of Texas agriculture and do not contribute to crop residue potential. Currently, rice presents the possibility for forty percent of its residue to be utilized, totaling nearly 58,000 dry tons of crop residue. The final crop of interest is cotton. Cotton crop residue utilized at twenty five percent of total acreage and an assumed .26 dry tons per acre rate will be one of the largest potential sources of residue in the state. Converted into gallons of petroleum products displaced at the assumed conversion rate of 75 gallons per dry ton, crop residue presents the near-term potential to replace 72,105,000 gallons of traditional fuel consumption. The feasibility of cotton residue as a biofuel will be tempered with low per acre yields and relatively higher logistical costs. **Exhibit 5-17** provides an estimate of biofuels production from crop residue referenced in **Exhibit 5-15**.

A 2007 survey of available biomass feedstocks in Texas by Cornwell, Sandhop, Shanks, Phillips, and Webb estimated that available forest biomass resources totaled nearly 14 million dry tons in Texas.[66] At a general conversion rate of 75 gallons per dry ton of forest resources and an assumed utilization rate of 20 percent of overall tonnage, **Exhibit 5-18** provides an estimate of biofuels production from forest resources as referenced in **Exhibit 5-15**.

Exhibit 5-15 Texas Biofuels Potential

	Input Volume/ Acreage	Units	Yield	Gallons
Crop Residue	961,400	Dry tons	75 g/dt	72,105,000
Forest/Wood Resources	3,000,000	Dry tons	75 g/dt	45,000,000
Grain (Ethanol)	355,000,000	Gallons	Fixed production rate	355,000,000
High-tonnage Sorghum	348,300	Acres	75 g/dt at 10 dt/ac	261,225,000
Oilseed Crops	108,110	Acres	100 g/ac	10,811,000
Algae	100,000	Acres	3,000 g/ac	300,000,000
Municipal Solid Waste	2,530,279	Dry tons	75g/dt	189,770,897
Energy Cane	6,375	Dry tons	75 g/dt at 10 dt/ac	4,781,250
Sweet Sorghum	42,130	Acres	300 g/ac	12,639,000
Switchgrass	2,162,291	Acres	75 g/ac at 4 dt/ac	648,687,300
TOTAL				1,900,019,447

Exhibit 5-16 Btu Content of Texas Biofuel Sources

Biomass Resource	Volume	Units	Rate per Unit	Total BTU's
Crop Residue	1,922,800,000	Lbs	6,000	11,536,800,000,000
Forest Sources	6,000,000,000	Lbs	7,500	45,000,000,000,000
High-Ton. Sorg.	6,960,000,000	Lbs	6,000	41,760,000,000,000
Mun. Solid Waste	5,060,558,000	Lbs	6,000	30,363,348,000,000
Energy Cane	12,750,000	Lbs	6,000	76,500,000,000
Animal Wastes	10,250,000,000	Lbs	6,000 – 8,000	64,740,000,000,000
Switchgrass	17,298,328,000	Lbs	6,000	103,789,968,000,000
TOTAL				297,266,616,000,000

Exhibit 5-17 Crop Residue

Biomass Resource	Acres	Dry Tons/Acre	% of Acreage Collected	Total dt/Crop
Wheat	3,800,000	1	10%	380,000
Corn	847,200	2	10%	169,440
Grain Sorghum	469,000	1	10%	46,900
Soybeans	86,000	0	0%	—
Rice	145,000	1	40%	58,000
Cotton	4,724,000	.26	25%	307,060
TOTAL DRY TONS				961,400

Exhibit 5-18 Forest Resources

	Dry Tons Available	Percentage Utilized	Total Applied Tonnage
Forest Residues	3,000,000	20%	600,000 dry tons

Grain ethanol production in Texas is a function of 4 plants currently producing roughly 355 million gallons (as of 2007). In the short run, it is not likely that the number of plants will change, as the plants will need to continue to operate to allocate high front-end investment costs and the outlook for an increasing number of grain ethanol processing plants is dim, as plants currently under construction have recently been placed on hold. Processors now face increasing costs of production coupled with smaller than desired returns on energy/resources invested. **Exhibit 5-19** provides an estimate of grain ethanol production referenced in **Exhibit 5-15**.

Exhibit 5-19 Grain Ethanol

	Inputs	Production Plants	Total Production
Ethanol	Grains	4	355,000,000 gallons

As cellulosic technologies have evolved to become increasingly efficient, crops such as high-tonnage sorghum have come to the forefront of the renewable fuels sector. Pertaining to Texas, high-tonnage sorghum has the potential to be grown in many areas; Areas now comprised of wheat, corn, grain sorghum, rice, and cotton were the focus of this estimation. As with almost all various energy crops, the goal of high-tonnage sorghum substitution with regard to more traditional crops is to minimize the impact on feed and food by allocating a small percentage of nearly each listed crop's acreage to a renewable fuel. In the short-run, none of the 2007 wheat production was assumed to transition into high-tonnage sorghum, but ten percent of corn acreage was applied to sorghum production for biomass. In the South Central and Coastal Bend agricultural districts, ten percent of the 2007 grain sorghum production was allocated to high-tonnage production, as sorghum is already successfully grown in these regions. As with the crop residue estimation, none of the 2007 soybean production acreage was allocated to high-tonnage sorghum production, as soybeans are not a highly produced crop in Texas, and the existing production was not estimated to be allocated to any other crops. High-tonnage sorghum was allocated to 2007 levels of production at a rate of fifteen percent, for both rice and cotton. As a result, at an estimated yield of ten dry tons of biomass per acre, high-tonnage sorghum crop allocation resulted in an estimated harvest of 3.48 million dry tons. **Exhibit 5-20** provides an estimate of biofuels production from sorghum referenced in **Exhibit 5-15**.

Exhibit 5-20 High-tonnage Sorghum

	Acres	Dry Tons/ Acre	% of Acreage Utilized	Total Utilized Acreage
Wheat	3,800,000	10	0%	—
Corn	1,025,000	10	10%	102,500
Grain Sorghum	469,000	10	10%	46,900
Soybeans	86,000	10	0%	—
Rice	145,000	10	15%	21,750
Cotton	4,724,000	10	15%	177,150
TOTAL				348,300
TOTAL DRY TONS				3,483,000

Exhibit 5-21 Oilseed Crops

	Acres	% of Acreage Collected	Total Utilized Acreage
Wheat	42,500	10%	4,250
Corn	2,150,000	0%	—
Grain Sorghum	469,000	10%	46,900
Soybeans	86,000	0%	—
Rice	145,000	15%	21,750
Cotton	352,100	10%	35,210
TOTAL			108,110

In the oilseed crops subsection, ten percent of the 2007 wheat production in the South Central and Coastal Bend agricultural districts was allocated to the renewable fuels estimation. As well, ten percent of grain sorghum production was allocated from the same regions. Corn was not included in the oilseed crops subsection, as corn is a major input factor of production to grain ethanol, and corn was already taken into consideration when calculating the estimations for high-tonnage sorghum and crop residue. As with the previous subsections, soybean acreage was not allocated to the renewable fuel production possibilities estimation. Rice was included in the estimation at fifteen percent of total Texas production acreage, and cotton was included at ten percent of production acreage in the South Central and Coastal Bend agricultural districts. **Exhibit 5-21** provides an estimate of biofuels production from oilseeds referenced in **Exhibit 5-15**.

Algae have the potential to yield up to 5,000 gallons per acre each year under commercial production conditions. However, as commercial production of algae for biofuel is relatively uncharted, the per acre yield for algae was estimated and calculated at 3,000 gallons per acre to be on the conservative side of total production feasibility. **Exhibit 5-22** provides an estimate of biofuels production from algae referenced in **Exhibit 5-15**. In the 1950s, there were over 250,000 acres of irrigated crops near Pecos, suggesting a much greater potential for the area.

Exhibit 5-22 Algae Production

	Acres	Gallons/Acre	Total Production
Algae	100,000	3000	300,000,000 gallons

If only ten percent of the 2007 levels of municipal solid waste were to be used as an input for renewable energy production, it would serve to act as a two-fold benison to the state of Texas by appeasing a portion of the demand for traditional fuel sources and eliminating over 3 million tons of municipal solid waste (which would have otherwise occupied local landfills). At a general conversion rate of 75 gallons per dry ton of municipal waste diverted from landfills, even a ten percent rate of waste reclamation can have a big impact on energy generation and landfill space. **Exhibit 5-23** provides an estimate of biofuels production from municipal solid waste referenced in **Exhibit 5-15**.

Exhibit 5-23 Municipal Solid Waste

	Dry Tons Available	% of Utilized MSW	Total Applied Tonnage
Forest Residues	30,000,000	10%	3,000,000 dry tons

The near-term potential for energy cane production was assumed to be portioned from current levels of sugarcane production in Texas. At a utilization of 15% of 2007 sugarcane production acreage and ten dry tons per acre, energy cane poses a source of equivalence to nearly 4.8 million gallons of traditional petroleum energy products. **Exhibit 5-24** provides an estimate of biofuels production from energy cane referenced in **Exhibit 5-15**.

Exhibit 5-24 Energy Cane

	Total Acreage	% of Utilized Cane	Total Utilized Acreage
Sugar Cane	42,500	15%	6,375

The sweet sorghum estimation was calculated from ten percent of the sugarcane production in Texas as well as ten percent of the 2007 sorghum production in the Coastal Bend agricultural district. At a conversion ratio of 300 gallons per acre, near-term sweet sorghum production could easily reach over twelve million gallons. **Exhibit 5-25** provides an estimate of biofuels production from sweet sorghum as referenced in **Exhibit 5-15**.

Exhibit 5-25 Sweet Sorghum

	Acres	% of Acreage Collected	Total Utilized Acreage
Sugar Cane	42,500	10%	4,250
Coastal Bend Sorghum	378,800	10%	37,880
TOTAL			42,130

Because switchgrass is a warm-season perennial grass native to Texas, it has the ability to thrive in various Texas climates, and has minimal need for tillage/cultivation. As well, it possesses a notable potential to be commercially grown while mitigating any perceived threat to feeds and food. While it is true that every acre of land dedicated to energy crops cannot jointly be used for food production, switchgrass is aimed to minimize viable farmland substitution, as it is estimated to replace certain portions of what is typically listed in Texas as "pastureland", "cropland idle", and CRP land. According to the 2002 Census of Agriculture's Land Survey Data, pastureland and cropland idle account for more than 17 million acres of growth-sustaining land in Texas. The switchgrass estimations for near-term petroleum replacement assumed that ten percent of these 17 or more million acres combined with ten percent of the 4.05 million acres of land in the 2007 Conservation Reserve Program could generate more than 8.6 million dry tons of convertible biomass in the state of Texas each year. However, Texas Agrilife's Blacklands Research Center estimates that switchgrass' yield potential in Texas could be even greater than calculated in the above estimation (4 dry tons per acre), at 6.25 tons per acre. **Exhibit 5-26** provides an estimate of biofuels production from switchgrass as referenced in **Exhibit 5-15**.

Exhibit 5-26 Switchgrass

	Acres	Dry Tons/ Acre	% of Acreage Utilized	Total Utilized Tonage
Pastureland	12,937,991	4	10%	5,175,196
Cropland Idle	4,609,293	4	10%	1,843,717
CRP	4,075,626	4	10%	1,630,250
TOTAL ACREAGE			2,162,291	
TOTAL DRY TONS				8,649,164

Key Issues

A number of key issues surround the future of biofuels and bioenergy in Texas:

Food–Feed–Fuel–Poverty–Environmental Concerns — the rapid expansion in ethanol production has been accompanied by a rapid expansion in commodity prices and an explosion in the news media of concern about food prices, poverty, and the environment. Concerns over these issues are rising and they could potentially cause RFS provisions of the Energy Bill to be modified. In particular, ethanol production has taken some corn out of the marketplace which, coupled with other supply and demand factors, has increased corn prices from $2 per bushel in 2000 to 2008's prices in excess of $6 per bushel. The resulting land competition and substitution possibilities have caused other commodity prices to increase, potentially making food prices higher domestically and internationally. Issues related to poverty (particularly concerns about the price of food) are partially offset by the fact that agricultural incomes worldwide are rising, and a large number of people identified as poor derive their income from agricultural employment. Recent increases in retail food prices in the U.S. are largely a function of higher wage rates and increasing oil prices. A portion of the increases are attributed to elevated corn prices.[6] A recent study by Texas A&M University, has determined that there are a number of factors affecting the increased cost of food and feed. Some of the factors include energy costs, fertilizer prices and supply levels, commodity speculation, and ethanol production. Data presented at the 2008 Texas Ag Forum showed that only fifteen percent of food price increases could be linked to ethanol production. Conversely, a 2008 study done for Kraft Foods Global by Keith Collins, while it did identify economic growth, declining U.S. dollar values, reduced commodity supplies, higher energy prices, foreign agricultural policies, and speculative investment as contributing factors, the study estimated that 60% (or $20 billion) of expected food price increases from 2006 to 2009 is accounted for by biofuels.[67]

Ethanol production has additionally put pressure on lands judged to be environmentally sensitive. Such lands include US CRP/forest land and international forested areas including land in rainforests.

An inevitable consequence of ethanol market expansion is, at least in the short run, higher commodity prices and land conversion pressures. Future ethanol forms using residues and byproducts that are not in competition with food production will partially alleviate such concerns.

Gasoline and energy price future—The oil embargo situation of the late 1970s, and the corresponding high oil prices, caused an explosion of interest in biofuel that continued into the early 1980s. However, interest waned when oil prices dropped; suggesting that oil prices must remain high to stimulate biofuel production. Even though fluctuations are anticipate because of economic conditions, indications are that oil prices will remain high, because the supply of conventional oil is peaking; non-conventional sources exist, but are more costly to extract, while global demand is rising fast and expected to remain high.[68] In particular, Asia is rapidly expanding its demand for energy.

Greenhouse Gas policy—Climate change and associated GHG emission concerns are prominent and expanding. Over 80 percent of U.S. emissions come from fossil fuel combustion. Policies such as carbon taxation, carbon cap and trade, and subsidizing energy efficiency are being discussed and could influence the future of biofuels. Biofuels are not all equal in GHG offsets, as different amounts of energy are consumed in the corresponding production processes. For example, corn ethanol offsets 20 to 30 percent of the emissions that would be generated by the fossil fuels it replaces (including production and land use change), cellulosic processes displace 50 to 70 percent, and electricity more than 85 percent.[69]

Technological advances in processing—Cellulosic ethanol is a widely discussed "second generation" form of ethanol production, while pyrolysis and gasification are discussed as other routes to alternative liquid energy forms such a bio-crude. Despite their theoretical potential, pyrolysis and gasification will not reach commercialization for at least three years. Production of cellulosic ethanol today is generally very small scale, and the pace at which cellulosic technologies will develop is uncertain.

Technological advances in production—The 2007 U.S. corn crop set a record, reaching over 13 billion bushels compared to 10 to 11 billion bushels in the several preceding years. This increase came about due to acreage expansion and technological change. High corn prices will stimulate additional production through improved practices and genetic developments. A key issue in the food vs. fuel debate involves the rate of growth/development in future corn yields.

Sustainable production capacity for biomass—While Texas has large agricultural areas and production capabilities, some limitations (especially water) will affect the future of feedstock production. Areas that are currently large agricultural producers, like the Rio Grande Valley and the High Plains, may not be able to sustain large biomass-based industries due to water availability. East Texas may be more suitable with a dependence on forest products and byproducts, along with energy crops.

Hauling, harvest, seasonality and transport—Biofuel refineries need large quantities of biomass on a year-round basis. Materials handling, suitability for year-round harvest, large potential crop density near refinery sites, storage, and adequate road systems are all key issues in industry location.

Climate change and production suitability—When discussing the future of Texas agriculture, potential climate change is a key issue. The recent trend has shown a warmer, drier state with more concentrated rainfall. The future is projected to have more of these same conditions with some indication that significant regions will be as dry as the affected areas observed during the Dust Bowl.[70]

Forms of preferred fuels—While ethanol is the dominant fuel being produced today, many in the energy industry prefer other forms of energy closer to gasoline or conventional crude oil because of ethanol's corrosiveness and water interactions. The issues then are: To what extent can technology develop pyrolysis, gasification, or chemical processes that deliver more desirable energy forms? And, how soon can this be commercialized?

Financing for ethanol plants—For the past 5 years, CoBank has financed the majority of new ethanol plants. Following the establishment of the 2005 Renewable Fuels Standard, venture capitalists began financing ethanol plants and now provide a significant share of the financial input.

Environmental permitting—Ethanol plants are required to obtain state and federal permits related to water, air, and waste disposal. This process takes a year, but has become a standardized procedure that is readily handled by experts.

Intellectual Property—New bioenergy technologies will contain significant value and will need to be protected by patents and appropriately commercialized.

References

1 United States Department of Energy. Energy Efficiency and Renewable Energy Homepage. http://www.eere.energy.gov/

2 The Energy Report. Last viewed June, 2008 http://www.window.state.tx.us/specialrpt/energy/

3 Wiltsee, G. November 1998. Urban Wood Waste Resource Assessment. National Renewable Energy Laboratory.

4 25% Renewable Energy for the United States By 2025: Agricultural and Economic Impacts, www.25x25.org

5 America's Energy Future. 25X'25 Homepage. http://www.25x25.org/

6 Anderson, D., J. Outlaw, H. Bryant, J. Richardson, D. Ernstes, M. Raulston, J. Welch, G. Knapek, B. Herbst, and M. Allison. The Effects of Ethanol on Texas Food and Feed. Texas A&M University. The Food and Agricultural Policy Center, 2008. http://www.afpc.tamu.edu/pubs/index.php?content=single&pub_id=515&type=2

7 McBee, GG, Miller FR, Dominy RE, and Monk RL. Quality of sorghum biomass for methanogenesis. In Energy from Biomass and Waste X, ed. by D.L. Klass, Elsevier, London. pp. 251-260. (1987)

8 Agrilife Research, Texas Agricultural Experiment Station. Agbioenergy Homepage, "From Field to Fuel Tank". http://agbioenergy.tamu.edu/

9 Kiniry, et. al. USDA-ARS. Texas AgriLIFE Blackland Research Center.

10 Scurlock, J.M.O. Miscanthus, A Review of European Experience with a Novel Energy Crop. Oak Ridge National Laboratory prepared for the U.S. Department of Energy, 1999.

11 Tyson, K.S. 1991. Resource assessment of waste feedstocks for energy use in the western regional biomass energy area. WRBEP project no. BF983232, February 1991.

12 Faidley, Richard. Energy From Biomass. Texas Renewable Energy Resource Assessment. July, 1995. Texas Renewable Energy Resources Database. Last Viewed June, 2008. http://www.infinitepower.org/pdf/re_study1995.pdf

13 Cornwell, Brett, David Sandhop, Lauralee Shanks, Lauralee Phillips and Debrorah Webb. 2007. Survey of Available Biomass Feedstocks Available for Energy in Texas. Office of Technology Commercialization, Texas A&M University System.

[14] Sokhansanj, S. and A. Turhollow. Stochastic Modeling of Costs of Corn Stover Costs Delivered to an Intermediate Storage Facility. Oak Ridge National Laboratory. ASAE Database, June 2002.

[15] Texas Forest Service, 2007. Texas Forests Today. Forest Resource Development and Sustainable Forestry.

[16] Mills, Patrick D. *Forest Inventory Mapmaker Web-Application Version 3.0.* St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. [Available only on Internet: http://www.ncrs2.fs.fed.us/4801/fiadb/index.htm].

[17] Soil Conservation Service. 1982 Texas Brush Inventory: June 1987, Temple, TX.

[18] Ansley, R.J. 2006. Economical Supply of Mesquite Biomass for Energy Uses. Final Report to Texas State Energy Conservation Office (SECO), Contract CM-406, 04 January 2006.

[19] Wright, L.L. 1994. Production technology status of woody and herbaceous crops. Biomass & Bioenergy 6: p.191-209.

[20] Xu, W. and B. Carraway. May 2007. Biomass from Logging Residue and Mill Residue in East Texas, 2005. Texas Forest Service.

[21] American Forest & Paper Association. December 2006. AF&PA Environmental, Health & Safety Verification Program, Biennial Report. American Forest & Paper Association.

[22] Department of Energy. February 2008. Climate Vision Progress Report 2007. Environmental Protection Agency. 2007. Solid Waste and Emergency Response (5306P), EPA-530-R-07-030, Washington, DC 20460

[23] Xu, W. October 2007. Harvest Trends 2006. Texas Forest Service.

[24] Wiltsee, G. NREL, 1998

[25] Cole, N.A., M.S. Brown, and V. Varel. 2007. Beef Cattle : Manure management in A. W. Bell and W. Pond (ed) *Encyclopedia of Animal Science*. http://dx.doi.org/10.1081/E-EAS-120023826

[26] Cole, N.A., R.C. Schwartz, and R.W. Todd**.** 2005. Assimilation versus accumulation of macro- and micronutrients in soils: Relations to livestock and poultry feeding operations. *Journal of Applied Poultry Research* 14;393-405.

[27] Mukhtar, S. 2007. Manure Production and Characteristics. Its Importance to Texas and Animal Feeding Operations. Texas Cooperative Extension publication L-5489.

[28] Amosson, S.H. 2007. Personal communication. Texas AgriLife Research and Extension Center, Amarillo, TX.

[29] ASAE. 2005. D384.2**:** Standard for manure production and characteristics. American Society of Biological and Agricultural Engineering, St. Joseph, MI.: ASABE.

[30] Sweeten, J.M., K. Heflin, K. Annamalai, B.W. Auvermann, F.T. McCollum, and D.B. Parker. 2006. Combustion-Properties of Manure or Compost from Paved vs. Unpaved Cattle Feedlots. ASABE Paper No. 06-4143, American Society of Biological & Agricultural Engineers, St. Joseph, MI. July 9-12. 12 p.

[31] Sweeten, J.M., B. W. Auvermann, S. Mukhtar, N. A. Cole, R. DeOtte, D. B. Parker, B. Weinheimer, K. D. Casey, C. B. Parnell, R. Todd, B W. Shaw, and J. Upadhyay. 2007. Natural Resource Management: Air Quality, Water Quality & Manure Management. In: Proceedings, High Plains Livestock 2007 Conference, Amarillo TX, Sept. 5-6, 2007. (In press).

[32] ASAE. 2005.

[33] Mukhtar, S. 2007.

[34] ASAE. 2005.

[35] Kalbasi, A., S. Mukhtar, S.E. Hawkins and B.W. Auvermann. 2006. Design, utilization, biosecurity, environmental and economic considerations of carcass composting. *Compost Science & Utilization* (14) 2, 90-102.

[36] Sweeten, J.M., B. W. Auvermann, et. al. High Plains Livestock Conference, 2007.

[37] Sweeten, J.M., K. Heflin, K. Annamalai, et. al. ASABE, 2006.

[38] Rachel Goldstein, "Trash to Treasure: Landfills as an Energy Resource," *District Energy Magazine* (Third Quarter, 2006), pp. 6-10, http://www.epa.gov/landfill/docs/3q06landfill.pdf (Last visited March 24, 2008).

[39] U.S. Environmental Protection Agency, "Solid Waste Combustion/Incineration," http://www.epa.gov/epaoswer/non-hw/muncpl/landfill/sw_combst.htm. (Last visited March 4, 2008).

[40] Texas Commission on Environmental Quality. 2007. Municipal Solid Waste in Texas: A Year in Review, 2006 Data Summary and Analysis, AS-187/.07.

[41] Phani, K. Adapa, Lope G. Tabil, Greg J. Schoenau. 2006. American Society of Agricultural and Biological Engineers and the Canadian Society for Bioengineering. Paper number: MBSK 06-209. Municipal Solid Waste-A Review of Classification System. http://asae.frymulti.com/request.asp?JID-8&AID=22368&CID=smpnc&T=2

[42] TCEQ. MSW Review, 2006.

[43] United States Department of Energy, homepage.

[44] McBee, GG, et. al. Sorghum Biomass, 1987. pp. 251-260.

[45] National Agricultural Statistics Service. United States Department of Agriculture. http://www.nass.usda.gov/

[46] Stassen, H.E.M., and W. P. M. van Swaaij. 1982.Application of Biomass Gasification in Developing Countries. Pp 705-714. In: Proceedings of the International Conference on Biomass held in Berlin, Federal Republic of Germany on 20-23 September 1982.

[47] Kemp, W.H. Biodiesel Basics and Beyond. A Comprehensive Guide to Production and Use for the Home and the Farm. Aztext Press, Ontario, Canada.

[48] Gerardi, M.H. 2003. The Microbiology of Anaerobic Digesters. John Wiley and Sons, Ltd., New York.

[49] Hobson, P.N. and A. D. Wheatley. 1993. Anaerobic Digestion: Modern Theory and Practice. Elsevier Science, London, UK.

[50] Capareda, S.C. 1995. Utilization of Residue from Agriculture and Agro-Industry. In: Capareda, S.C. (Ed.). Appropriate Energy Sources for Rural Areas. Asian Productivity Organization Publications, Tokyo, Japan.

[51] Kessler, R. W., M. A.Gutjahr and R. L. Scholz. 1982. Defibration Studies on Pine Wood. Pp 940-944. In: Proceedings of the International Conference on Biomass held in Berlin, Federal Republic of Germany on 20-23 September 1982.

[52] Boyle, G. 2004. Renewable Energy: Power for Sustainable Future. Oxford University Press, Oxford, England.

[53] Hiler, E.A. and B. A. Stout. 1985. Biomass Energy: A Monograph. Texas Engineering Experiment Station Monograph Series. 313 pp. The Texas A&M University Press, College Station, Texas.

[54] Stout, B.A. 1984. Energy Use and Management in Agriculture. Breton Publishers: A Division of Wadsworth, Inc., Belmont, CA.

[55] Steynberg, A. and M. Dry. (Eds.). 2004. Fischer-Tropsch Technology. Elsevier Science Ltd., Oxford, UK.

[56] Stassen and van Swaaij. 1982. Application of Biomass Gasification in Developing Countries. pp 705-714.

[57] United States Department of Agriculture, Natural Resources, 2006. Digital General Soil Map of U.S. Publisher: NRCS-USDA Fort Worth, Texas. Available online at http://SoilDataMart.nrcs.usda.gov/ (last checked April 25, 2008)

[58] United States Department of Agriculture Natural Resources, 2007. National Resource Inventory 2003 Annual NRI State Report. Available online at http://www.nrcs.usda.gov/technical/NRI/2003/statereports/all.html (last checked May 5, 2008)

[59] United States Geological Survey, 2008. National Land Cover Database 2001. Publisher: U.S. Geological Survey, Publication_Place: Sioux Falls, SD. Available online at http://www.mrlc.gov (last checked April 25, 2008)

[60] Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-ton Annual Supply, http://www.eere.energy.gov/biomass/biomass_feedstocks.html.

[61] Texas Water Development Board, 2006. The 2007 State Water Plan. Available online http://www.twdb.state.tx.us/publications/reports/State_Water_Plan/2007/2007StateWaterPlan/2007StateWaterPlan.htm (last checked May 5, 2008).

[62] H.R. 2419: Food and Energy Security Act of 2007, http://www.govtrack.us/congress/bill.xpd?bill=h110-2419

[63] Energy Policy Act of 2005—Pub.L. 109-058

[64] The University of Tennessee. UT Board Approves Biofuels Business Partnership. UT Institute of Agriculture. Released September, 2007. http://www.agriculture.utk.edu/news/releases/0709-Biofuels-site-announcement.htm

[65] United States Energy Information Administration. Converting Energy Units 101. Official U.S. Government Energy Statistics, Energy Basics 101. Last Viewed September, 2008. http://www.eia.doe.gov/basics/conversion_basics.html

[66] Cornwell, Sandhop, Shanks, Phillips, and Webb. Survey of Biomass Feedstocks Availabe for Energy in Texas.

[67] Collins, Keith. The Role of Biofuels and Other Factors in Increasing Farm and Food Prices. A Review of Recent Developments with a Focus on Feed Grain Markets and Market Prospects. Included as a review conducted by Kraft Foods Global: June, 2008.

[68] McCarl, B.A. “Lifecycle Carbon Footprint, Bioenergy and Leakage” *Choices*, 1st Quarter 2008, 23(1). http://www.choicesmagazine.org/2008-1/theme/2008-1-09.htm

[69] McCarl, B.A. "Biofuels: Will we see more? An Economists View", Presented at Texas Renewable Energy Industries Association, Texas Renewables '06 Conference, Austin, November 13, 2006. http://agecon2.tamu.edu/people/faculty/mccarl-bruce/renewfuel.ppt

[70] Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H.-P. Huang, N. Harnik, A. Leetmaa, N.-C. Lau, C. Li, J. Velez, N. Naik, "Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America" *Science* 25 May 2007, Vol. 316. no. 5828, pp. 1181 – 1184

[71] The University of Tennesse Institute of Agriculture, 2007.

[72] Penn, Michael. Bioenergy research center gets early boost from U.S. Department of Energy. University of Wisconsin-Madison Press. Released September, 2007. http://www.news.wisc.edu/14208