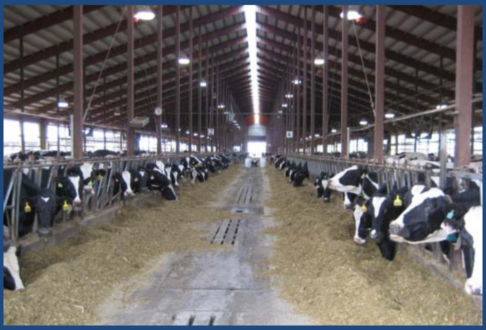
TEXAS DEPARTMENT OF AGRICULTURE
2010 BIOENERGY STRATEGIC PLAN AND RESEARCH REPORT



A report of the Texas Bioenergy Policy Council and the Texas Bioenergy Research Committee

Prepared by Tetra Tech, Inc. and the Texas Department of Agriculture

January 21, 2011

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TEXAS DEPARTMENT OF AGRICULTURE

Todd Staples
Commissioner

January 21, 2011

Dear Fellow Texans:

Around the world, Texas is known as a land with a larger-than-life reputation. From the cattle barons of the 19th Century to the wildcatters of the 20th, Texans have built that reputation by living up to an ideal: that with vision and determination, anything is possible. While agriculture built the Lone Star State in its first century and energy built it in its second, these two strong traditions can come together to blaze a new tradition in its third.

Bioenergy holds an incredible potential to transform our nation's energy crisis into an energy opportunity. It offers a potential for a domestic source of energy and an area for new economic activity for Texans and the rest of the country.

Recognizing the many efforts to establish a bioenergy industry, the 81st Legislature in 2009 established the Texas Bioenergy Policy Council and the Texas Bioenergy Research Committee to create a coordinated approach and focus resources to facilitate a successful bioenergy industry. Comprised of stakeholders from the private sector, government and academia, these two bodies bring a wealth of experience and knowledge to the table that will be essential to proposing policies that are sustainable, equitable and defensible.

Sustainable: Government policies should have the long-term goal of establishing a self-sufficient, market-driven, renewable energy industry for the benefit of the industry and consumers.
Equitable: Government policies must not favor one technology over another, nor pit existing industries against emerging ones.
Defensible: Government policies must show a measurable return on the taxpayers' investment, generating jobs and private investment.

These three foundational principals are the basis of both the policy council's and the research committee's work and the content of the following report, which is a resource for policymakers and the host of bioenergy industry stakeholders as they seek to expand the industry.

Through 2019, the Bioenergy Policy Council and Research Committee will continue working to address challenges to the bioenergy industry. Over the next year, the group plans to work towards developing a bioenergy research consortium that draws from the public and private research efforts in Texas, explore the advantages and disadvantages of using bioenergy consistent with state and federal regulation and use standards, and developing web and mapping resources to aid agricultural producers in growing bioenergy feedstocks.

I look forward to continuing to work with the policy council and research committee as we evaluate the merits and promise of expanded bioenergy production in the state of Texas through policies that are sustainable, equitable and defensible.

Sincerely yours,

Todd Staples

Todd Staples

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EXECUTIVE SUMMARY

As Texans, we take pride in being the biggest and the best. This dedication and innovation across many sectors of our economy make the Lone Star State a leader in many areas of agricultural production, alternative energy production, and a key supplier of the nation's energy needs. These industries are key to the success of the Texas economy, and as such, the Texas Bioenergy Policy Council and the Texas Bioenergy Research Committee were established to create a state framework that supports the joint efforts of these industry sectors in the goal of positioning Texas as a leader in bioenergy.

While bioenergy production presents many opportunities, the challenges for the industry are significant. Like other renewable energy sources in Texas and the United States, bioenergy faces strong competition for market share, regulatory approval, and finite state and federal resources to fund research, development and other incentives.

For this industry to grow rapidly and sustainably, the Texas Legislature has asked the Texas Bioenergy Policy Council (Policy Council) to set a bold agenda for the expansion of the bioenergy industry in Texas by 2019. The 81st Legislature, in Senate Bill 1016, instructed the Policy Council to address several elements which were considered important to a holistic policy approach for industry development. In that same bill, the Legislature created and charged the Texas Bioenergy Research Committee (Research Committee) with gathering and determining a number of research specific tasks. This report, presented to the 82nd Legislature, addresses work done by both bodies this past interim and reflects the path both will pursue to meet the "goal of making biofuels a significant part of the energy industry in this state no later than January 1, 2019."

INTRODUCTION

Modern bioenergy, commonly defined as “renewable energy from biological sources,” has gained increased attention in the past decade. Not only does bioenergy provide an effective option for the provision of energy, fuels, alternative chemical feedstocks and value-added bio-based products, but it is also based on resources that can be utilized on a continuous basis around the globe. In addition, the benefits accrued go beyond the provision of bio-products, creating unique opportunities for regional economic development.

Obviously, the potential of deriving renewable bioenergy services from biomass or biomass-derived feedstocks is not a novelty, and many states, including Texas, have developed a variety of bioenergy programs and policies. Still, it is not until more recently that the understanding of the far reach of bioenergy options has come to a turning point, and efforts to promote bioenergy started to be made in a more concerted form at a global level. Today, bioenergy is seen as a renewable energy source which may have societal advantages, including environmental benefits, energy security and economic development.

Studies detailing the potential of biomass have multiplied in the past few years. Markets for bioenergy-related products have grown quickly, driven largely by the factors mentioned above. The challenges for the production of energy from biomass and the delivery of this energy to market are many. The development of bioenergy systems with the reliability required of modern energy systems involves sustainable natural resource management, sophisticated organization schemes, and proper market strategies under renewable bioenergy markets. These challenges should not be underestimated particularly when a broad use of bioenergy is contemplated.

This report on the potential and challenges of the bioenergy industry was initiaited by the 81st Texas Legislature, which charged the Texas Department of Agriculture (TDA), Texas Bioenergy Research Committee (Research Committee), and the Texas Bioenergy Policy Council (Policy Council) to determine the biomass potential and utilization for renewable bioenergy in the state of Texas.

Based upon the predefined scope, the objective of this report is to identify the potential of a bioenergy market and challenges that need to be addressed to achieve that potential. Because of the complexity of this issue, the strategies and information in this report should not be considered comprehensive, nor should it be used to advance or prohibit certain technologies to the exclusion of others. The information provided here offers a reference point to address the complexities of deploying biomass energy options and a channel to communicate that effective solutions are possible and are being implemented at various scales and under different social, environmental and technical conditions. The Policy Council’s strategic plan and the Research Committee’s report is an effort to evaluate existing options and discussing relevant policies and measures that will shape bioenergy utilization in Texas, as well as to providing direction for future government action in the immediate future. It goes without question, that the Legislature has established the Policy Council and Research Committee as the best-positioned entities in Texas to offer coordination and consultation on bioenergy matters and therefore should be consulted prior to significant policies or programs being implemented in Texas. This will help ensure new information is considered as changing prices and technologies affecting feedstocks and federal policies can greatly affect the industry.

The first section of this report is Texas’ first bioenergy strategic plan, prepared by the Policy Council. In this plan, the Legislature’s specific charges to the Policy Council are highlighted, and a brief summary of the issue is provided. The Policy Council then provides a strategy for future action on the issue, which includes subsequent updates to this strategic plan.

Following this strategic plan is the Research Committee report which gives more technical analysis of the needs and progress of the industry. As envisioned by the Legislature, the duel committees afford policymakers both a high level and a scientific resource to advance bioenergy in the state of Texas.

LEGISLATIVE DIRECTIVE 1: PROVIDE A VISION FOR UNIFYING THIS STATE'S AGRICULTURAL, ENERGY, AND RESEARCH STRENGTHS IN A SUCCESSFUL LAUNCH OF A CELLULOSIC BIOFUEL AND BIOENERGY INDUSTRY.

At the foundation of its vision, the Policy Council finds that state policies should be sustainable, equitable, and defensible. To ensure sustainability, the state should have the long-term goal of establishing a self-sufficient, market-driven, renewable energy industry where businesses willing to invest in this emerging industry can expect stability and certainty in government policy. To be equitable, government should not favor one technology over another without sound cost-benefit analysis, nor should it create unnecessary or unfair competition between existing industries and emerging ones. Finally, accountability to taxpayers can never be discounted, so state programs must show a measurable return on investment. A defensible bioenergy program will generate jobs, private investment or other benefits that return benefits to taxpayers and consumers.

In addition to these three priorities, government policies should coordinate Texas' agricultural, energy, and research strengths into a successful next-generation bioenergy industry by:

Maintaining the Balance between Food/Feed Security and Energy Security:
Government policies should take a measured approach to ensure that bioenergy feedstocks do not disrupt the use of food, feed, and fiber supplies. Existing state policy attempts to strike this balance by investing in research for new technologies, such as cellulosic ethanol conversion, and new feedstocks such as camelina, and algae, that minimize competition for existing feedstocks, arable land, and potable water while also valuing the benefit of renewable energy in the form of fuel tax exemptions, the renewable portfolio standard, and state purchasing guidelines.

Utilizing All Available Resources:
State bioenergy policy should seek to maximize growth opportunities with existing waste products that would carry a cost for disposal and would not otherwise be put to beneficial use. By prioritizing efforts to convert waste products into the production of power or heat, or biofuels, natural efficiencies may prove attractive based on economic and environmental considerations. Waste can come in the form of agricultural crop, logging, or livestock residue; but it also important to consider municipal solid waste and wastewater feedstocks. Traditionally non-agricultural areas like arid acreage, marginal land, or coastal areas should also be considered for the production of appropriate non-food bioenergy feedstock crops.

Supporting Collaboration and Partnership to Encourage Private Investment:
Policies should promote collaboration between existing, traditional energy providers and bioenergy stakeholders where possible. Within this partnership, the state and energy industry should collaborate to facilitate investment in capital infrastructure and avoid duplication of existing infrastructure while allowing for low cost borrowing to build needed infrastructure. Retention of the considerable investment in existing bioenergy resources already built in the state, such as biodiesel production facilities, should be considered.

Recognizing All Levels/Types of Bioenergy Production:
Texas should embrace policies that consider both macro solutions to the global need for energy and local solutions that involve smaller, localized bioenergy production. A policy that facilitates scaling up smaller industries should be pursued without harming existing bioenergy production facilities. Likewise, policies should be technology neutral and structured around outcomes, or production, goals rather than use of a

specific technology type – that is, the state should remain technology and feedstock neutral and avoid picking winners and losers.

Considering Resource Constraints, and Environmental and Economic Externalities:
Effective policy formulation and implementation must account for the physical limitations of the land, the logistical challenges of getting a product to market, potential limitations from federal policy, and other constraints. The Policy Council is a useful consultative resource for legislative and congressional staff and members, as well as regulatory entities, regarding constraints and ways to address them in bioenergy policies.

Accounting For Existing Infrastructure, Social and Economic Conditions:
State policy must also recognize that any new technologies and market-based products may compete with existing technologies, and consider the costs and benefits to the people of the state, as well as both the existing and emerging technologies and industries.

In the next biennium, the Policy Council proposes forming two subcommittees to consider and make recommendations on two important topic areas. The first subcommittee will examine regulatory roadblocks and incentives to the use and expansion of bioenergy and will assess the current framework for regulation of bioenergy crop production. The second subcommittee will pursue the creation of a research consortium to leverage state, university and private research and development resources in order to obtain federal grants and funding resources. Other issues to be explored over the next two years include:

- Providing guidance for the implementation of the Renewable Energy Credits program outlined in Chapter 39 of the Texas Utilities Code to ensure the definition of "renewable energy technology" does not unjustifiably exclude renewable technologies, for example biomass feedstocks;
- Validating the potential of implementing renewable energy adoption through government fleet or facility operations. Include in the review benefits to the state from any enabling private sector self-funding of research and development;
- Increasing awareness of existing resources, like the Texas Agricultural Finance Authority or the Texas Capital Fund, to facilitate bioenergy projects;
- Maintaining and promoting research initiatives as a key component of publicly-funded bioenergy research and development in Texas;
- Utilizing Policy Council expertise to assist state agencies and the legislature as a resource when those entities are proposing or considering regulations related to bioenergy production, or prior to the promulgation of rules;
- Working to ensure private sector research and development entities, that self-fund, are able to operate on a level playing field with university and government led programs and examining the extent to which existing regulation may be impeding their development;
- Developing a framework to further address future policy and environmental goals that can evaluate optimum use efficiencies for biomass based on the advantages and disadvantages of existing regulatory structures, emission targets, and technologic and economic capabilities.

LEGISLATIVE DIRECTIVE 2: FOSTER DEVELOPMENT OF CELLULOSIC-BASED AND BIO-BASED FUELS AND BUILD ON THE TEXAS EMERGING TECHNOLOGY FUND'S INVESTMENTS IN LEADING-EDGE ENERGY RESEARCH AND EFFORTS TO COMMERCIALIZE THE PRODUCTION OF BIOENERGY.

The Texas Emerging Technology Fund (ETF) infuses promising start-up companies and university-based research projects with the capital needed to rapidly advance their research. The fund was established under Chapter 490, Government Code, with the guiding principles of: developing and diversifying the Texas economy by expediting innovation and commercialization of research; attracting, creating, or expanding private sector entities that will promote a substantial increase in high-quality jobs; and increasing higher education applied technology research capabilities.

The fund has made several awards to advance the research and development of bioenergy and biofuels. Below are descriptions of the projects and funding awarded by the ETF:

Commercialization Investments

Sunrise Ridge Algae, Inc. is a private Texas corporation engaged in research, development and commercialization of algae biomass technology for reduction of water and greenhouse gas pollutants and production of renewable fuel feedstocks and animal feeds. Targeting large potential markets, including biodiesel and ethanol feed stocks, animal feed supplements, waste water cleanup (nitrogen, phosphorus) and greenhouse gas emission reduction, Sunrise Ridge Algae's strategy is to focus on production system scaling and cost issues while harnessing the superior productivity and yields of select algae strains. http://www.sunrise-ridge.com/

Photon8, Inc., whose primary mission is to develop a commercial algae growth and oil production process design tuned to the specific site resource conditions, area resource conditions, and partnerships available in the Rio Grande Region. http://www.photon8.com/Home.shtml

Research Grant Match

Texas A&M University Algae Biofuels Project
$4,025,000 ETF Grant
$8,995,297 in matching funds
Coalition partners include: General Atomics, U.S. Defense Advanced Research Projects Agency, U.S. Army, U.S. Air Force, National Alliance for Advanced Biofuels and Bio-Products, U.S. Department of Energy
The mission of the Texas A&M University Algae Biofuels project is to demonstrate the economical production of algae-derived transportation fuels and commercialize the technology in Texas. The Texas A&M/General Atomics partnership anticipates a phased research and development program leading to a demonstration system that scales promising systems to a pre-commercial size and the construction and operation of a commercial-size operation of 50-100 acres. Currently, efforts to evaluate and select an algal species with high oil producing capacity is ongoing at Lubbock and Galveston, Texas, and at General Atomics operations in San Diego, California. Development, testing and demonstration of advanced algae production systems are underway at the operations in Pecos, Texas.

The ETF provided resources for design and construction of the pilot plant facility including three algae test-beds, laboratories, and support systems to accomplish testing of production, research, and development. The infrastructure now in place and operating, has placed the Texas AgriLife Research algae biofuel and bio-product production facility in Pecos at the forefront of the industry on research related to large-scale algae production.

Research Superiority Acquisition of Talent Grant
Texas A&M University Bioenergy Alliance
$3,250,000 ETF Grant
$5,000,000 in industry matching funds
Texas A&M University was awarded an ETF grant to bring superior talent to Texas to accelerate research and development of preferred feedstock for lignocellulosic conversion and production of biofuels and related bioproducts, a cornerstone of the Texas A&M Agriculture & Engineering BioEnergy Alliance. This increased investment in research and development talent will lead to improvements and optimization of: a) sorghum (and other biomass) as a premier biofuels feedstock; and b) new biomass conversion technologies such as the MixAlco lignocellulosic conversion process. The addition of this talent will increase knowledge and expertise in these endeavors and will help catalyze the production of intellectual property. More information on this project can be found at *http://energyengineering.org/bioenergy*.

In the future, efforts can be made to foster these investments by:

- Utilizing Policy Council resources to evaluate the regulatory structures that limit or support innovation or capital investment in technologies produced by ETF funding;
- Supporting bioenergy projects in the ETF application process and serving as a liaison for applicants and the fund;
- Assisting with the coordination of various research and development funding opportunities to create a clearinghouse of information for potential applicants.

LEGISLATIVE DIRECTIVE 3: PURSUE THE CREATION OF A NEXT-GENERATION BIOFUELS ENERGY RESEARCH PROGRAM AT A UNIVERSITY IN THIS STATE.

The Policy Council finds value in pursuing a next-generation biofuel energy research program in the state. Texas is a leader energy development and biotechnology research and maintains the resources necessary to expand research in the bioenergy industry.

Three university systems, Texas A&M University System, The University of Texas System and Texas Tech University System, are represented on the Policy Council and Research Committee. Additional information about initiatives currently pursued by the three university systems is included in Section 11 of this report. It is also important to realize that research is ongoing in other universities, technical schools, community colleges and private institutions across the state. While specific details about these projects are beyond the scope of this report, many of the research efforts focus on the regional development of biofuels to address the wide variation in growing and climate conditions across the state and many are used not only to facilitate commercialization but also to train and provide experience to students.

Options to pursue a federal research facility will require collaboration of a cross section of stakeholders. Private sector research firms partnering with energy companies also have substantial research resources, both knowledge and funding, to add to the advancement of research and development.

The Policy Council plans to prioritize the challenge of linking research and industry interests to leverage federal, state, university and private research and development resources. Potential future activities include:

- Assisting in establishing research agreements between universities to facilitate information sharing and coordination of research goals;
- Assisting in transferring research to application in the private sector;
- Encouraging the research of feedstocks that meet the climatic conditions unique to Texas;
- Ensuring regulatory policies do not jeopardize the confidentiality of proprietary information or otherwise unnecessarily impede research efforts;
- Establishing a working group to organize private and public sector stakeholders to seek federal funding for a research institution;
- Encouraging partnerships to support technical training to fill workforce needs created by the renewable energy industry.

LEGISLATIVE DIRECTIVE 4: WORK TO PROCURE FEDERAL AND OTHER FUNDING TO AID THIS STATE IN BECOMING A BIOENERGY LEADER.

The federal government's emphasis on developing alternative energy through policies, like renewable energy standards, direct funding in research and development, tax credits and grant programs provide a worthwhile source of funding for fostering this industry. A list of federal programs can be found on Table 12.1 and will provide a foundation for future Policy Council consideration and action.

A variety of federal agencies are involved and have access to various forms of funding. The Policy Council has identified several ways to enable Texas companies to utilize these funding sources:

- Continuing to utilize the Texas Department of Agriculture's bioenergy website and outreach resources to increase public education efforts on federal programs;
- Coordinating support for application to federal programs;
- Continuing to examine federal incentive programs to ensure they are technology neutral and make comments when applicable.

LEGISLATIVE DIRECTIVE 5: STUDY THE FEASIBILITY AND ECONOMIC DEVELOPMENT EFFECT OF A BLENDING REQUIREMENT FOR BIODIESEL OR CELLULOSIC FUELS.

Determining the impacts of a state-based blending requirement for any biofuel, such as biodiesel or cellulosic fuels, is difficult without extensive scientific and economic analysis that measures the benefits of the new industries and its fuel, as well as the potential harms to existing industries. This analysis must include direct and indirect costs such as infrastructure changes, as well as behavioral changes. In the case of expanded use of ethanol beyond existing federal mandates, extensive cost analysis must be factored due to the enormous infrastructure needs that higher blends of ethanol require, ranging from transportation, fuel terminals, automotive fuel systems and impact to smaller non-automotive engines. Any potential mandate has significant impact on the economy and should be incremental and reversible if Texas-based production is unattainable or if it alters the market to the detriment of consumers.

TDA sought background research for this task to aid Policy Council members in their knowledge of national requirements, as well as efforts in other states. The findings are in Section 6 of the research committee report with the summary reprinted below:

> The demand for energy in the U.S. is projected to continue to increase. Similarly, the demand for biofuels within the United States is projected to continue as the nation looks to decrease its dependence on imported oil. Numerous states have passed biofuels legislation mandating differing blends of biofuels to increase a state’s economy and position in agriculture, fuels production, employment opportunities and the state’s GDP.
>
> During the compilation of this research, the U.S. Environmental Protection Agency granted a partial Clean Air Act waiver to the ethanol industry's request to allow the use of a higher blend of ethanol into gasoline. The EPA will allow E15 (a mixture of 85% gasoline and 15% ethanol) to be used in model-year 2007 or later cars and light-duty trucks.
>
> Until such time the benefits of a blending mandate, imposed beyond a federal mandate, can be demonstrated to outweigh the costs, market mechanisms such as fuel tax exemptions on the portion of renewable fuel blended into gasoline or diesel seem more appropriate ways to stimulate supply and demand. Further, the state should look at ways to promote existing infrastructure in meeting national requirements such as the Renewable Fuel Standard. Such efforts could include getting biodiesel blends more widely approved for pipeline distribution.

The Policy Council will continue to work towards:

- Investigating further ways to ensure continued use of Texas-based supply to meet national and international demand for biofuels; and
- Reviewing federal policies like pipeline regulation, export restrictions, and production incentives in order to assess the needs of existing infrastructure and industries in Texas.

LEGISLATIVE DIRECTIVE 6: PURSUE THE DEVELOPMENT AND USE OF THERMOCHEMICAL PROCESS TECHNOLOGIES TO PRODUCE ALTERNATIVE CHEMICAL FEEDSTOCKS.

In an effort to more closely define the technology and potential of thermochemical process technologies, the Policy Council has further defined this task area to read: Pursue the development and use of advanced conversion processes including thermochemical and sugar-based process technologies to produce drop-in fuels and alternative chemical feedstocks.

The Research Committee developed background information on this charge, as they were tasked with the similar research task. Below is a summary of Section 7 of the research report:

> The production of energy, fuels, and chemicals from low cost and renewable feedstocks has gained attention in the past decade with thermochemical and sugar-base conversion technologies benefitting from reductions in overall production costs and an increase in commercial viability. Similar to a petroleum refinery, much of the feedstock in this process is consumed in the production of commodity-scale fuels, while bio-based chemicals and materials make up a smaller, but higher-valued product stream.
>
> Current R&D efforts and activities are focused on developing an understanding of the gasification processes and their chemistries for woody biomass feedstocks, low-quality agricultural residues, and lignin-rich biorefinery residues.
>
> In addition, pyrolysis of similar feedstocks is being pursued. The activities in this process include basic studies of catalytic and chemical mechanisms for improving quality and yields of bio-oil catalysis for stabilizing the intermediate and catalytic upgrading of bio-oil to biofuel blending stocks. National laboratories, industry, and universities perform this core research, which addresses many of the technical barriers that must be overcome for research and development to proceed to the next level.

The Policy Council recognizes both of these processes need further research to attain widespread commercial application and will pursue their development through technology developments. The Policy Council also recognizes that such direct conversion processes also necessitate consideration of the most attractive environmental and economic solution, and thus need to consider the direct use of biomass for power and heat, in addition to thermochemical upgrading routes to liquid fuels. Exploration and production of unconventional natural gas and oil reservoirs has substantially increased our domestic energy resources, lowering the price of natural gas. Supplies are predicted to be substantial for years to come, given this, any alternative bioenergy process needs to be cost effective with regard to pricing realities of existing domestic fuel sources.

LEGISLATIVE DIRECTIVE 7: STUDY THE FEASIBILITY AND ECONOMIC DEVELOPMENT OF THE REQUIREMENTS FOR PIPELINE-QUALITY, RENEWABLE NATURAL GAS.

Renewable natural gas has been the focus of several bioenergy ventures in the state. To date, animal wastes have seemed to be the feedstock most often utilized but other ventures in biogas production involve anaerobic digestion or thermal gasification of crop residues, wood waste and municipal solid waste.

Through its research, the Policy Council has identified several factors that influence production of this resource. First, the state's renewable portfolio standard considers biogas electricity generation as renewable and eligible for renewable electricity credits. Additionally, renewable natural gas offers the opportunity to expand the use of renewable resources as transportation fuels as an additional supply source for compressed natural gas. Finally, renewable natural gas produced from agricultural waste products creates an incentive for farmers and ranchers who otherwise would face disposal costs.

Additional efforts to assist in the development of pipeline-quality, renewable nautral gas include:

- Working with the policy makers to ensure renewable natural gas can be considered in renewable energy goals set by the state through the renewable portfolio standard;
- Utilizing the resoucres of the Texas Railroad Commission and the Texas Commission on Environmental Quality to identify opportunities for using renewable natural gas as an alternative or supplement to existing transportation fuels;
- Encouraging state policies that recognize "waste heat" from chemical manufacturing processes as a hybrid renewable energy source, if generated from natural gas, and a true renewable energy source, if generated from renewable natural gas;
- Encouraging federal policies to recognize renewable natural gas as a renewable energy source.

TEXAS BIOENERGY RESEARCH COMMITTEE REPORT TO THE LEGISLATURE

Bioenergy is not an energy source in transition, as it is often portrayed, but a resource that is becoming increasingly important as a modern energy choice. Today, bioenergy continues to be the main source of energy in many developing countries, particularly in its traditional forms, providing on average 35 percent of the energy needs of three-quarters of the world's population. This rises to between 60 and 90 percent in the poorest developing countries where buring wood or dung is commonplace. However, modern bioenergy applications are increasing rapidly both in the industrial and developing countries, so that they now account for 20–25 percent of total biomass energy use.

In fact, because of the almost universal, multipurpose dependence on biomass, it is important to understand the interrelations between bioenergy uses, and to determine the possibilities for more efficient production and wider uses in the future. The success of any new form of bioenergy will most probably depend upon the use of reasonably advanced technology. Indeed, if bioenergy is to have a long-term future, it must be able to provide what people want: affordable, clean, and efficient products such as electricity, liquid and gaseous fuels, chemicals including alternative chemical feedstocks, and value-added materials. This also entails direct competition with other energy and product sources.

There are large variations between the many attempts to quantify the potential for bioenergy. This is due to the complex nature of biomass production and use, including such factors as the difficulties in estimating resource availability, long-term sustainable productivity and the economics of production and use, given the large range of conversion technologies, as well as ecological, social, cultural and environmental considerations. Estimating bioenergy use is also problematic due to the range of bioenergy end-uses and supply chains and the competing uses of biomass resources. There is also considerable uncertainty surrounding estimates of the potential role of energy crops, because the traditional sources of biomass they could replace, such as residues from agriculture, forestry and other sources have a much lower and varied energy value. Furthermore, the availability of biomass varies greatly according to the level of socio-economic development and production capacity. All these factors make it very difficult to extrapolate bioenergy potential, particularly at a global scale or even a statewide scale.

Despite the overriding importance of bioenergy, its role is still not fully recognized. There is surprisingly little reliable and detailed information on the production, consumption, and supply of biomass in many countries. This serious lack of information is preventing policy makers and planners from formulating satisfactory sustainable bioenergy policies. Programs to tackle this breakdown in the biomass system will require detailed information on the production, consumption, and supply of biomass in order to plan for future. Clearly, standardized comparisons are required to assess bioenergy in relation to other sources of energy.

As one of the nation's leading agricultural states, Texas is a major producer of a number of biomass biomass resources. The variety of plants, animals, crop residues, and other sources that fall under biomass feedstock is difficult to recount in a short space, but in general, these feedstocks will remain important biomass energy sources, with those that currently present a disposal problem having the greatest near-term potential. This includes manure, crop, mill and logging waste. Dedicated energy crops are available now and will make longer-term contributions to the energy sector once conversion technologies are on line and can help farmers and rural communities establish new markets for their products. Prime agricultural areas include regions along the Gulf Coast and Interior Coastal Plains, the

Blackland region, the High Plains, and the Rio Grande Valley. Also, if efficient harvest systems can be developed, the brush country west of I-35 has significant potential to add to the woody biomass feedstock available from the Pineywoods and Post Oak regions. The state's very large urban base can also contribute substantial amounts of biomass-derived wastes from lawn clippings to wood waste.

Overall, this study provides an overview of the biomass potential in Texas. The study examines the classification and role of biomass sources, their potential, the classification of biomass conversion technologies and products, and finally other details such as barriers, policies, and funding opportunities for the use of biomass energy in Texas.

Given a focused scope, the first step in this study was to involve a screening process to select an initial set for biomass and bioenergy analysis. Representatives of the project team from Tetra Tech NUS, Inc. NEAtech, LLC, and Texas AgriLife Research applied criteria to conduct the screening. These criteria included the following factors related to biomass feedstocks and bioenergy potential in the State of Texas:

- Potential biomass and biomass-derived feedstocks
- Current bioenergy and biofuel policy
- Current biomass and biofuel conversion technologies
- Strategies for federal and other funding opportunities

The overall study scope in this report is organized and discussed in the following Legislatively defined tasks and subsequently comprised the following twelve sections:

- Identify and research appropriate and desirable biomass feedstocks for each geographic region in the state of Texas;
- Investigate logistical challenges to the planting, harvesting, and transporting of large volumes of biomass and provide recommendations to the Policy Council that will aid in overcoming barriers to the transportation, distribution, and marketing of bioenergy;
- Identify strategies for and obstacles to the potential transition of the agriculture industry in western regions of Texas to dry land bioenergy crops that are not dependent on groundwater resources;
- Explore regions of this state, including coastal areas, that may contain available marginal land for use in growing bioenergy feedstocks;
- Study the potential for producing oil from algae;
- Study the potential for developing a blending requirement for biodiesel or cellulosic fuels;
- Study the potential for the advancement of thermochemical process technologies to produce alternative chemical feedstocks;
- Study the potential for producing pipeline-quality natural gas from renewable sources;
- Investigate federal bioenergy policy and study federal regulatory developments;
- Study the potential for genomics-based research;
- Identify strategies for a next-generation biofuels energy research program; and
- Identify strategies for federal and other funding opportunities for the State of Texas in becoming an industry leader.

1.0 INITIAL FEEDSTOCK ASSESSMENT

The intent of this section is to identify potential feedstocks and the average crop yield per acre, quantities of byproducts currently available, type of bioenergy produced (biofuel, biogas, etc.), and the approximate geographic growing region of Texas for each crop or any other feedstock with growing potential in Texas. Factors such as water needs, fuel balance and/or sustainability claims, and efficiency reports for each feedstock and its bioenergy product were included where possible and available.

Bioenergy, biofuel, or biomass feedstocks are comprised of biological based materials grown, produced, or are a by-product of extant agricultural or forestry operations. In the context of this report these include agricultural based products including crops, agricultural waste products, and co-products. The intent of this section is to identify and summarize the feedstock that can produce sustainable bioenergy, biofuel, and/or biomass in the State of Texas.

For this report, sustainable bioenergy feedstock, especially crops grown specifically as primary cellulosic bioenergy feedstocks (i.e. not agricultural waste and co-products), is defined as having to simultaneously satisfy several basic guiding principles:

Minimize direct competition for land presently growing food and fiber crops;
Minimize inputs (e.g. irrigation, fertilizers, herbicides/pesticides, energy, water, etc) needed to produce beyond natural conditions or basic agronomic practices;
Provide a sufficient supply of feedstock, available at an economical price.

These guiding principles were used to identify the feedstock that is most likely to support a robust Texas bioenergy industry that expands, rather than competes with, current agricultural and forestry production. An example of how these principles were used in general terms is included here. Almost any crop in the world can be grown anywhere in Texas if sufficient investments are made to create a controlled growing environment with irrigation systems, infrastructure and inputs. While productive, the required investments would make the resulting bioenergy too costly for the general market to purchase and consume it.

Adaptation and average crop yield of each bioenergy source in Texas will vary with combinations of latitude and longitude and climatic variability. Latitude loosely dictates temperatures, year-long averages ranging from 68-75 ºF from southeastern Texas moving in a general northwesterly gradient to 49-55 ºF in the extreme northwest corner of Texas. More important than the year-long averages are the extremes, especially low winter temperatures that kill most true tropical plants and top-kill many sub-tropical plants in Texas. Extreme warm summer temperatures in Texas have an effect on bioenergy crop adaptation in the state mostly because they combine with very low average precipitation during the warmest months of July, August, and September. Even irrigation cannot keep up with the resulting evapotranspiration so that annual crops need to be harvested before this annual drought and perennial crops basically cease to grow until temperatures cool and rainfall returns in early autumn. What further complicates the temperature picture is that not only do extremes vary from year-to-year but the timing of their occurrence (e.g. first or last frost date) will also vary from year-to-year. Figures 1.1 and 1.2 (Appendix C) illustrate how temperature and rainfall, respectively, will influence crop planning.

Rainfall patterns also affect bioenergy crop adaptation and production potential. Texas essentially has a bimodal rainfall pattern, with most precipitation falling in the spring (March-May) and autumn (September-November) months. If the natural growth pattern of potential crops does not fit these patterns, they were not considered in this report. In addition, average rainfall amounts within Texas follow a very distinctive longitudinal pattern, from 60-62" rain in the east to 9" or less in the extreme west (Figure 1.2). This is a huge variation in a very short distance, especially considering that altitude is only minimally involved. If we consider that at 33º N the state is approximately 550 miles across, that means that rainfall decreases from east to west, on average, nearly 1" for every 10 miles.

Finding the best location to grow with regions of adaptation along a north-south temperature gradient crossed by an east-west rainfall gradient provides both challenge and opportunity for cellulosic bioenergy production in Texas. Some crops evaluated will simply not grow in Texas and, if they do grow, will do so only in acreage where they would be in direct competition with existing food, lumber, and fiber crops or are not sustainable over the long-run in Texas. There are other crops, including but not limited to herbaceous and arboreal leguminous species, bermudagrass, native prairie grasses, peanut stover, and rice straw, that have potential cultivation for recruitment to cellulosic and biodiesel bioenergy cropping. All of the species and their characteristics evaluated were tabulated in Appendix B. The characteristics tabulated in combination with the following text provide some description on their suitability as a sustainable feedstock. Those that are favorable to Texas are summarized in Table 1.1.

Such an endeavor is fraught with scientific concerns based upon the need for broad strokes when defining adaptability or availability of bioenergy resources. When interpreting the tables and approximate georaphic region, it is strongly recommended that the reader keep in mind that micro-conditions on the ground make broad generalizations dangerous. For example, soil textures, pH, inherent fertility, topography, and historical use (or abuse) all contribute to determining whether individual crops will grow and where. Geographic region references are based off of USDA's Texas Agricultural Statistics Districts, of which TDA is a contributor. A link to their map, along with regions listed and their description can be found at: http://www.nass.usda.gov/Statistics_by_State/Texas/Charts_&_Maps/distmap2.htm and is included in Appendix A. In some cases simply crossing a fence will change production feasibility, not to mention one end of a county to the other. So as investments are made in bioenergy research, infrastructure, and incentives, on-the-ground verification of broad adaptation will be necessary on every ranch, farm, dairy, or feedlot.

1.1 Identify Average Crop Yield Per Acre

Crop yields per acre are reported in Appendix B and Table 1.1 along with other agronomically or biologically important factors for each potential bioenergy source. Yield ranges, rather than a single average, are reported when possible because the climate and soil variability within Texas preclude a single average (see discussion above). These averages will be for DRYLAND cultivation, as the legislature indicated an interest in crops that would require minimal input, but note that irrigated cultivation yields are presumed higher and may ultimately be necessary for stable crop production. In all cases, future advances in plant biology, agronomy, or other factors undertaken by farmers and researchers will lead to increases in production.

1.2 Type of Bioenergy Source

1.2.1 Cellulosic Biomass

1.2.1.1 Annual Grasses

Daylight Sensitive Energy Sorghum: Most of Texas has the potential for viable yields of daylight sensitive energy sorghum excluding the majority of the Trans-Pecos region. These are annual sorghums and their hybrids that only flower once daylight hours are less than 12-13 hours, depending on the species or ecotype. Their advantage is that, by the time they are planted and growing during early summer, they are genetically set to grow throughout the Texas summer season without flowering. High biomass yields therefore accumulate and can be harvested at a single cutting (more economical than multiple harvests) in the autumn or as standing biomass after frost/freezing. This genetic material has been available to agronomists and plant breeders for centuries from tropical Africa where daylight variation throughout the year is minimal near the equator. Sorghums are generally drought tolerant throughout the state but rely on fertilizers (mostly nitrogen) and adequate soil moisture to obtain maximum production potential. This crop would be produced on prime agricultural land in rotation with other crops with comparable inputs (fertilizer and cultivation; irrigation and herbicides to maximize yields). However, it is highly productive (10-15 dry tons per acre), more water efficient than the other energy crops, and ratoons (regrows after the first cutting). Another advantage is that, as a seed-planted annual, it can be established quickly and can occupy only 4-5 months in crop cycles.

Energy Cane: The production region in Texas for energy cane is largely confined to the coastal regions of the state which includes the Lower Valley, South Texas, Coastal Bend, parts of South Central, the Upper Coast, and South East Texas regions. This is a hybrid between domestic sugar cane varieties and cold tolerant varieties from Asia. Energy cane has a lower sugar concentration than sugar cane, but is more cold-tolerant so it can be grown further north than the typical sugar cane region. It is vegetatively propagated with similar traits to sugar cane. Scientists with the Agricultural Research Service (ARS) anticipate that the stand life is 7 to 8 years, but more time is needed for data collection. If annual establishment is required where low winter temperatures limit perenniation, then the expense of planting might limit the use of energy cane.

Giant Reed: Considered noxious by TDA, a permit is required to sell, distribute or import this species into the state. Its common growing region in Texas is the eastern half of the state though giant reed can be found along most waterways not controlling for this invasive. Giant reed is a perennial, rhizomatious (produces new plants from roots) grass native to the Mediterranean region adapted to warm, dry climates. Because it is considered a noxious weed, supporting its propagation as a bioenergy crop, in its current form, would not be conducive to efforts to protect existing cropland and native species. The prevalence of this species to invade waterways makes it a good candidate for bioenergy harvesting efforts tied to brush remediation. It is a C_3 grass so it will not be as productive in warm climates as equivalent C_4 grasses but grows in southern, especially southeastern, regions of Texas where poorly drained soils preclude growth of other species.

Miscanthus: The production region in Texas that has the potential for viable yields with the least input the Blacklands, South Central, the Upper Coast, South East Texas, and North East Texas regions. The potential for using miscanthus in Texas has not been fully explored. In a few trials in southern Texas it has done well on fertile soils but other grasses, such as switchgrass, out-produce it and persist longer. Even though it is a C_4 grass, it appears to be poorly adapted to warmer climates although lack of adequate moisture and soil fertility are likely as limiting in Texas as any other factor. Additionally, the fact that it is an infertile hybrid that must be propagated vegetatively (no viable seed so new plants come from root cuttings) further limits its potential due to high establishment costs.

Sweet Sorghum: Most of Texas has the potential for viable yields of sweet sorghum excluding the majority of the Trans-Pecos region. Sweet sorghum has been selected for its high concentration of sugars found in the pith of the stalk, so it is a potential source of ethanol and sugar-based Generation III fuels and can replace sugarcane in regions with regular winter frosts. In North America it is mostly used as a human food, usually syrups. In Texas it grows mostly as an annual because of freeze susceptibility, so it requires a yearly investment in cultivation, weed control and seed/fertilizer/pesticide purchase. Although up to four times more water efficient than sugarcane, it requires more soil moisture than cellulosic bioenergy sorghum varieties. It is also nutrient demanding, especially nitrogen, compared to closely related grain or cellulosic sorghum varieties. Advantages include a wide range of pH tolerances (5.0-8.5 although 5.8 is advised as minimum) and adaptability to saline soils. Besides the ethanol, cellulosic material left after sugar removal is a potential secondary bioenergy resource. This bagasse is a good candidate for cellulosic bioenergy feedstock and can contribute over 10 dry tons/acre/year in wetter, warmer (or irrigated) portions of Texas. This is a crop that would be produced on prime agricultural land in rotation with other crops with comparable inputs (fertilizer and cultivation; irrigation and herbicides to maximize yields). However, it is highly productive, more water efficient than the other sugar crops, ratoons (regrows after the first cutting), and can produce from 200-400 gallons of ethanol per acre in southern and eastern Texas. Another advantage is that, as a seed-planted annual, it can be established quickly and can occupy only 4-5 months in crop cycles.

1.2.1.2 Perennial Grasses

Bahiagrass: The production region in Texas that has the potential for viable yields with the least input is along the coastal regions extending into east Texas. Bahiagrass is utilized as a pasture and lawn grass in the southeastern United States. It is naturalized in east Texas where precipitation is greater than 29 inches (”) per year, and soil is sandy and acidic. When cut at no lower than 2” stubble height it can tolerate frequent cutting, and is a high producing species. The fertility requirement is less than that of bermudagrass, and the crude protein concentration is also lower, which is desirable for some bioenergy feedstock purposes. It is a seeded, perennial crop, and, whereas most cultivars take one season to establish, a rapidly establishing cultivar was released recently (‘TifQuik’). Bahiagrass develops a thick sod, which aids in its persistence; however, the stolons are very close to the ground compared to bermudagrass. Therefore, inclusion of legumes to provide part of the nitrogen fertilizer requirement can be more easily managed with bahiagrass than with bermudagrass. It has potential for multiple-uses and, as a common hay crop; equipment is readily available for harvest, baling, transport, and storage. Bahiagrass is invasive and has no value for wildlife; therefore, location of planting should be considered carefully.

Bermudagrass: The production region that has the potential for viable yields with the least input is the majority of the state excluding the Northern and Southern High Plains and the Trans-Pecos regions. Bermudagrass may be the herbaceous species most overlooked among all potential cellulosic bioenergy feedstock species, because improved cultivars such as ‘Coastal’ and ‘Tifton 85’ are currently used extensively as forage for cattle and horses. Managed to maximize cellulosic bioenergy feedstock under low-input conditions, however, its yields are at least 40% greater than when managed as a forage crop where animal nutritive value dictates harvest of more tender material. Potential as a multiple-use crop is good, namely as forage in the spring or in dry years as opposed to accumulated cellulosic bioenergy feedstock in high rainfall years. Perennial growth that makes year-to-year costs low, once-a-year harvests that decrease harvest costs, and versatility combine to make it an excellent “opportunistic” cellulosic bioenergy feedstock. For example, during high rainfall years when hay cutting is interdicted by muddy conditions or excessive hay production lowers market prices, its sale as alternative cellulosic bioenergy could benefit producers. However, because it is not native, can become an aggressive invasive, has basically no wildlife value, and requires fertilizer inputs for stand survival and minimal production, it may not be an ideal cellulosic bioenergy feedstock for every situation.

Switchgrass: Most of the state, excluding the Trans-Pecos region, has the potential for viable switchgrass production. Switchgrass has public appeal as a cellulosic bioenergy feedstock for several reasons. The first is that it is widely adapted, both in terms of soils as well as climates, with native ecotypes found from the Red River down to the coastal plains. Second, once established, its perennial growth fosters long-term persistence, even through drought years and in infertile soils. Finally, it has been widely studied and more is known about its specific adaptations as well as its limitations in Texas than any other cellulosic bioenergy feedstock. It is not, however, a panacea for all of Texas' bioenergy needs. It has the potential to displace food and fiber crops as well as hay because it naturally prefers fertile soils in areas with greater moisture. Secondly, it requires some nitrogen fertilizer to maintain reasonable growth, which currently entails use of fossil fuel-derived nitrogen; alternative sources of nitrogen, such as legumes or poultry, dairy and feedlot manure, can be harnessed if acceptable yield levels are to be sustained. Research is currently ongoing to address weak seedling vigor of currently available cultivars because this often contributes to establishment failures, especially in marginal soils.

Other Perennial Native Bunchgrasses: Native perennial bunchgrasses such as big bluestem, indiangrass, little bluestem, and old world bluestems have excellent cellulosic bioenergy feedstock potential on less fertile, well drained soils where switchgrass is difficult to establish and does not do well in drought years. They generally do well in more neutral pH soils and require some rainfall, so north-central Texas is where they would be most promising. Yields will likely never be high so they may be harvested more sustainably in multiple-use systems that include rangeland cattle, wildlife, tourism, or carbon-sequestration land use rather than in exclusively cellulosic bioenergy feedstock monocultures. Because of diffuse production (low yields), they are ill suited to supplying large bioenergy conversion platforms but will work well with small-scale or mobile units once these are on the market.

1.2.1.3 Other

Atriplex: The production region in Texas that has the potential for viable yields with the least input is the southern and coastal regions of the state including the South Texas, Lower Valley, Coastal Bend, and the Upper Coast regions. *Atriplex* spp. include a wide array of species, many of which are halophytes or tolerant of saline (high-salt) soils. Old man saltbush (*A. nummularia*), of semi-arid Australian origin, is the best known because of its widespread cultivation as a deep-rooted perennial forage. There are many other species within this genus that could be useful as well. Its use as a cellulosic bioenergy crop has not yet been tested but, because of its productivity as forage, it has some potential. The primary assets of this species to Texas include: 1) low rainfall requirement, 2) high soil pH tolerance and, 3) freeze resistance down to 20° F for short periods. Its drawbacks include lack of adaptation to long periods of freezing and high salt content of harvested material. As such, it is more likely adapted to warmer climates of southern Texas and less likely useful in the high-pH soils of the panhandle.

Kenaf: The majority of Texas, excluding the Trans-Pecos region, has the potential for viable yields with the least inputs required for production. Kenaf (*Hibiscus cannabinus*) is an annual broadleaf fiber or forage crop that has been tested in Texas. It is both frost and daylight sensitive (12.5 hrs) so must be planted after and harvested before days become short or frost occurs. Varieties that do not flower in Texas are available, making it an unlikely candidate for invasiveness but also allowing for single, season-end harvests. It requires some nitrogen (it is not a legume) and a minimum rainfall of 20" so it cannot be grown as a dry land crop every year in much of western Texas and may not do well in acidic soils of east Texas. Its moderate drought tolerance is an advantage since it is able to shut down growth without much leaf loss during long periods when soil moisture becomes too low to sustain production. It has been widely tested throughout central Texas from south to north, with dry land yields of up to 6,000 lbs/year and much greater under irrigation.

Herbaceous Legumes: There are both native and introduced legumes that will grow wherever native and introduced grasses will grow. These include winter-growing annuals as well as summer-growing annuals or perennials. Legumes have one important advantage over grasses when it comes to sustainable cellulosic bioenergy feedstock: they can provide their own nitrogen and therefore do not require extensive fertilizer inputs. Being C_3 plants, however, they are not as productive as most native or introduced Texas grasses. Although there may be some that can be harvested directly as cellulosic bioenergy feedstock, their role in sustainable, low-input efficient bioenergy systems will likely be as nitrogen providers to grasses. This occurs as leaves drop and decompose on the soil surface as well as when roots and nodules slough off in the soil. The challenge of inter-seeding legumes into grasses is to avoid competition among them such that the combination becomes beneficial to the whole system. This can be done either by planting/growing the legumes at different times from those when grass is actively growing (for example clovers in winter-dormant switchgrass) or spatially separate such as in micro-environments the grass has not occupied (for example between clumps of switchgrass).

1.2.2 Woody Biomass

Woody biomass is a tremendous energy resource for the state of Texas as documented by Texas Forest Service and TDA-sponsored "*Estimation of Woody Biomass Availability for Energy in Texas, December 2008"* as well as Chapter 15 of Texas Comptroller's "*Energy Report 2008"*. In the broadest sense, woody biomass is the total mass of roots, stem, limbs, tops, and leaves of all trees and shrubs (live and dead) in the forest, woodland, or rangeland environment. In practice, woody biomass generally refers to woody material that historically has a low value and is not suitable for traditional higher value forest products such as lumber, plywood, paper and pulp, furnitures and other wood products. There are several major sources of woody biomass in Texas, including logging residue from conventional thinning and final harvesting, mill residue generated at primary wood-using mills, wood waste from precommercial thinning (non-merchantable trees less than 5 inches in diameter at breast height) and timber stand improvement, wood waste from brush control in pastures and rangeland, urban wood waste, and short rotation woody crops such as eucalyptus for energy.

It should be noted that the feasibility of using woody biomass to produce bioenergy depends largely on the economic availability of woody biomass resources, rather than just the physical availability. Assessing the economic availability of woody biomass takes into account the physical availability of each type of woody biomass resource in the region, varying procurement costs for different types of woody biomass, costs of producing woody biomass materials into desirable forms, and transportation cost.

Below is a list of individual species considered for woody biomass harvesting and propagation.

Cedar (Juniper): Ashe juniper (*Juniperus ashei*) is a native tree/shrub to Texas and can be found in much of west and central Texas. The total amount of biomass on forestlands is a good starting point for understanding the amount of the resource. However, the amount actually available is more difficult to estimate, as it depends on a variety of factors including: ownership, management objectives, age, condition, accessibility, proximity to markets, policies, and economic conditions. According to the USDA Forest Service 2007 Forest Inventory and Anaysis (FIA), there is an estimated 54.4 million tons (oven-dry) of aboveground biomass of live Ashe juniper trees and saplings on forestlands in Texas. Ashe juniper usually grows in association with mesquite, although its geographic range of prevalence is more limited (Central Texas) than mesquite. It competes with mesquite only in thin, well-drained, alkaline, and infertile soils. The overwhelming majority, 93.1 percent, of Ashe juniper biomass is located on private lands. In a survey of Central Texas ranchers conducted to determine woody biomass volumes in compliance with the 80th Legislature's HB 1090, Ashe juniper ranked near the bottom in terms of desirability. A high proportion of respondents (69 percent) reported some brush control operation in the preceding five years. The most common reasons for brush removal were for better grass production for livestock and control of further brush expansion. High cost was the reason most often cited for not conducting brush control (*Source: Xu, W., Li, Y., and Carraway, A.B. 2008, Texas Forest Service*). Its area of adaptation is limited by colder temperatures to the north and low precipitation to the west, and like mesquite, it cannot compete with tall forest species in high rainfall, low pH soils of East Texas. Harvest patterns will likely be similar to mesquite: cutting every 8-15 years, with biomass accumulation accelerating as the individual shrubs/trees mature. Surprisingly little is known, however, about its productivity (biomass yield per acre per year) since most agricultural efforts have focused on eradication or aromatic oil extraction. Research is needed to determine yields and sustainable production since it does not resprout after cutting and stands must regenerate from seedlings. Redberry juniper (*J. pinchotii*) is another native juniper often found in close association with ashe juniper Redberry does regenerate from stumps but tends to be smaller and multi-stemmed (and possibly more difficult to harvest) compared to ashe juniper.

Eucalyptus: Eucalyptus has the potential to produce not only cellulosic bioenergy feedstock but oils for potential biodiesel or ethanol production. However, as a group (there are over 700 eucalypts originating in Australia), they appear to be poorly adapted to Texas conditions, preferring climates devoid of freezing winter temperatures. The development of a frost tolerance hybrid *E. grandis* X *E. urophylla* opens the door for exploring the use of eucalyptus in Texas. However, until it has been tested in Texas soils and climates, the potential for sustainable cellulosic bioenergy feedstock from this hybrid is basically unknown. Further research is needed on this hybrid.

Hybrid Poplar: Hybrid poplar is a rapidly growing tree with high yield potential; however, it is not adapted to even short durations of high temperature. It is therefore not currently adapted to Texas. There are species of poplar adapted to Texas (Cottonwood). However, because of the moisture and nutrient requirements of these species, they are typically limited to riparian areas thus reducing the feasibility of large-scale production without irrigation infrastructure. Short rotation woody crops, like hybrid poplar, are receiving considerable attention as potential biomass resources and their further development could lead to viability in the Texas climate.

Mesquite: Mesquite can be found in most areas of Texas, excluding parts of the North and South East Texas, and Upper Coast regions. Like Ashe juniper, honey mesquite is not a desirable species throughout Central and West Texas and given the right economics, ranchers could be expected to harvest significant amounts in order to improve conditions for livestock production. In association with juniper (cedar), it will generally dominate more fertile, moist soils. According to the 2007 Forest Inventory and Anaysis (FIA), there is an estimated 115.8 million tons (oven-dry) of aboveground biomass in live honey mesquite trees and saplings on forestlands in Texas. Honey mesquite accounts for 13.5 percent of the total aboveground biomass on forestlands in Texas, second only to loblolly pine. Approximately 96.5 percent of honey mesquite biomass is on private lands. It does not compete well with tall forests and acidic soils of eastern Texas but appears to have no natural enemies other than fire to the west. Although of minimal forage value, it can be an important wildlife food source (seed pods) as well as protective habitat. Most research has focused on its eradication which has met with limited success—it is very persistent from both regrowth and seed propagation, especially since it is a legume and fixes its own nitrogen. Its productivity per tree, however, is slow: twelve-year old regrowth mesquite in north-central Texas (26” annual rainfall) averaged 291 lbs of total biomass, a 12 lb dry matter/year accumulation. If an acre has 600 trees, however, mean average production of mesquite can total approximately 7,200 lb/year if completely cleared from the land, likely much lower as production moves west. A typical harvest cycle basis, to maintain annual availability of this feedstock, would yield less. On average, the yield would be attractive with so few inputs in drier regions; besides the woody material, the undergrowth (mixed native prairies) could also be harvested for cellulosic bioenergy feedstock on an annual basis, making this system even more attractive. Harvest equipment for smaller mesquite already exists on the market. Once again, however, such a diffuse cellulosic bioenergy feedstock production rate can create a sustainable bioenergy system only if 1) mobile conversion units are developed or 2) small-scale individual landowner units are eventually marketed. Harvest management research of this species is lacking and needed for the commercial use of this feedstock.

Pine/Mixed Hardwood in East Texas: The North and South East Texas, and Upper Coast regions of Texas have abundant and established pine and mixed hardwood forests. Biomass derived from pine and mixed hardwood is found mostly in East Texas where soil (lower pH) and rainfall (greater than 36") combine to make this a viable industry. Because timber is the primary product and will most likely out-price cellulosic bioenergy feedstock in the near future, major sources of woody biomass for energy in the region will come from logging residue, mill residue, and wood waste from pre-commercial thinning (non-merchantable trees less than 5 inches in diameter at breast height) (non-merchantable trees less than 5 inches in diameter at breast height) and timber stand improvement.

Lumber and paper mill companies have commonly used mill residue for steam and electrical power at their facilities but advances in technologies could yield fuel as well from this feedstock. Logging residue, or what is at the logging site, is potentially available for energy includes tops, limbs, and unutilized cull trees. Stumps are not included since the cost of obtaining stump biomass is prohibitively high. Texas Forest Service estimated that there was around 1.0 million dry tons of logging residue in East Texas potentially available for energy in 2009, 66 percent from softwood (like pine) and 34 percent from mixed hardwood. Availability of logging residue is highly related to mill production, which may be affected by a variety of economic and market factors. Most of the logging residue has not been marketed for competing uses and is left unused at the logging sites. Mill residue includes chips, sawdust, shavings, and bark. There was a total of 2.8 million dry tons of mill residue produced in East Texas in 2009, 85 percent from softwood and 15 percent from hardwood (*Source: Li, Y., Carraway, A.B., and VanderSchaaf, C.L. 2010, Texas Forest Service*). Currently, nearly all of the East Texas mill residue has already been marketed and utilized for pulping, fuel, landscaping, or other higher value-added products (e.g. particleboard).

Another potentially significant source of woody biomass for energy in East Texas is wood waste from pre-commercial thinning (non-merchantable trees less than 5 inches in diameter at breast height) and timber stand improvement. Pre-commercial thinning removes excess sapling-sized trees to improve growing conditions for the remaining trees. Timber stand improvement removes poorly formed, diseased, dying or cull trees to improve the composition, structure, condition, health and productivity of forest stands. Pre-commercial thinning and timber stand improvement are usually expenses for landowners and do not provide income to cover the costs of the operations. Potential wood waste from pre-commercial thinning (non-merchantable trees less than 5 inches in diameter at breast height) and timber stand improvement is estimated to be 2.8 million dry tons annually in East Texas (*Source: Xu, W., Li, Y., and Carraway, A.B. 2008, Texas Forest Service*). This tremendous resource of woody biomass, in addition to its value as an agricultural commodity, plays a significant role in powering mill operations and two or potentially more biomass power stations in the East Texas region.

Urban Wood Waste: Urban wood waste generally refers to wood contained in municipal solid waste including yard trimmings, and construction, renovation, and demolition wood wastes. Urban wood waste could be a significant source of woody biomass in Texas. However, research on overall characterization, current utilization, potential difficulties with co-mingling fuel sources, and availability of urban wood waste in Texas is lacking.

1.2.3 Oil crops

Algae: Algae production is limited only by its input needs. Viable production areas include near brackish, coastal and wastewater areas. Microalgae are very promising for oil production because its production does not need to compete with arable land or with fresh water consumption if salt-water algal species are grown. The coastal region of Texas and areas with brackish irrigation water are the most sustainable locations for production. Algae production needs include carbon dioxide and nutrients, therefore a nexus exists to tie algae production into proximity with municipal and industrial sewage and flue gas. In addition to municipal and industrial sewage as a nutrient source, utilization of lagoon water from dairy or feedlot operations (which contains both water and nutrients) could move algae production facilities beyond coastal or brackish water land; creating a nutrient and carbon sink. The co-product has promise as an animal feed or soil amendment (herbicide, fertilizer, organic matter additive). At this time, the added value of the co-product is critical to economic viability because production of oil from algae with current technology is not cost effective at current prices of fuel.

Macroalgae has not received as much attention as micro algae, likely because of the invasive nature of the plants and the relatively low oil concentration. However, techniques to contain the macroalgae are available and hybrids with greater oil content could be developed. Macroalgae is an extremely rapidly growing plant, and does have promise as a cellulosic biomass producer or oil crop.

A more detailed discussion of algae is included in Section 5.

Camelina: The entire state has the potential for viable yields of camelina though production would likely be limited to west Texas due to its drought tolerance. Oil from camelina is currently used for beauty products and nutritional supplements because of the high omega fatty acid and vitamin E concentrations. Vitamin E stabilizes the fatty acids from oxidation. It is not commonly grown in Texas, but it is one of the most drought tolerant of the oil seed crops and tolerates many soil types. It is important to have a well-prepared seedbed to ensure successful and rapid establishment. Camelina germinates quickly to inhibit weed competition, which reduces the need for herbicides. Pods are nearly shatterproof making harvest easy though drying is necessary prior to storage. Initial studies in south Texas indicate that spring varieties have promise.

Castor: The entire state has the potential for viable yields of castor though production would likely be limited to the Trans-Pecos, Edwards Plateau, and Southern High Plains regions due to the need to isolate it from grain and livestock and its remarkable drough tolerance. Historically, castor was planted and studied in Texas. The main research laboratory was in Chillcothe in north Texas. The oil was used in lamps and for other industrial uses. It is not leguminous and has a moderate to high nitrogen fertilizer requirement, dependent upon soil type. It is a hardy plant and well adapted to much of Texas; however, the exterior of the seed contain ricin in its raw form, which is toxic to livestock and humans. If production increases to meet demand for bioenergy, then special precautions need to be made to ensure that it does not enter the food or feed supply. This would include dedicated production areas and processing facilities to prevent contamination of feed and food facilities.

Chinese Tallow Tree: Considered noxious and an invasive species by TDA, a permit is required to sell, distribute or import Chinese tallow trees into the state. Despite this limitation, the tree has begun to invade and dominate coastal prairies, marshes, and forest floors from the Gulf Coast to East Texas and throughout parts of Central Texas according to a 2005 map by the Texas Forest Service. Researchers along the Gulf Coast have found a number of advantageous characteristics for the propagation of its oilseed for biodiesel and other uses. These characteristics include few natural pests, multiple seedpods per fruiting that contain a high lipid count, and the ability to grow in both wet and dry soils unsuitable for production agriculture. Oilseed yields range greatly among naturalized tree varieties but ongoing research has been able to isolate desirable traits and reproduce them through grafting and micropropagation. Isolation to prevent its threat to native species must occur if permitted stands or orchards are able to produce reliable oilseed harvests.

Cottonseed: Cotton is well-suited for Texas and grows across the state in both dryland and irrigated regions of Texas. Texas is a leading producer of cotton in the U.S. and worldwide. It is mainly grown under irrigation, and its production has continuously moved westward and is often dependent on irrigation due to cotton root rot in higher rainfall regions. Because more seed is produced than is needed to plant the following season's crop, cottonseed is abundant. Since it is a byproduct, no additional means are needed to produce the seed. Oil is currently removed from cottonseed with hexane, and the remaining product is used as a livestock feed ingredient. Protein is the most expensive feed ingredient, and whole cottonseed is a relatively affordable protein source to livestock producers in areas close to cotton production. In fact, about 60% of whole cottonseed is now used by dairies. Use of the extracted oil for bioenergy is not a competing product with feed; however, it would compete with higher-value uses of that oil. The residue after cotton boll harvest is usually shredded and incorporated into the soil; however, this residue could be harvested as cotton straw (agricultural co-product) as a cellulosic bioenergy feedstock if technology and soil needs are addressed. Cotton stalks are not a common feed for livestock and would not compete with livestock production. However, removal of residue affects soil fertility and tilth and evaluation of this practice is recommended prior to widespread adoption as a bioenergy byproduct. Because of its value as a high-quality food oil, cottonseed oil is not a viable low cost fuel source; however, cotton gin trash, as mentioned later, has tremendous value as a energy source for process heat and electricity production.

Flaxseed: The entire state has the potential for viable yields of flaxseed excluding the Trans-Pecos region. Flaxseed oil is used to produce paints, varnishes, linoleum flooring, and omega-3 fatty acid supplements for human consumption. Linseed germinates and establishes slowly and is not as competitive as other crops, so weed control during establishment via total weed control prior to planting or use of pre-emergent herbicides are crucial as is its placement within crop rotations. It is recommended in the United Kingdom (England etc.) that flaxseed not be planted after rapeseed because volunteer rapeseed are not inhibited by the uncompetitive flaxseed. Fall planting is recommended for central and south Texas. Flaxseed may be grown in many soil types as long as it is well-drained and the pH is greater than 5.8. It can be spring planted as well, but the earlier it is planted, the greater the yield potential of the crop. As such, yields might be greater in the southern zone of recommended production. Moderate levels of nitrogen application are required, depending on soil texture, and return of residue to the soil limits the phosphorous and potassium requirement. Desiccation and combining are options for harvest, and drying is required after harvest. Flaxseed has not been grown in Texas for some time, and it is unknown which cultivars are adapted. However, research is underway to identify potential varieties for Texas.

Jatropha: The production region in Texas that has the potential for viable yields with the least input is largely limited to the South Texas and Lower Valley regions. *Jatropha curcas* is a tropical perennial euphorbiaceae of New World origin with a long history of cultivation for biofuel. Portuguese merchants originally spread jatropha throughout the world as a source for lamp oil, which was extracted from the seed. These oil extracts lend themselves easily to biodiesel conversion, and husks have cellulosic bioenergy feedstock potential as well. Today it is hailed throughout the world as a potential biodiesel feedstock for regions with poor soil, arid climates, and inexpensive labor. It has severe limitations for regions such as Texas. These include: 1) indeterminate flowering/fruit set which lends itself to labor-intensive harvesting, 2) 30-50-year perennial tropical that flowers only after a full year of growth and peaks only after 3-5 years, 3) toxicity of some cultivated ecotype (but not all) leaves, bark and seed to humans, 4) invasive weed in some environments, 5) does not tolerate water-logging and, most importantly for Texas, 5) it is frost-intolerant. All these negatives combine to make jatropha unlikely to succeed as a bioenergy crop in Texas though many trials with varying successes have been conducted in south and west Texas.

<u>Palm</u>: Oil palm is an extremely labor intensive crop to grow. Only recently has equipment been designed and produced to allow for mechanized harvest of the crop. Labor costs in the US do not allow for economical production of oil palm. In addition, there is not enough precipitation to allow for sustainable production. Even in east Texas twice the annual rainfall would have to be added in irrigation just to replace the water lost through plant evapotranspiration.

<u>Peanut</u>: The peanut plant is well-suited for Texas and grows across the state in both dryland and irrigated regions of Texas. *Arachis hypogea*, the cultivated peanut, is a single-season leguminous (fixes its own nitrogen) annual crop (although really a true perennial) grown mostly on sandy soils under irrigation in Texas. Its cultivation thrives in west Texas because the dry climate does not favor the many diseases and pests (mostly soil nematodes) that have discouraged its production in other sections of the state, such as north-central counties, where it used to be an important crop and where there is sufficient precipitation for dry land cultivation. Its promise for bioenergy comes in two forms: 1) cultivars with 47-50% oil for biodiesel and up to 8000 lbs of kernel and 2) crop stover (residues) for cellulosic feedstock. However, use of the peanut kernel for bioenergy production will create competition with human food and edible oil. Plant breeding efforts to develop pest-resistant varieties high in oil are currently under way that could expand the areas well-suited for peanut production and thereby lessen the impact on the food and edible oil markets. When these become available, peanut production for biodiesel without irrigation in Texas has tremendous potential.

<u>Rapeseed</u>: Excluding the Trans-Pecos region, the entire state has the potential for viable yields of rapeseed, better known by canola. Rapeseed is a versatile plant that tolerates many soil types and growing conditions. There are two general types: spring and fall (winter-growing) seeded. Spring types do not require vernalization and are suitable for USDA hardiness zones 7 to 9; by contrast, winter types do require vernalization (winter growth interrupted by freezing above-ground growth) and could be produced in the northern regions of Texas (USDA hardiness zones 6 and 7). Winter types should be planted in the fall and spring types planted in the spring. Winter types have a greater nitrogen requirement than that of spring types, but both are heavy users of sulfur. Rapeseed is an excellent breakcrop to use in rotation with cereal grain crops, and it does well when no-till planted. Harvest methods are flexible and include swathing, combing, or post-harvest desiccation. Most seed can go directly to storage without drying, which reduces the energy input to the crop.

<u>Safflower</u>: Excluding the Trans-Pecos region, the entire state has the potential for viable yields of safflower. Seeds of the safflower plant contain about 35-45% oil and are used for human foods that are low cholesterol and the flowers are used to make dyes. Safflower is a hardy crop with a deep root system that tolerates salinity in the soil as long as the soil is deep and fertile. Its deep root system allows drought tolerance greater than other annual plants. It is susceptible to frost and the planting date should take this into consideration. It is a moderate user of nitrogen and phosphorous, and a scavenger of potassium within the soil. Harvesting is done by combining and post-harvest drying may or may not be necessary, dependent upon the moisture content at harvest.

Sesame: Excluding the Trans-Pecos, South Texas, and Lower Valley regions, most of the state has the potential for viable yields of sesame. Sesame is grown in Texas and is well adapted to droughty conditions in Texas when soil salinity is not a problem. Shatter of pods is a limitation unless shatter resistant cultivars are developed. It is not as productive as other oil crops; however, the oil content by weight is high (50% or greater) and the fertilizer input is low.

Soybean: Soybean is the number one oil crop produced worldwide and is grown on almost 100,000 acres in various regions of Texas. Soybeans are a leguminous crop, fixing atmospheric nitrogen through symbiosis with soil microbes, and only moderate amount of phosphorous and potassium fertilizer are required. Legumes are more sensitive to soil pH than trees and grasses, and soil pH is sometimes as different within a 100-acre area as it is from east to west Texas. Therefore, extreme care should be given to site selection. Use of soybean oil competes with human consumption.

Sunflower: Excluding the Trans-Pecos region, most of the state has the potential for viable yields of sunflower. Sunflowers are susceptible to many diseases, but planting in rotation with other crops easily breaks the pest cycle. It will volunteer in subsequent crops, but herbicides specific to these volunteers are available. It is a versatile crop in regards to soil type (texture and pH) and volunteers over much of North America where rainfall is adequate. It requires moderate fertilizer input to maximize production and many oil type cultivars are available for the Texas environment. Sunflowers are already produced in Texas and the acreage doubled from the 2002 and 2007 agriculture census (National Agriculture Statistics Service).

1.2.4 Agricultural Waste / Co-Products

Animal Processing/Mortality: As a result of the many species of livestock produced in Texas, there are numerous harvest facilities including those for cattle and poultry. The residues from processing are often used in rendering facilities where value added products are generated. For example, rendered products are used to produce pet foods, lard, and animal feed. However, this industry can be evaluated more carefully as fatty materials and byproducts, if well quantified, can be excellent feedstock supply for various bioenergy and biofuel end products. Use of animal fats for biofuels does not compete with human food or arable land and some animal processors are already investigating the technology to scale up to commercial production.

Corn Stover: Corn is grown across Texas exlcuding the Trans-Pecos region. Corn grain is the most consumed grain in the world and it is vital to the world market. Corn stover as a biofuel feedstock does not compete with human or livestock consumption. Therefore, corn stover is a viable option for biofuel feedstock. Corn has been bred to be water and fertilizer dependent and in Texas production costs are greater than in Midwestern states. Corn stover is fed to livestock as a low cost, low quality hay to provide fiber in winter months when warm-season forages are not actively growing. In addition, removal of crop residue may have negative implications on soil nutrient cycling and tilth. Evaluation of the effects of corn stover stubble height on the soil has been conducted in the Midwest. This work should be replicated in Texas in order to understand the process under Texas environmental conditions. In addition, caution to avoid competing with livestock feedstuffs should be taken.

Cotton Gin Trash: Similarly to cotton seed production, no additional irrigation water or fertilizer is necessary to produce cotton gin trash. However, cotton gin trash is an important fiber supplement to livestock during winter months when warm-season forages are not actively growing. Use of gin trash is an attractive option to add value to the co-product; however, this use may be detrimental to the state's cattle productionthough it has potential as a fuel source for process heat and electricity production.

Confined Animal Feed Operations (CAFO) Manure: Animal manure is a useful biomass source, and is plentiful around areas that have numerous animals under confinement. Once known primarily as a beef cattle state, Texas is now also home to thriving dairy, poultry, sheep, and hog production facilities, ranking among the top 10-15 states for each category of production. This entails primarily dairy confined animal feeding operations (CAFO) in the north-central regions and panhandle, beef feedlots in the panhandle and south, as well as poultry units mostly in East Texas.

In particular, large CAFOs are becoming more common across the US and Texas is consistently observing a rise in large CAFOs, in particular, large CAFO dairy farms where the milking cows are confined and thus the manure is recovered. It is at the large dairies where use of the manure as feedstock to an anaerobic digester can economically produce biogas used for combined heat and power or gas that can be input into the natural gas grid (discussed in Section 7 and 8).

In the past animal manure has mostly been recovered and sold as fertilizer or simply spread back onto agricultural land since it is widely valued as a soil amendment that improves soil health (organic matter) as well as plant nutrition (primarily phosphorus and nitrogen). However the introduction of tighter environmental controls on odor and water pollution, from chemicals such as phosphate and nitrogen found at high concentrations in manure, means that better forms of waste management are now required. This provides incentives to consider bioenergy and treatment opportunities of the waste material. Therefore, bioenergy would compete with food and fiber agriculture for manure; however, the annual supply volume, seasonal variations and specific characteristics of the resource should carefully be assessed before developing a plant.

Mill Waste: See Woody Feedstock section.

Peanut Stover: It is unlikely that peanut (*Arachis hypogea*) will be cultivated specifically for cellulosic bioenergy because of its value as human food. However, it has some potential as an opportunistic cellulosic feedstock because it is currently cultivated on 140,000 to 180,000 acres every year in Texas as a food and oil crop. If additional pest resistance is bred into new cultivars thereby allowing for a return of its cultivation to much of Texas, additional sources of stover may become available over the years. Under heavy irrigation and low disease conditions in west Texas it is capable of producing up to 15,000 lbs stover and hulls per acre, all of which can be utilized as cellulosic bioenergy feedstock. Actual harvestable hay will be much lower than this; likely between 1.5 to 2.5 tons/acre once plants have gone through combines, been raked and then picked up by a baler. Even if efficiency is not improved, this is a potential 450,000 tons/year of feedstock. The drawback is that peanut hay is already sold as high quality cattle feed despite pesticide label prohibitions against feeding to animals, so the price of peanut hay is high relative to other straws/stovers such as rice or wheat which have low nutritive values to ruminants.

Rice Hulls/Straw: Rice is produced in the South Central, Coastal Bend, and Upper Coast regions of Texas. Although it is unlikely that rice will be grown as a dedicated cellulosic bioenergy feedstock due to high costs, rice grain to straw ratios can be as high as 1:2 or higher, making this a potential source of opportunistic cellulosic bioenergy feedstock. Depending on variety and growing conditions, this can result in 7,000 to 16,000 lbs rice cellulosic bioenergy feedstock/acre. In 2009, 170,000 acres of rice were harvested in Texas, providing a conservative estimate of 600 tons of rice hulls and straw as cellulosic bioenergy feedstock.

Sugarcane Bagasse: Sugarcane is produced in the Lower Valley region of Texas. Sugarcane bagasse is a co-product of sugar production which, on a dry matter basis, produces an estimated 25% fibrous bagasse of which 60-70% is carbohydrate. Approximately 1.9 million tons of sugar production is forecast for Texas, making the potential production of sugarcane bagasse considerable. In most regions with significant sugarcane production, bagasse is burned at plants to produce electricity to run the sugar refineries or ethanol conversion plants. Sugarcane is a true tropical and a perennial, so its cultivation in Texas is limited to regions that are generally freeze and frost free. This means it is a viable crop only in the Rio Grande Valley. Likelihood of expanded sugarcane acreage may prove difficult due to climatic limitations, though comparable energycane production could extend along the Gulf Coast.

Wheat Straw: Wheat is grown across Texas. Wheat was grown on over 3 million acres in 2008, and the amount of straw from that land area would be significant enough to warrant use for biofuel feedstock. However, care to balance removal of straw with soil health must be made. Research has focused on the amount of corn stover removal that provides cellulosic ethanol feedstock while still aiding nutrient return and organic matter maintenance of the soil. A similar research effort is recommended for wheat. In addition, wheat straw is a common crop that is harvested for livestock forage and use of wheat straw for bioenergy would compete with livestock production.

1.2.5 Grain and Food Crops

Barley: Most of the state is well-suited for growing barley. Barley is grown in Texas primarily as a “graze-out” small grain forage. Only isolated growers during high-rainfall years harvest grain. Its adaptation range is therefore poorly documented. It is an annual crop that requires intensive soil preparation and fertilizer amendment, making its usefulness as a cellulosic bioenergy feedstock dubious. Some spent brewers’ grains are available for cellulosic bioenergy feedstock although the livestock industry will be in direct competition for this limited resource.

Corn: Corn is grown across Texas exlcuding the Trans-Pecos region. Corn is grown on 2 million acres in Texas and is the most consumed grain for human, livestock, and ethanol conversion uses. Although current ethanol efforts are focused on corn grain, recent federal policies, and research have led to consideration and preference for corn stover’s use as a feedstock for cellulosic biofuel production to avoid competition for food and feed. That being said, corn production yields continue to increase annually with record yields for 2009 at 164.7 bushels per acre, approximately 30% more than the record yields in 1997 at 126.7 bushels per acre.

Grain Sorghum: Grain sorghum is grown in most of Texas, excluding the majority of the Trans-Pecos region. Compared to corn or more temperate grain crops such as wheat or barley, grain sorghum and millets are annuals of tropical origin that thrive in hot climates and tolerate dry weather. Sorghum will likely continue to be grown for human consumption, animal feed, and existing ethanol production. Grain sorghum residues may become an additional economic source as a cellulosic bioenergy feedstock.

Daylight sensitive high biomass sorghums, originally developed as forage varieties, are those that, in Texas latitudes, will flower only when day length shortens in the autumn, meaning they will grow vegetatively all season long. This makes them very attractive as cellulosic bioenergy feedstocks because they will grow whenever soil moisture allows, go dormant through short dry periods, and then start growing again when rainfall returns — all without interruption for seed production. This means they can be harvested once yearly, usually during or after the end of the growing season.

Sugar beets: Sugar beet production began in Texas during the 1950s, and in 1997, the last year that data are available, 15,000 acres were harvested in the High Plains regions of Texas. Sugar beets are bulky and the sucrose depletes rapidly after harvest; therefore, the processing facility must be within transport distance of the field. There was a production facility in Hereford, Texas, but it is no longer open due to the decline of sugar beet acreage in Texas (peak production was 41,000 harvested acres in 1990). Pulp from sugar beets has value as an animal feed and for other added value products. Because sugar beets have tap roots, they are efficient scavengers for water and nutrients within the soil profile. In addition the tops can be used for grazing or silage for animal forage. It has potential as a dual use crop (livestock and cropping) in the panhandle, but facilities for processing are not available.

Sugarcane: Sugarcane is produced in the Lower Valley region of Texas. Sugarcane (*Saccharum* spp.) is a perennial tropical monocot (grass) that must grow for two years to maximize harvests and must be propagated vegetatively. It can grow in much of Texas but will produce harvestable canes with peak sugar concentrations only where it can overwinter without exposure to freezing temperatures or minimal frosts, for example in extreme southwestern Texas. Today nearly 40,000 acres are grown in the lower Rio Grande Valley with expansion limited by competition with food crops, irrigation and freezing winter temperatures. Approximately 1.9 million tons are forecast for production in Texas in 2010. It survives in a wide range of soils but prefers clay soils with a pH around 6.5, fertile and balanced nutrients, including high rates of nitrogen fertilizer. There are many pests and pathogens that attack sugarcane, so pesticide inputs can also be very intense. It is approximately 37% sugar which is efficiently converted to ethanol. That means about 60% of the harvested portion is available as cellulosic bioenergy feedstock from field litter as well as processed stalk (see sugarcane bagasse above).

Rice: Rice is produced in the South Central, Coastal Bend, and Upper Coast regions of Texas. In the United States rice is grown in flooded fields. This is done not because rice has a high water requirement, but because rice tolerates standing water and weeds do not. Other cultivation practices require greater herbicide inputs. This requires heavy clay soils which will hold water. Rice is a high producing crop, and the grain is energy dense, lending well to ease of conversion into bioenergy. Using rice for biofuel production, however, will compete directly with human food and agriculture exports. Crop and grain residues may prove an excellent option as a bioenergy feedstock because no additional input, other than harvest, is required (see rice hulls/straw above).

Wheat: Wheat is grown across Texas. Wheat is grown dry land as a grain, forage, or combination only in north-central and, in above-average moisture years, northwestern Texas. Because of this competition with human consumption and animal feed, wheat will likely be a minor player in the Texas bioenergy future. Its crop residue (wheat straw) will more likely play a role than the grain for ethanol because of the high fossil-fuel costs involved in soil preparation, annual seeding, weed control and, finally, harvest at low yields.

1.3 Approximate Geographic Region for Each Crop

An approximate geographic region using USDA's Texas Agricultural Statistics Districts were included in the above description of each feedstock. The Policy Council and Research Committee, in conjunction with input from TDA staff and TetraTech, will produce maps associated with each feedstock throughout 2011 and 2012 to reflect current and potential production areas as a resource for law and policy makers.

1.4 Water Needs

Minimum rainfall requirements were reported for each crop in Appendix B. If these crops are grown in greater rainfall areas or with irrigation, yields will increase accordingly and only on-farm trials can provide the necessary site-specific information. Rainfall distribution during the growing season and over various years is probably more important in determining crop adaptation than long-term average precipitation which sometimes can mean little for crop adaptation in any given year. The assumption is that where irrigation is considered for bioenergy crop production such that climatic limitations (mostly rainfall and ambient high temperatures) are overcome, these will usually be minimal. Namely "emergency" irrigation is preferred over irrigation to achieve "optimal" growing conditions. Given sufficient irrigation resources, just about any crop can be grown anywhere in Texas. Irrigation will likely be considered when selecting bioenergy crops if: 1) return on irrigation potential may be reasonably expected and 2) where irrigation is not already being applied to the crop, for example agricultural waste and co-products. An example of the latter would be sugarcane bagasse or corn stover: irrigation will be applied to grow cane for sugar or corn for starch, but no additional irrigation will be applied to grow the co-product which is used for biofuel production. Listing irrigation requirements for sugarcane bagasse or corn stover would therefore be nonsensical.

A general average yearly precipitation map is also provided in Appendix C and can be used for considering additional crops. However, please note that these yearly rainfall averages often mean little to crop management in any given year. They are 30-year averages and most years have more or less than this average. As such, crops should be selected conservatively when it comes to rainfall. If the minimum requirement for jatropha is 24", for example, and rainfall averages 24" but is less than that every other year, then a 50% chance of crop failure is likely. Even years with 24" or greater rainfall may not sustain that crop because of uneven precipitation distribution through the growing season. Three ways around this conundrum include: 1) growing crops in regions with more than the minimum rainfall or 2) over-producing crops to address the risk or 3) providing emergency irrigation during critical periods. The problem with the latter option is that irrigation infrastructure, not to mention applying it, is expensive and the margins for profitability may be too thin for most bioenergy crops. Another option is to design bioenergy cropping systems for droughty regions that depend on perennial, deep rooted crops. Harvesting naturally occurring juniper or mesquite every 10 years in regions with 24" or less rainfall averages, for example, is almost a risk-free proposition. It may not be considered a traditional agricultural approach and may require developing systems that can accommodate dispersed, decade-long harvest intervals, but for many regions of Texas where rainfall is limiting, such unconventional systems may be the most viable.

1.5 Sustainability

The general categorization of crops and other bioenergy resources labeled as having no, low, medium or high "sustainability" (see Table 1.1) is based on the guiding principles identified in the second paragraph of this section and a review of the results discussed above. There is an inherent bias in this analysis, since sustainability is in the eye of the producer, industry, and, most importantly, consumer (market). For example, charging extra for "green energy" does not improve efficiency of a crop (bioenergy out vs. fossil fuel energy in) but does affect economic feasibility. A purely bio-physical approach is taken rather than getting involved in the socio-cultural factors that affect sustainability which are beyond the scope of this task. If a crop will persist under harvest with few inputs or as agricultural waste or a co-product is likely to be plentiful in the near future, it will likely rate a "high." If, on the other hand, input requirements are high or risks related to climatic factors exist, "low" is the likely rating.

1.6 Summary

An economic analysis and life-cycle assessment of feedstocks should be given strong emphasis going forward. Other factors, such as fuel consumption and other inputs required for crop production, should be considered in determining which crops are ideal for Texas. Additionally, mapping and strategic planning to project and secure available feedstocks and resources are an important component in the due dilligence and site selection of bioenergy projects. State and federal mapping resources can and should be fully-leveraged by developers in the creation of business and project plans. Approximate growing regions have been included in this report but an additional resource is the just-released interactive BioEnergy Atlas created by National Renewable Energy Laboratory which, "allows users to layer related bioenergy data onto a single map to gather information on biomass feedstocks, biopower and biofuels potential, production and distribution", among other things. http://www.nrel.gov/news/press/2010/891.html

2.0 LOGISTICAL CHALLENGES

2.1 Logistical Challenges

The intent of this section is to investigate logistical challenges to the planting, irrigating, harvesting, and transporting of large volumes of biomass or oil crop and provides recommendations that will aid in overcoming barriers to the transportation, distribution, and marketing of bioenergy. Understanding and overcoming the logistical challenges is often a critical step when developing a bioenergy program. Many of these issues were introduced in the last section whereas this section provides additional insight.

The approach taken includes identification of crops shown in Section 1 and from that list 1) summarizes what is already known about logistical challenges or 2) identifies knowledge gaps that should be addressed to facilitate implementation of crop production. Because of the large number of resources investigated, an overview is presented in Table 1.1. Possible limitations or changes in agronomic practices as mentioned for each resource are included in this table. These factors will change (intensify or vice versa with latitude/longitude, soil type, topography, proximity to market, variations in yearly precipitation patterns, and other climatic and environmental factors.

2.2 Recommendations to Overcoming Barriers

Transportation, distribution, and marketing are currently barriers to large-scale biofuel production in Texas. Without a market for feedstock, producers are unlikely to change management or type of crop grown in order to produce biofuel feedstocks. Development of a market and a program to ensure success of crop establishment and productivity is necessary. Tennessee has had success with switchgrass production through a system working with farmers to secure long-term production agreements. This system may serve as a model for transition of forage growers to cellulosic ethanol feedstock producers. The concept is that investors are more likely to fund start-up bioenergy conversion facilities if they know there is a source of material. However, growers are not likely to produce the material until they know there is a buyer for their product. Contracts within the referenced program allowed for successful transition of both growers and the start-up conversion facility.

Overriding much of the challenges to producing renewable energy in Texas from agricultural products is the lack of second generation (cellulosic ethanol) conversion facilities. Investors need to be reassured that renewable energy is a viable emerging industry. Government policies or investment benefiting these facilities may attract investment when competing traditional energy sources are priced low. Another limitation to building conversion plants is that the technology of most processes is proven on a small scale; however, it has not been scaled up because of lack of investors. Research and development of scaling up current technologies is vital. It is also necessary to continue to discover additional renewable energy alternatives and how to make it more efficient once it is in place.

Transportation systems are already in place for agricultural products and this system is appropriate for the transport of feedstock. Care must be taken to ensure that the energy used to transport the feedstock does not exceed the energy produced from the feedstock. If this is not the case, then more energy will be used to transport feedstock to the plant and distribute to the end-user than is being transported and distributed. It is obvious then, that location of processing plants should be strategically planned. Another issue to resolve is the type of material to be utilized. For example, use of high moisture content (MC) materials may be ideal because they do not need energy to dry; however, storage may be volatile and transport more expensive (high MC material weighs more and takes up more volume than dry) and consequently is more difficult. Investment in densification technology would greatly improve logistic economics and increase opportunities to capture these widespread, but underutilized biomass resources.

In the case of woody feedstocks mill residue is already fully utilized to produce value-added building products and green energy in East Texas. These are co-products from an already developed industry operating within a value chain anchored by a well-managed and sustainable forests; processing plants are within radius of the main timber products production region, and conversion plants are also located in association with the supply of feedstock. Within this value chain exist other available woody feedstocks including logging residue and thinnings that add to the overall biomass availability of East Texas. Juniper and mesquite are, for the most part, a species present on native rangelands. Product for a conversion facility may not be uniform in age or growth habit and would not be available year round. Transportation might be over long distances. However, these trees are cleared periodically from rangelands to promote grassland vegetation and to restore water available for the rangeland. If conversion technologies can be developed, their use for biofuel, instead of burning or chipping, would add value to the waste and likely incentivize landowners and water authorities to invest in rangeland management on a greater scale.

Most oil crops grown in Texas are harvested and transported long distances for oil extraction. The limitation to using oil crops, other than most would compete with human consumption, is that the oil must be extracted and then processed further for biofuel. However, it is a feasible concept that one location could be developed to handle both tasks either as a mobile unit or one centrally located The scale of oil crop production and the ultimate biofuel product would determine the ideal model. In general, biodiesel production is well-suited for multiple oil crop feedstocks, which may favor a mobile unit; while a more specialized product like jet fuel would necessitate a dedicated crusher and processing facility.

There are also regulatory challenges and advantages to the expanded use of biofuels which should be considered by continuing implementation research and ongoing Policy Council work. The Texas Commission on Environmental Quality (TCEQ) has a very successful air quality program to address compliance with National Ambient Air Quality Standards (NAAQS). In particular, substantial progress has been made in reducing ozone concentrations. Despite tougher standards and increasing population, ozone concentrations in Texas cities continue to fall. Based on monitoring data compared to the current 1997 8-hour ozone standard, every Texas metropolitan area, except the Dallas-Fort Worth area, is in compliance with the standard, and Dallas-Fort Worth is within one part per billion of meeting the 1997 8-hour ozone standard of 85 ppb. The progress the state has made is based on an array of emission control strategies, specifically including two fuel standards aimed at reducing both nitrogen oxide (NO_X) and volatile organic compound (VOC) emissions, which are the primary precursors to ozone formation. Currently, the United States Environmental Protection Agency (EPA) is considering lowering the national ozone standard. Depending on how much the standard is eventually lowered, many Texas metropolitan areas could become nonattainment areas with respect to the new standard. It is vitally important to the health of Texas citizens and to the economy of the state, that the progress made by Texas in addressing current ozone standards is maintained and improved and that the ability to meet newer, even tougher, future standards is not hampered. With that as a backdrop, research on environmental effects, both negative and positive, and methods to reduce or eliminate them through the most advantageous and efficeint use of biomass and its bioenergy product will help to streamline the expanded use of biofuels.

Another area of regulatory ambiguity is the ability of biofuels, particularly biodiesel and renewable diesel, from being transported via pipeline throughout the United States as it is done commonly in Europe. Ethanol is not able to be transported via common pipeline due to its corrosive attributes and high water soluability. Increasing modes of transportation would likely improve the demand for Texas-based feedstocks, and consequently Texas-based biofuel production. The Policy Council should work with industry stakeholders to facilitate federal policy development to expand Texas' role as a low cost biofuels provider to the country.

2.3 Summary

Cellulosic biomass and agriculture waste and co-products are an immediate area for transition. Many of these co-products, including animal fats, corn stover, cotton gin trash, manure, mill waste, peanut stover, rice hulls and straw, sugar cane bagasse, and wheat straw, all have value for biofuel conversion. The equipment is generally available to harvest and transport this material, however, improvements in densification and logistics systems are needed. A lack of conversion assets limit expanded use of these abundant and existing biomass sources. Investment or policy incentives in conversion facilities to be built in Texas would increase bioenergy use and production beyond existing use today. The Policy Council should continue to investigate and analyze regulatory advantegs and disadvanteges to the use of bioenergy, particularly with respect to environmental and transportation regulation.

3.0 STRATEGIES FOR WESTERN TEXAS NOT DEPENDENT ON GROUNDWATER

The intent of this section is to identify strategies for and obstacles to the potential transition of the agriculture industry in western regions of this state to dryland bioenergy crops. This strategy is focused on bioenergy feedstock that is not dependent on groundwater resources.

3.1 Obstacles

To identify opportunities in west Texas it is essential to 1) identify crops that have potential in these agro-climatic regions; 2) delineate strategies for establishing and managing these crops; and 3) enumerate research into agronomic practices or the search for alternative species not yet identified will take place. Based upon this research there are few viable options and very little is known about some of these options. We have summarized the potential feedstock options in Table 3.1. Viable woody feedstock options are cedar and mesquite. Oil, grain, and food crop options include algae, camelina, castor, safflower, sunflower, barley, and wheat. Agricultural waste and co-products include cotton gin trash, manure, and wheat straw. Based upon this conclusion, focused and careful bioenergy investment should neither focus on high rainfall cropland where food and fiber is already produced nor on ecologically sensitive arid regions where the climatic limitations and costs, both financial and environmental, are high for sustainable bioenergy production. In this section we provide an overview of these recommendations (please see individual descriptions in Section 1.0).

Climatic characteristics in the arid or semi-arid western regions of Texas indicate that sustainable bioenergy crop production will be limited to native or naturalized vegetation that requires basically no input. In such environments, opportunistic harvest of deep-rooted weedy species such as mesquite or cultivation of other native perennial leguminous shrubs such as leadplant (*Leucaena retusa*) may be the only realistic, sustainable options since they require no irrigation or fertilizers (they establish their own nitrogen requirements via atmospheric conditions). Utilizing manure from dairy and beef feedlots, cottonseed, or cotton gin trash are also attainable options.

The unpredictable and unevenly distributed precipitation of the western region precludes any sustainable cultivation of annual herbaceous bioenergy crops without irrigation. As the state's water demands and reliance on aquifers continue to grow, pressures will increase on irrigation users to use less. Except in the case of brackish irrigation water, growing irrigated crops for bioenergy feedstocks will prove difficult because: 1) groundwater is limited and becoming more so every year due to increasing demand; 2) food and fiber crops will likely take priority for economic as well as national/state security reasons; and 3) the high fossil-fuel consumption required to maintain high-input production systems make the energy and economic return unsustainable.

Of the potential crops for west Texas, camelina, castor, and safflower are the most drought tolerant. Raw castor seeds have a toxic compound that is harmful to livestock and humans; therefore, castor should be insulated or confined away from food, fiber and livestock production. Risks could be minimized while recognizing the high-value of castor oil, which can be used from cosmetics to jet fuel. Camelina requires only 9" of rainfall a year; therefore, it has the most potential in a climate such as west Texas. That the rain will fall at the ideal times (planting, flowering) during the growing season of camelina every year is unlikely. The same situation is true for safflower. It will be a risky venture to produce feedstock without irrigation.

Based upon our assessment central Texas is where the greatest potential for sustainable cellulosic bioenergy feedstock production is likely to reside. Yet extensive dryland production of cellulosic bioenergy feedstock may only be feasible if appropriate harvest, transport, and conversion technology is developed, especially for perennial crops requiring few inputs. This section summarizes known information and what information is still needed to grow bioenergy feedstocks in arid and semi-arid regions of western Texas with the overarching goal of providing tools for landowners.

3.2 Strategies for Transition

Naturally occurring vegetation such as mesquite appears to be the most viable option for primary (dedicated) cellulosic bioenergy production west of I-35. This would involve developing strategies that harvest dispersed feedstocks and transporting them to small, mobile conversion platforms. Advantages include 1) no agronomic inputs required and 2) vegetation removal often improves livestock/wildlife production. Disadvantages include 1) elevated transport costs; 2) long harvest intervals for woody species; and 3) harvestable herbaceous biomass will be available only during extraordinary high-rainfall years.

High input bioenergy cultivation systems that overcome semi-arid and arid conditions via irrigation or fertilizers to produce feedstocks are unlikely to compete vis-à-vis urban usage as well as irrigation for food and fiber cropping. Alternative options involve opportunistic use of existing agricultural production, like feedlot and dairy manures or agricultural waste and co-products. Dairies and beef feedlots provide concentrated feedstocks. Irrigated cotton and peanut stover or milling co-products are examples of other potential resources.

West Texas has considerable land areas that have high pH and some saline soils. These soils have pH levels beyond what most agronomic crops will tolerate, even when irrigation is applied. The cultivation of halophytic species capable of growing in low rainfall regions may not only produce some limited (dispersed) biomass but could also be used to phytoremediate these soils and eventually lead to their returned use as cattle/wildlife rangeland or irrigated fiber/crop cultivation. Some species are enumerated above and others are discussed below in Section 4. In addition, algae are a promising option in areas where irrigation water has a high saline content.

3.3 Summary

Native and naturalized species, such as mesquite, juniper, and leadplant, are the most promising opportunities for west Texas. Manure and agricultural waste and co-products (cottonseed, cotton gin trash, and peanut stover), which do not require additional input beyond milk, meat, or crop production, are also viable options to locate centralized digesters. However, these operations can be costly and tedious to logistically and financially organize. Collection of the forages, specifically perennials, halophytes, and algae are other viable feedstock worthy of future evaluation. More information, through research and development, is needed on the feasibility, management, and productivity of these potential practices.

4.0 REGIONS THAT MAY CONTAIN AVAILABLE MARGINAL AGRICULTURAL LAND

The intent of this section is to identify regions of Texas, including coastal and arid areas that may contain available marginal agricultural land for use in growing bioenergy feedstock.

Marginal agricultural land may be very useful for cellulosic bioenergy feedstock development because these lands are currently underutilized. However, usually there is good reason that marginal lands are underutilized. Tilled land in arid regions takes decades to stabilize due to fragile ecosystems and the potential for water runoff and soil loss to wind erosion. Use of steep slopes without vegetation to feed bioenergy needs can also cause soil erosion. Poorly drained wetlands may be more important as natural bio-diverse communities for fish and waterfowl nurseries than for bioenergy feedstock production. Caution should be used in considering bioenergy cultivation as an alternative use of marginal lands in Texas. Keeping that caution in mind, however, there are some potential bioenergy feedstocks that may be grown on marginal lands.

4.1 Low Rainfall

Sub-humid, semi-arid and arid regions, all under 20” precipitation in an average year, are rarely used currently for dry land row (annual) cropping without irrigation. A map of rainfall patterns across Texas (Figure 1.2) shows that much of West Texas falls into this category. Not only is average rainfall limiting, but actual rainfall in any given growing season may be even lower than the average. Even more limiting is rainfall distribution through the growing season which may also be problematic. Even a year-long rainfall total of 28” is insufficient for annual crop production if it falls in two or three events rather than in 2” increments every 10 days of the growing season, the later is an unlikely scenario.

Arid region analysis of crop potential is partially addressed in Tasks 1 and 3. Cultivation, if it occurs without irrigation, invariably involves perennial, deep-rooted forage crops that could be diverted to cellulosic bioenergy feedstock production when rainfall allows. Such forage crops, irrigated agricultural waste or co-products, and natural vegetation capable of sustained production without high inputs (primarily irrigation and fertilizers) in dry climates have already been identified in Table 1.1 and the attached maps. Harvesting juniper or mesquite are prime examples of bioenergy feedstocks for these regions. Their deep taproots, natural re-growth, and native abundance make them natural choices.

4.2 Soil pH

Marginal lands affected by high pH are of particular interest. Many of these “salt pans” exist naturally and were around long before farming was introduced into the region. Others are man-made, a result of poorly engineered irrigation projects. An example is high pH soils irrigated with Santa Rosa water. In either case, sustainable bioenergy options are few mostly because irrigation is limited and will likely be invested in high-value food and fiber crops if at all. If there is at present insufficient soil moisture (rainfall and irrigation) or drainage to salvage these lands for high-return food and fiber crops, there will be even greater limitations for low-return bioenergy crops.

Despite these limitations, there are some crop options in marginal (but not extreme) salt-impacted soils. These include halophytic (salt-tolerant) plants such as *Atriplex* spp. (saltbush) which is discussed above. The usefulness of these has yet to be studied, especially in terms of bioenergy yield and limitations of high salt content in harvested cellulosic feedstock and its potential inhibition to pyrolysis and/or gasification. Where irrigation water is has a high saline content and is unusable for crop production, the water may be used for algae production.

The possible exception to sodic soils located mostly in the panhandles is the coastal region where native halophytic (salt-tolerant) plants have some potential in low-lying drainages and coastal soils affected by field runoffs or periodic seawater invasion, for example hurricane surges. Examples with bioenergy potential include cordgrass (*Spartina* spp.), *Atriplex* spp., and *Salicornia bigelovii*. Salicornia is a special case as the biomass may have potential as a cellulosic feedstock and the oil extracted from the seed, which has a low saline content, has potential for bio-oil production. The residue after oil extraction may then have potential as a valuable livestock feed. Such crops may also be used for hurricane surge remediation and, as such, will have multiple economic values.

4.3 Slope

Potential agricultural land marginalized due to steep slopes exists throughout Texas (Figure 1.7). Our few mountainous regions are more limited by low rainfall due to their western locations, than slope. The Hill Country in the central parts of the state as well as the slopes leading up to plateaus in the western portions has greater bioenergy potential. However, planners and landowners may want to consider the potential soil erosion and water runoff losses if vegetation is removed indiscriminately. Periodic harvest of deep-rooted perennial invasives such as juniper (cedar) and mesquite may be the least damaging; in some situations, removal of this vegetation may improve water harvesting for aquifer replenishment as well as increased productivity from other land-use options such as livestock grazing and wildlife leases.

4.4 Drainage

Poorly-drained areas often result from soil structure that does not favor water infiltration or from shallow water tables. Environmental concerns discourage drainage, so options usually allow for cultivation of crops that tolerate water-logging or protection in favor of the high density of water and avian species that depend on these areas for food and habitat. This severely limits bioenergy agriculture just as it has food and fiber production over the years. There are, to be sure, options such as rice straw or periodic native prairie grass harvests, but these should be considered within the larger picture of fragile ecosystems such as swamps, lagoons, streambeds, and marshes.

4.5 Thin soils

Despite adequate precipitation, bioenergy production will be limited in some regions of Texas because of shallow soils. The central region Hill Country is a prime example. Early settlers quickly found that cultivation in this region was limited to small pockets of alluvial soils. The majority of the land cannot be tilled and was traditionally used almost exclusively for animal husbandry (cattle and small ruminants, but increasingly wildlife). Here, once again, environmental concerns or even high-income hunting leases may preclude bioenergy agriculture. Harvesting existing perennial vegetation, such as junipers and mesquite, judiciously and with long cutting intervals may be the best option. The integration of animal production, wildlife income, and tourism (aesthetically pleasing landscape management) will likely be as important, if not more, than cellulosic bioenergy production.

4.6 Summary

Deep-rooted perennial grasses, legumes, juniper, and mesquite may prove to be the best option for bioenergy feedstock in arid regions of the state. In addition, the use of halophytes (*Cordgrass*, *Atriplex*, or S*alicornia*) for remediation of saline soils are options. Generally, irrigation water with a high saline content may also be used for algae production on these lands. Research and mapping, using the Texas Water Development Board's brackish groundwater research, is needed to investigate potential algae biofuel production systems located on marginal lands in West Texas that overlie underutilized and untapped brackish groundwater sources. Growing plants that are adapted to alkaline soils is a more economical option than remediating soil pH. All of these areas need research to determine specific management and production practices.

5.0 POTENTIAL FOR PRODUCING OIL FROM ALGAE AND IDENTIFY TEXAS-BASED EFFORTS

The intent of this section is to evaluate the potential for producing oil from algae and to identify Texas-based efforts currently underway. Because the use and production of algae for fuel is still a relatively new and emerging science, it is necessary to introduce the types, production, operational challenges, economics, and then current initiatives. Because of ongoing aggressive research programs in both academia and industry this is a rapidly-evolving science and industry. Therefore, this section provides an overview of this potential as of 2010.

5.1 Types of Algae

5.1.1 Macro- and Microalgae

Algae have recently received a lot of attention as a new biomass source for the production of renewable energy. With the advent of increased oil prices and the promise of renewable fuels technology, today there are over 50 algae companies worldwide. Parameters that set algae apart from other biomass sources are that algae can have a high biomass yield per unit of light and area, can have a high oil content, do not require agricultural land, fresh water is not essential and nutrients can be supplied by wastewater and CO_2 from combustion gases. Therefore, algae are seen as carbon sinks, which are key for carbon sequestration. The ideal feedstock for the production of biofuels would be a non-food feedstock that is renewable and requires minimal inputs. Algae are thought to be the ideal feedstock for biodiesel production and possess the majority, if not all, of these feedstock requirements.

There are two major types of algae that are considered when discussing the topic of biofuels production. Macroalgae, more commonly known as “seaweed,” are fast growing marine and freshwater plants that can grow to considerable size (up to 60m in length). Macroalgae are less versatile since there are far fewer options of species to cultivate, and there is currently only one known viable technology for producing renewable energy from macroalgae: anaerobic digestion to produce biogas.

Microalgae are, as the name suggests, microscopic photosynthetic organisms. These organisms are found in both marine and freshwater environments. Microalgae have many different species with widely varying compositions and live as single cells or colonies without any specialization. Although this makes their cultivation easier and more controllable, their small size makes subsequent harvesting more complicated compared to macroalgae. Microalgae generally produce more of the right kinds of natural oils needed for biodiesel and aviation fuel. While the mechanism of photosynthesis in microalgae is similar to that of higher plants, they are generally more efficient converters of solar energy because of their simple cellular structure. In addition, because the cells grow in aqueous suspension, they have more efficient access to water, CO_2 and other nutrients. For these reasons, microalgae are capable of producing 30 times the amount of oil per unit area of land, compared to terrestrial oilseed crops such as soybeans or rapeseed. Both algae groups will be considered in this report, but as there is more research, practical experience, and more fuel options with microalgae. These will be the primary focus of Section 5.

Macroalgae were being cultured as far back as the 1600s in Japan (Source: Buck, B. H. and Buchholz, C. M. (2004). "The offshore-ring: A new system design for the open ocean aquaculture of macroalgae." Journal of Applied Psychology 16(5): 355-368). Seaweed is harvested from natural occurring colonies in the ocean or harvested on the beach. Seaweed is mainly used as a food product, either eaten directly, or used in many processed foods as stabilizers or emulsifiers. Besides culturing seaweed, part of the current seaweed production comes from harvesting natural populations or collecting beach-cast seaweed.

Microalgae are smaller and must be cultured in a specific manner due to their size. The development of dedicated culture systems for microalgae started in the 1950s when algae were investigated as an alternative protein source for the increasing world population. Later, algae were researched for the interesting compounds they produce, to convert CO_2 to O_2 during space travel and for remediation of wastewater.

The energy crisis in the 1970s initiated the research on algae as a source of renewable energy. A small effort was funded by the U.S. Department of Energy (DOE) at the National Renewable Energy Laboratory (NREL) in 1978 to investigate the genetic manipulation of microalgae for increased oil production. The effort was termed the Aquatic Species Program. This program had approximately 300 species, mostly green algae and diatoms. Wild algae grow fast, but do not yield tremendous amounts of oil naturally – two thirds or more of the body weight of wild algae will be proteins and carbohydrates instead of oil. Genetically modified algae can boost the oil content, but that slows the growth process. One of the major emphases of the program was to identify genes associated with the increased accumulation of oil in the cells. Due to lower fossil oil prices and budget cuts, the program was terminated by DOE in 1996, and the microalgae collection was transferred to the University of Hawaii. More recently, the program has been restarted by DOE and NREL (*Source: Sheehan, J., Dunahay, T., Benemann, J. and Roessler, P. (1998). Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae; Close-Out Report),* https://events.umn.edu/005584.

On September 28, 2010, the U.S. House of Representatives passed H.R. 4168, the Algae-based Renewable Fuel Promotion Act of 2010. The Act amends the Internal Revenue Code to (1) expand the definition of "cellulosic biofuel" to include algae-based biofuel for purposes of the cellulosic biofuel producer tax credit; and (2) provide for accelerated depreciation of property used in the production of algae-based biofuel. http://thomas.loc.gov/cgi-bin/query/z?c111:H.R.4168

5.2 Algae Production Systems

For algae to produce economic qualities of oil, complex operating conditions have to be met that assure consistent delivery of: light, carbon source, water, nutrients, and a suitably controlled temperature. Many different culture systems that meet these requirements have been developed over the years; however, meeting these conditions for scaled systems is difficult. The necessary technology for developing profitable algae-based fuel generation is still in various states of development and the final configuration is yet to be determined and demonstrated at the industrial scale.

Two systems are currently considered for the production of macroalgae and microalgae. These are land-based and sea-based systems. The former is used primarily for microalgae while the latter is used for seaweed or macroalgae production. Most algal biofuels companies are basing their designs on one of the land-based systems discussed below.

5.2.1 Land-Based Systems

5.2.1.1 Open Ponds and Raceways

Ponds are static ponds in which algae are grown without agitation. These are simple open algal cultivation systems that are not optimized as there is not even distribution of nutrients, water or sunlight (Figure 5.1).

FIGURE 5.1 an Example of a Static Algae Pond
(*SOURCE: BIOTECHNOLOGICAL AND ENVIRONMENTAL APPLICATIONS OF MICROALGAE – BEAM)*

"Raceway" designs are kinetic ponds in which the algae, water and nutrients circulate around a racetrack. Paddlewheels provide the flow (see Figure 5.2). The algae are thus kept suspended in water. Algae are circulated back up to the surface on a regular frequency. The ponds are kept shallow because of the need to keep the algae exposed to sunlight and the limited depth to which sunlight can penetrate the pond water. The ponds are operated continuously; that is, water and nutrients are constantly fed to the pond, while algae-containing water is removed at the other end. A harvesting system is required to recover the algae, which contains substantial amounts of natural oil.

Figure 5. 2 Example of a Raceway Algae Pond (*Source: NEAtech, LLC*)

5.2.1.2 Circular Ponds

Circular ponds are another form of a stirred pond. The concept is that the algae are enclosed in a circular containment structure, and the agitation is provided by a circular pivot arm (Figure 5.3).

Figure 5.3 Circular Pond (*Source: BEAM)*

5.2.1.3 Algae Farm

The concept of an "algae farm" is a large group of interconnected ponds. The size of these ponds is measured in terms of surface area (as opposed to volume), since surface area is so critical to capturing sunlight. Their productivity is measured in terms of biomass produced per day per unit of available surface area. Even at levels of productivity that would stretch the limits of an aggressive research and development program, such systems will require thousand of acres of land. At such large sizes, it is more appropriate to think of these operations on the scale of a farm (see Figure 5.4).

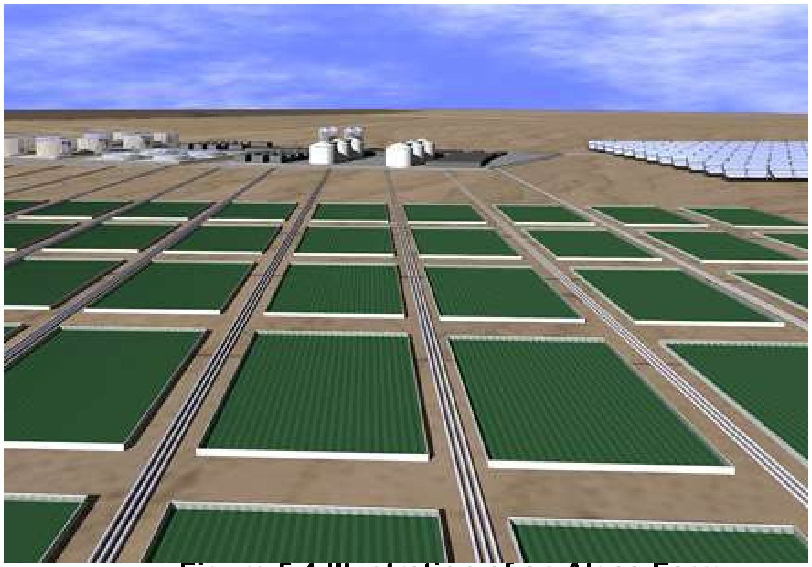

Figure 5.4 Illustration of an Algae Farm

(SOURCE: HTTP://CDN.CBSI.COM.AU/STORY_MEDIA/339289867/ALGAE-FARM-RENDERING_1.JPG)

One of the main disadvantages of open systems is that parameters are harder to control than in closed systems. Management of environmental factors is very important in maintaining pure monocultures in open ponds. Because of a long light path, relatively poor mixing, and low photosynthetic efficiency, which lead to low biomass concentration and volumetric productivity, the algae growing season is largely dependent on location. Nevertheless, open ponds are the most common, commercially used algae cultivation systems in operation today.

5.2.1.4 Closed Photobioreactors

Closed photobioreactors (PBRs) have distinct advantages as well as disadvantages. PBR systems are more technologically complex compared to open systems. There is some expectation that PBR cultivation could improve efficiency in attaining greater biomass density and provide potential environmental benefits, such as decreased inputs of certain natural resources. However, the increased complexity and design typically leads to higher costs for utilizing closed systems than open ones.

A PBR can be described as an enclosed culture vessel that is designed to utilize light to support photosynthesis for controlled biomass production. Because of the variety of approaches taken to balance light distribution with maximizing culture density and total oil content, countless PBR designs have emerged that can be categorized generally into either indoor or outdoor closed PBRs. Indoor closed PBRs usually require artificial illumination. Outdoor closed PBRs utilize natural daylight and in some cases may also incorporate artificial illumination, such as tubular PBRs. PBRs tend to have higher volumetric productivity than open ponds. The most efficient large-scale PBRs should in theory accommodate large volume, occupy less space, have high biomass yields, and, for outdoor PBRs, should also have transparent and high illumination surfaces.

General categories of PBRs include indoor/outdoor polyethylene sleeves or bags (Figure 5.5), outdoor tubular (Figure 5.6) and flat plate systems that come in several variations, and indoor columns or modular tank systems. Continuous and hybrid PBR systems, which are variations of the linear, single-step cultivation practices discussed thus far, address more specific biological limitations and economic barriers to large-scale algae cultivation. Each of these various PBR systems has its advantages and disadvantages. Compared with open ponds, PBRs exhibit better control of temperature, pH, and light intensity, with higher biomass densities in lower quantities of water and on less land. Tubular PBRs are very suitable for outdoor mass cultures of algae since they have large illumination surface area. On the other hand, one of the major limitations of tubular photobioreactors is poor mass transfer. It should be noted that mass transfer (oxygen build-up) becomes a problem when tubular photobioreactors are scaled up. For instance, some studies have shown that very high dissolved oxygen (DO) levels are easily reached in tubular photobioreactors *(Source: Molina, E., J. Fernandez, F.G. Acien and Y. Chisti. 2001. Tubular photobioreactor design for algal cultures. 92:113-131).*

The Japanese, French and German governments have previously invested significant R&D dollars on novel closed bioreactor designs for algae production. Numerous U.S. firms base their processes on PBR technology. The main advantage of such closed systems is that they are not as subject to contamination by organisms carried in the wind. The Japanese have, for example, developed optical fiber-based reactor systems that could dramatically reduce the amount of surface area required for algae production. While breakthroughs in these types of systems may well occur, their costs are, for now, prohibitive—especially for production of biofuels.

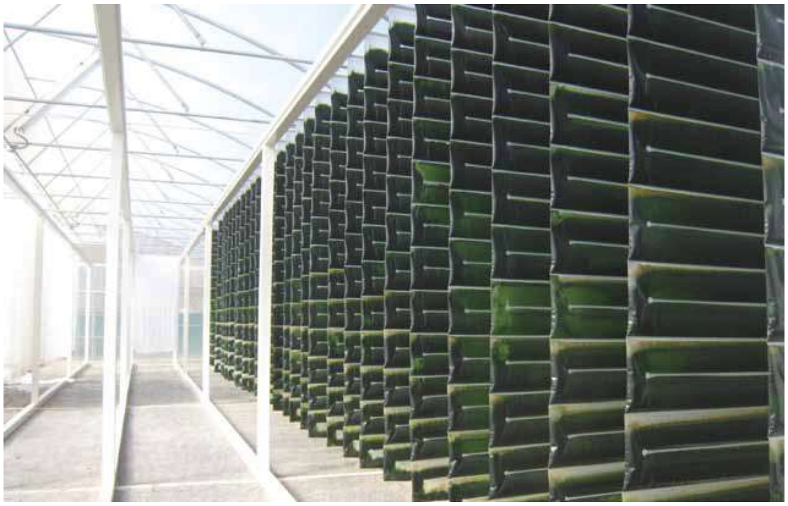

Figure 5.5 Polyethylene Sleeves for Microalgae Production
(*Source: Valcent Products Inc.*)

Figure 5.6 an Outdoor Tubular PBR System for Microalgae Propagation
(*Source: Bioprodukte-steinberg.de)*

5.2.2 Offshore Based Systems

Offshore systems are currently being utilized for seaweed production. These systems have inherent advantages and disadvantages. Advantages include the availability of potential large production areas and no mechanical mixing requirements. Disadvantages include no temperature control, no light control, destruction due to rough waters, maintenance of correct salinity and harvesting. Algae strains used for offshore-based systems are usually non-native species that are able to attach themselves to supports that are either located horizontally or vertically in the water. For growth and harvesting it is important that constant (or as constant as possible) temperature, availability of nutrients, shallowness of water and proximity to shore be considered for the best conditions.

A few companies are developing the use of off-shore culturing systems for biofuels production. For synergy, the use of areas already dedicated to wind farms or wave energy projects may be appropriate sites for culturing of macroalgae for biofuels. The idea is that the wind farms or wave energy equipment could provide light for the algae during night time. Texas with its abundant offshore areas may be an ideal place for technology providers to consider off shore algae operations along with wind mill operations.

The question of where algae farms for biofuels should be located is an important one. In addition to the need for water (salt water for growth and freshwater for maintaining the right salinity), there is the need for adequate sunlight and a supply of essential nutrients, including CO_2. Both the freshwater and the nutrients can be supplied by municipal wastewater; however, it should be noted they would emit odor and may be considered a nuisance. As the distance between the algae farm and the source of nutrients increases, the issue of plumbing and pumping or trucking impacts the economics of the farms.

While a few large-scale commercial raceway examples exist, the biggest closed systems cover a few acres. For either option, no commercial example of energy production from algae exists. In recent years, many claims have been made on possible productivities (and often oil contents) that approach or even cross the theoretical maximum. However, no commercial algal energy producer yet exists and high-yielding terrestrial crops currently exceed algae's energy content (but the area available for algaculture surpasses that of terrestrial crops by far). Attaining a positive energy balance of energy output versus energy input for the operation and production of the cultivation system, and maintaining the needed financial returns to cover costs and investment present large challenges to overcome for the use of algae as a viable bioenergy feedstock.

5.3 Operational Cost Barriers

For algal biodiesel production numerous steps are required. These include culturing, harvesting of the algal biomass, oil recovery, and biodiesel/biojet and co-product production. Co-products can include chemical, polymers, plastics and animal feed. Figure 5.7 illustrates the process in general.

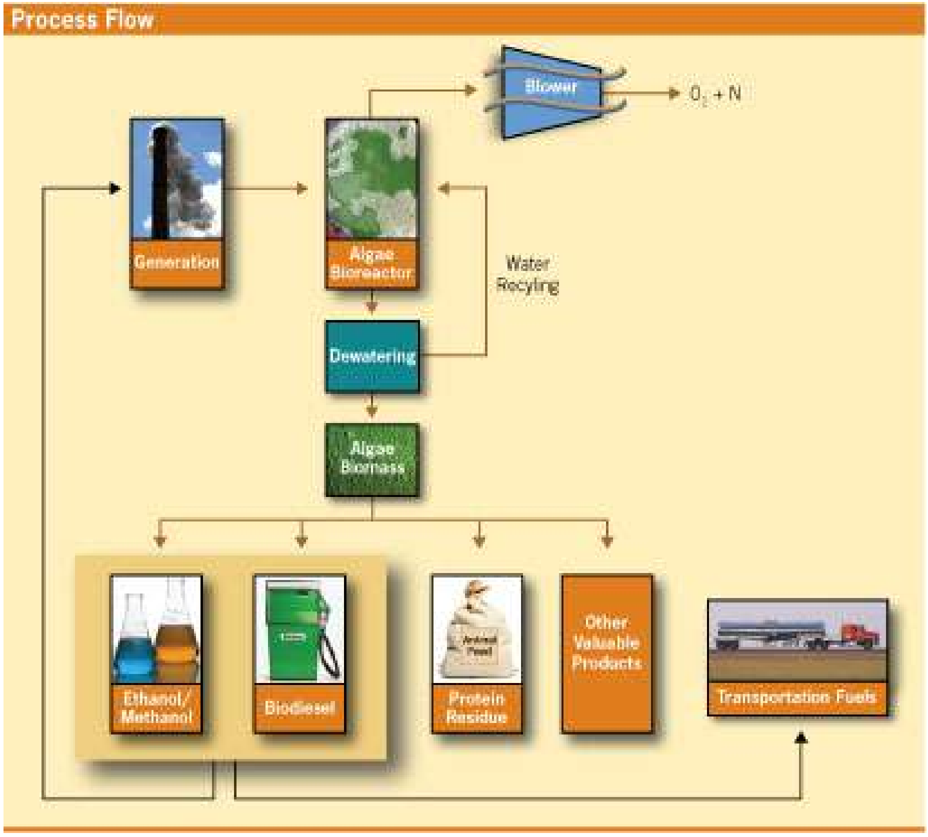

Figure 5.7 Algae Biodiesel Process Diagram
(*Source: http://www.reuk.co.uk/Biodiesel-From-Algae.htm*)

Operational costs of several algal biodiesel production steps still need to be reduced substantially to decrease the cost of production. The following section discusses the major operational barriers needed to be considered to decrease those costs and some of the newer technologies being considered for cost reductions.

5.3.1 Water

Today's engineered open cultivation systems require large quantities of water which affect the operational costs. The water demand for vast ponds creates concern, most particularly where either water reclamation or wastewater treatment is not an integral component of the cultivation process. How water demand for commercial algae cultivation compares to oil seed crops is unclear; nevertheless, such demands on water could present immense challenges for algae biofuels development, particularly in that the majority of these open systems could be located in water-constrained regions of the Southwest, including Texas. Another consideration is how great an impact millions of acres of ponds (possibly with ground liners) will have on the water table, groundwater salinity, nutrient regulation, and natural runoff to rivers and reservoirs. Even with the recycling of process wastewater, evaporation will require new inputs of water on a regular basis, especially in arid and semiarid climates. Conversely, off-shore ponds may utilize seawater, which would limit impact on freshwater supplies. Nevertheless, the introduction and continuous cycling of saline water through a naturally freshwater ecosystem to control salinity will likely have some effect on the immediate environment, certainly in terms of an increased chance for chemical contamination and groundwater salinity. High evaporation rates could influence salinity or nutrient concentration. To prevent salt accumulation, some water needs to be discharged continuously from the ponds—the faster the evaporation, the larger the discharge. The impact of continuous discharging will vary depending on the quality and volume of the water and the manner in which it is discharged, and whether it is reused or released into the local environment.

5.3.2 Nutrients and CO_2

Algae rely on several nutrients to prosper, such as nitrogen, phosphorous, and carbon dioxide. Each nutrient is an important component of the algal growth cycle. Eutrophic or mixed waters (such as animal litter, tertiary wastewater, and agricultural or industrial effluents) are rich in nitrogen, phosphorus, and other nutrients and minerals. The use of nutrient-rich water helps algae grow and decreases the need for endogenous nutrient inputs, thus decreasing operational costs. Cultivation systems that do not utilize wastewater must add nutrients such as phosphoric acid and urea or ammonium nitrate. Fertilizers are often used as the nutrient source and these can be expensive.

Atmospheric CO_2 is adequate for algae growth in the wild; however, most commercial systems inject air, pure CO_2, or liquid CO_2 to boost productivity. The CO_2 concentrations are significantly lower than what is required. Based on the average chemical composition of algal biomass, approximately 1.8 tonnes of CO2 are needed to grow 1 metric ton of biomass. Natural dissolution of CO_2 from the air into the water is not enough. This could be improved by bubbling air through the water, but, since air contains about 0.0383 percent of CO_2, all of the CO_2 in about 37,000 m3 air is needed for 1 metric ton of dry algae. Additional warm air or CO_2 inputs in cold climate conditions may also keep open ponds at tolerable temperatures, ensuring algae survival and even a degree of continued cell growth. However, purging in open or closed systems increases production costs.

One viable option, which companies consider as a CO_2 source is flue gas from power plant emissions. Flue gas typically contains approximately 4 percent to 15 percent of CO_2 and is free of charge or even produces revenue if a financial structure for the prevention of greenhouse gas emissions is available. The only cost is the supply from the source to the cultivation system, which can be significant depending on the distance and water depth. The flue gas can also be utilized as an external heat source for temperature control. Therefore, co-location with power plants should be considered if other infrastructure requirements are available. There are other scalable sources of CO_2. In West Texas, CO_2 for enhanced oil recovery comes from natural CO_2 deposits in Colorado. Co-location with existing distribution networks or pipelines should also be considered, although this CO_2 is considered a commodity and priced accordingly.

BioEcoTek, a Hawaii-based company, is actively deploying a system, which integrates wastewater treatment with algae growth to significantly reduce operational costs. In this process wastewater generated form a wastewater treatment facility is clarified and is fed to an anaerobic digester, which produces biogas (methane and CO_2). The biogas is cleaned and used for generating power for the facility. The wastewater coming from the digester now has reduced solids concentrations but has a high concentration of nutrients for the algae. This water is then used for algae cultivation thus eliminating the costs of water and nutrient input for algae growth. http://www.triplepundit.com/2010/06/breaking-the-cost-barrier-on-algae-based-biofuels/

5.3.3 Biomass Harvesting

One of the major operational costs that needs to be overcome is algal biomass harvesting costs. Harvesting has been claimed to contribute 20 to 30 percent to the total cost of producing the algae biomass *(Source: Grima, E. M., Belarbi, E. H., Fernandez, F. G. A., Medina, A. R. and Chisti, Y. (2003): "Recovery of microalgal biomass and metabolites: process options and economics." Biotechnol. Adv. 20 (7-8): 491-515).* Harvesting costs are high due to the micrometer size of microalgae and the amount of water that needs to be removed to obtain the algae biomass. In order to produce energy from algae as economically as possible, the most inexpensive methods for concentrating the algal biomass for oil pressing is essential.

Harvesting methods include settling tanks, dewatering, flocculation, filtration, and centrifugation. Other methods exist, but these are the most commonly used. For open ponds, settling tanks are ideal. Once the algae culture is mature, it is passed from the culturing pond to a settling pond where the cells are allowed to settle and the water removed. Centrifugation can be used at this time to dewater the biomass from a concentration of approximately 3 percent to a 20 percent concentration (*Source: Sazdanoff, N. (2006). Modeling and Simulation of the Algae to Biodiesel Fuel Cycle, College of Engineering, Department of Mechanical Engineering, The Ohio State University)*. Centrifugation by itself is an expensive harvesting method. The high-energy costs associated with this type of separation is acceptable for high value products but by itself, is prohibitive for fuels production. However, it can be used effectively as a secondary recovery method as described above.

Dewatering is a necessary step due to the nature of the feedstock. The dewatering process can increase biomass solids content up to approximately 20 percent via a draining tank or screw press. The recovered biomass can be directed to a vessel, such as a stainless steel tank, where the water settles to the bottom and is drained out of the tank. A mechanical screw press expels water with pressure and directs wastewater to a treatment facility if necessary and then back to the cultivation facility. Dewatering uses few inputs, if any, which are restricted to the energy required for operating and maintaining the screw press or draining tank.

Flocculation is used extensively in wastewater treatment. In a similar application, flocculating agents cause the algae to clump in large biomass sheets, which can then be skimmed from the surface of the water or be secondarily harvested using other methods via centrifugation or filtration. Methods include bioflocculation, chemical flocculation and electroflocculation. Removal of chemical flocculating agents is required.

Microfiltration, a method where algae are filtered from the water utilizing microscreens can also be used for biomass harvesting. The use of screens can be difficult due to plugging of the filters.

Microfiltration does not necessarily employ chemicals and does not require treatment of filtered water before it is recycled to the cultivation system, along with the immature, unharvested algal cells.

Harvest methods are currently being developed to reduce the high operational costs. Algaeventure Systems in Ohio is developing a unique harvesting system that dewaters and dries suspended algae solutions using an absorbing moving bed. The research is partially funded through DOE. The technology produces an algae flake ideal for downstream processing or used as is. http://www.algaevs.com/. Research and commercial development is underway on algae that do not need to be harvested, but rather rely on the algae to secrete oil or ethanol directly.

5.3.4 Oil Extraction

Oil extraction yields are critical to the economics of biodiesel production and can be expensive. Oil harvesting can be accomplished by using mechanical or chemical methods. The most common methods include pressing (mechanical expulsion), osmotic shock, sonication and solvent extraction. The percent yield of total available oil from the biomass will depend on the efficiency of the extraction method used. In some instances, technologies may be favored for their superior performance (e.g., chemical extraction) over less efficient technologies (e.g., mechanical extraction), despite higher operational costs.

Mechanical expulsion technologies include the screw press, extruder and expander, and pulverization in a mortar. In the mechanical expulsion process, oil is expelled from dried algal cells by one or more of these methods. Mechanical methods are not as efficient as chemical methods but are lower cost. Thus you can sacrifice yield for operational costs. The main energy input for mechanical methods are electricity.

The firm Origin Oil claims that it has a portfolio of technologies that it can deploy to algae project developers that can reduce the oil extraction cost. It claims to possess a single step oil extraction process, which dewaters, extracts and separates the algae biomass in one step. It also claims to have a technology that "milks" the oil from the algae without having to disrupt the cells; a process termed "Live Extraction." http://www.originoil.com/

5.4 Algal Biodiesel Economics

Presently the process of producing fuel from algae would appear to be uneconomic with over 50 algal biofuel companies in existence and none yet producing commercial-scale quantities at competitive prices. Advantages of open ponds or raceways are their inherent lower capital costs when compared to those of bioreactors. Some disadvantages of the open raceways however, are lower yields, evaporation, and intrusion of contaminating algal species. Bioreactors have advantages in that high concentrations of biomass are possible in lower space requirements, but they require high capital costs, have problems with scaling to sufficient size for biofuels production, temperature control, and biofouling limiting light availability, all of which impact the economics of their operations. Raceways are considered the more economical systems at approx $40,000/acre, while the current designs of closed bioreactors on land are estimated to be close to $1,000,000/acre (*Source: Benemann 2007: Algae Biomass Summit; Seattle*). Bryan Wilson of the biodiesel start-up company Solix stated recently that using their bioreactor technology they can currently produce a gallon of biodiesel at approximately $32.81 a gallon. The production cost is high because of the energy required to circulate gases and other materials.http://www.greentechmedia.com/articles/read/algae-biodiesel-its-33-a-gallon-5652/

In 1998 NREL concluded that open systems were the only economic solution for large-scale production. http://www.nrel.gov/docs/legosti/fy98/24190.pdf. NREL/TP-580-24190. A recent study by Auburn University again concluded that open systems were the only economic system (*Source: Putt, R. Algae as a Biodiesel Feedstock: A Feasibility Assessment. s.l.: Department of Chemical Engineering, Auburn University, Alabama, 2007).*

A common feature of the three most common algal species currently produced commercially for food supplements is that they are grown in open-air cultures. The production cost of oil from algae, grown in open saline ponds in a project involving Murdoch University in Perth, Western Australia, has been reported below US $1.82 per pound reduced from US $5.45 per pound in a year, but their aim is to get the cost down to less than US $0.45 per pound to be competitive.
http://www.eurekalert.org/pub_releases/2009-11/uoa-cab110409.php

A review of the potential of marine algae as a source of biofuel in Ireland estimated that the cost of algal biodiesel feedstock produced in open ponds in Israel is over $1.27 per pound and concluded that a cost reduction of at least a factor of five is required and that current cultivation costs can only justify extraction of high-value products, not biodiesel.
http://www.sei.ie/algaereport

5.5 Texas-based Algae Biodiesel Companies, Projects, Technologies and Associations

Numerous Texas-based algae projects, technologies, associations and universities are involved in the development of algae biodiesel. These details are shown in Table 5.1.

5.6 Texas Algae Biodiesel Potential

The U.S. government enacted the Energy and Security Act of 2007 (EISA) on December 19, 2007. The legislation expanded the Renewable Fuels Standard and for the first time specifically provided for a renewable component in U.S. diesel fuel. RFS2 required the use of 500 million gallons of biomass-based diesel in 2009, increasing gradually to 1 billion gallons in 2012. From 2012 through 2022, a minimum of 1 billion gallons must be used domestically, and the Administrator of the EPA is given the authority to increase the minimum volume requirement. In the case of Biomass-Based Diesel, just recently the EPA elected to carry the 500 million gallon mandate of 2009 forward and combine it with the 650 million gallons required in 2010 by EISA. Therefore, the Biomass-Based Diesel mandate in 2010 will now be 1.15 billion gallons. To qualify as biomass-based diesel, the fuel must reduce greenhouse gas emissions by 50 percent compared to petroleum diesel. Biodiesel is the only fuel available in commercial quantities in the U.S. that meets the definition of biomass-based diesel.

Biodiesel production from 2004 to 2009 in the U.S. is shown in Figure 5.8. Production increased significantly from 2004 to 2008, but, with drops in oil prices, increased costs in soybeans and no extension of the federal tax credit for biodiesel, this trend diminished in 2009 to just over 500 million gallons. Texas leads the Nation in energy consumption, accounting for more than one-tenth of total U.S. energy use. With regards to diesel consumption, Texas consumed 141.35 million barrels of distillate fuel in 2006, 144.54 in 2007 and 143.80 in 2008. Diesel consumption in 2008 was equivalent to 10% of the U.S. consumption; thus its diesel demand is significant. http://www.eia.gov/state/state_energy_profiles.cfm?sid=TX#Datum

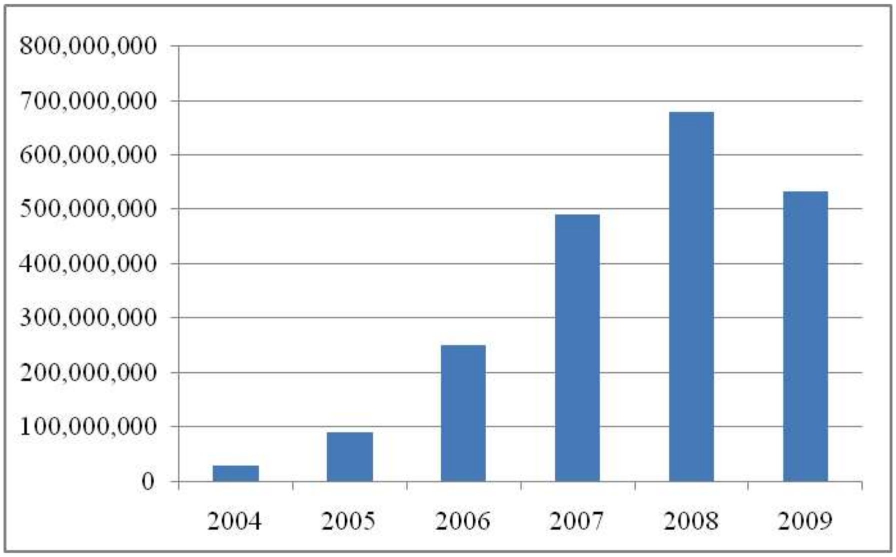

Figure 5.8 U.S. Biodiesel Production (Gallons)
(*Source: U.S. DOE Energy Information Administration*)

In the U.S., biodiesel is blended at a minimum of 2% by volume. If 2008 is considered as the base case for diesel consumption in the state, for a 2% blend there would need to be an approximate availability of 121 million gallons of biodiesel, or 23% of the current U.S. production. Blends of up to 5% have been considered, thus requiring 302 million gallons, or 56% of current U.S. production. While these numbers seem large, it represents a small fraction of the nation's 2 billion gallons of production capacity.

In February of 2009 there were 19 biodiesel producers in Texas with a production capacity of 448 million gallons – more than sufficient production capacity to provide even a 5.5% blend mandate with significant exports. http://tonto.eia.doe.gov/whatsnew/newwhatsnew.cfm Unfortunately, due to the issues mentioned previously, U.S. biodiesel production is currently at less than 20% of capacity, and some of the existing facilities have been closed or sit idle.

For algae-based biodiesel production land-based systems such as open ponds in the state could be considered. For open ponds, production of 2,000 to 5,000 gallons an acre per year would be realistic. This would require 24,200 to 60,500 acres to produce the 121 million gallons required for a 2% blend. With a state the size of Texas, and with its natural resources, land availability should not be a barrier. To this point, Texas AgriLife Research (part of the Texas A&M University System) has a $12.5 million in long-term algae development program funded from the Texas Emerging Technology Fund, the Department of Defense, and the Department of Energy to develop technologies that can lead to rapid economical commercialization of fuels and co-products. The program is developing brackish water algae production systems in Pecos, Texas, in the western part of the state, and at Corpus Christi. The program objective is to: utilize non-potable water; high solar radiation areas of the state; CO_2 from utilities, industrial complexes, and pipelines; and waste water from municipalities to produce drop in fuels – diesel and jet fuel.

According to the National Oceanic and Atmospheric Administration, Texas has 367 miles of coastline. It is the second longest coastline in the nation. Offshore based systems could certainly be demonstrated in Texas; however, as mentioned previously, these technologies have their limitations due to control of growing condition parameters. With deployment or commercialization of any of these algae systems, the economics of the project should always be considered.

5.7 Summary

The production economics of algal biodiesel are still too high to be competitive with fossil-based diesel. It may take another 10 to 15 years to turn laboratory experiments into industrial-scale production of algal biofuel http://www.reuters.com/article/idUSTRE5526HY20090603. For this to be achieved, an economic process must be established that will include efficient algal cultivation, harvesting and extraction and may require the movement away from the historical emphasis on fuel from algal lipid. It will also require that yield of economic products is maximized, be that energy, chemical, feed or fertilizer and that the entire algal biomass is utilized. Anaerobic digestion could be a vital part of an economic algal energy process.

Current investments are predominantly focused on next generation algae production systems that employ low-cost ponds and high-technology production methods. It is envisioned that the markets for algae-based biodiesel, biocrude, and biomass-derived green chemicals and plastics will start to enter early-stage commercial production by the end of 2013.

6.0 FEASIBILITY AND ECONOMIC DEVELOPMENT EFFECT OF A BLENDING REQUIREMENT FOR BIODIESEL OR CELLULOSIC FUELS

6.1 States' Biofuels Legislation – RFS Mandates

On October 13, 2010, the United States Environmental Protection Agency (EPA) granted a partial Clean Air Act waiver to the ethanol industry's request to allow the use of E15. The EPA will allow E15 to be used in model-year 2007 or later cars and light-duty trucks. The EPA will decide whether to allow E15 to be used in vehicles built between 2001 and 2006 after it receives further testing data from the Department of Energy (DOE). In addition, the EPA stated that E15 cannot be used for any other vehicles or engines, including those with heavy-duty engines such as delivery trucks; motorcycles; all off-road vehicles, such as boats and all terrain vehicles; and engines in off-road equipment, such as lawnmowers and chain saws. The agency plans to rely on a new proposed fuel pump label and industry education campaigns to prevent what critics say could be widespread misfueling.

Studies have shown that increased biodiesel blends do not result in the motor and fuel system wear that higher ethanol blends do.

Several states have legislated either ethanol and/or biodiesel mandates. Table 6.1 shows the states that have current mandates and the description of those mandates. Some states have mandated the use of ethanol and biodiesel while others have mandated one or the other. Currently twelve states have introduced their own Renewable Fuels Standard (RFS) and thirty-eight states provide incentives promoting ethanol production and use. Minnesota is known for aggressive mandates, and it has actively pursued biofuels legislation; the state currently has the most number of ethanol plants in the nation.

In 2005, Minnesota passed a law mandating use of 20% ethanol in the state's gasoline by 2013, if certain conditions are met. The State of Minnesota and the Renewable Fuels Association are sponsoring research on E20 in support of the mandate. Their research areas include automotive exhaust and evaporative emissions, materials compatibility, drivability, and air-quality effects. Preliminary research from the study suggest E20 presents no immediate problems for current automotive or fuel dispensing equipment (which is listed for E10 use only by Underwriters Laboratories) and that vehicles fueled with E20 operate with similar power and performance as those fueled with E10. These studies must be evaluated in the context of more current and definitive research and data analysis on effects of ethanol blends higher than E10 (this is the on-going DOE Catalyst study that formed the basis for EPA's E15 waiver approval). EPA's analysis of the testing results includes discussion of the Minnesota and Renewable Fuels Association report and other reports cited by the ethanol industry, and concludes those studies were not robust enough or designed appropriately to definitively rule out negative impacts from ethanol blends higher than 10% on vehicles other than new Tier II light-duty vehicles (2007 and newer). DOE is continuing to test model year vehicles 2001-2006, and that data should be available in late December 2010 or early 2011.

6.2 Feasibility of a Biofuel Blending Requirement in Texas

Although Texas does not have any current biofuels mandate, it has enacted several legislative measures that promote the use of various renewable fuels. These are listed in the Section 9 report. Figures 6.1 and 6.2 show historical gasoline and diesel consumption data for the state of Texas from 2000 to 2008.

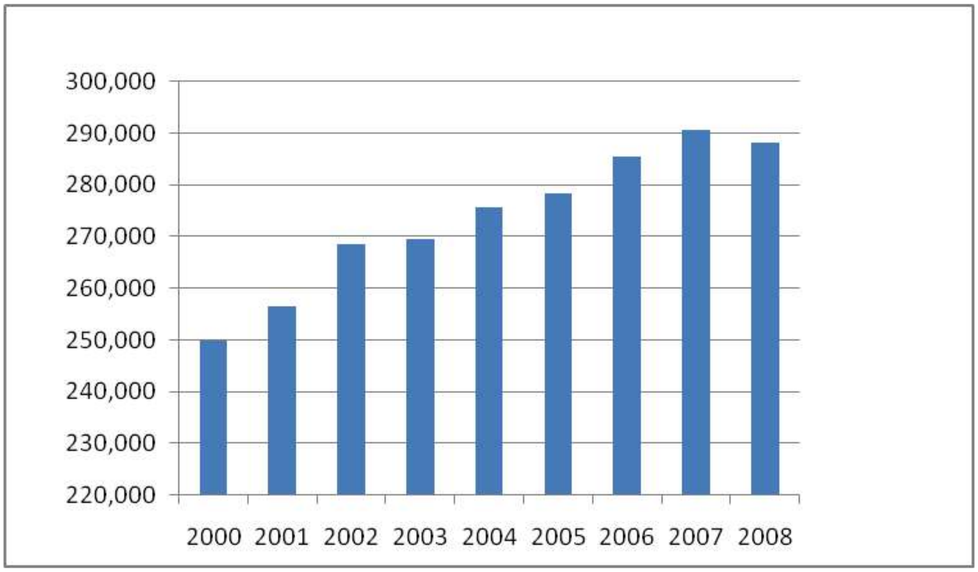

Figure 6.1 Texas Gasoline Consumption (Thousands of Barrels)
(Source: *http://www.eia.gov/emeu/states/_seds.html*)

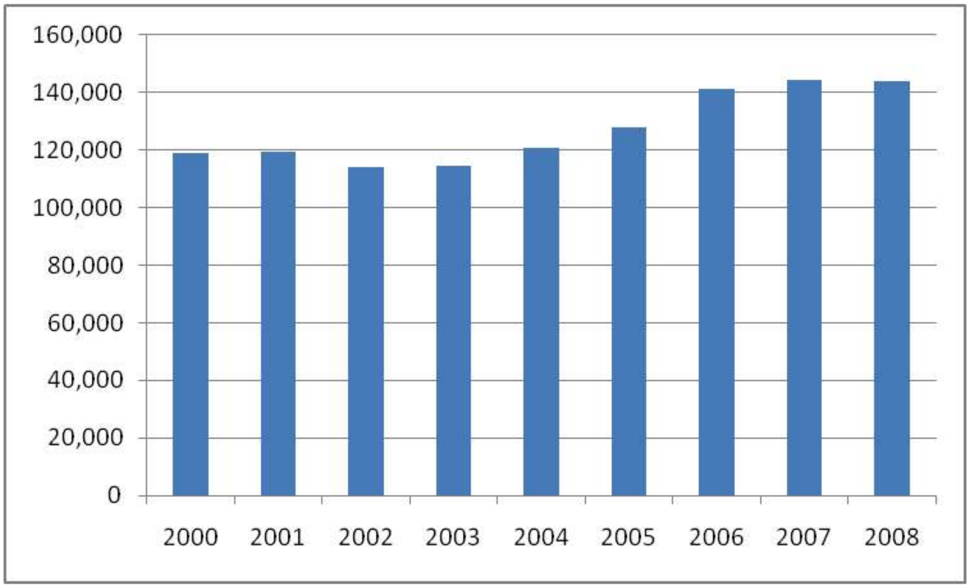

Figure 6.2 Texas Diesel Consumption (Thousands of Barrels)
(Source: http://www.eia.gov/emeu/states/_seds.html)

The trend shows an increase in gasoline use from 2000 to 2007. The year 2008 showed a slight decrease, most likely due to the spike in gasoline prices that year. Although diesel consumption does not show the linearity observed in gasoline consumption, an increase in consumption is evident from 2003 to 2008.

Texas is the number one state in total energy consumption in the nation and the second in consumption in the energy transport sector (http://www.eia.gov/emeu/states/_seds.html). Figures 6.3 and 6.4 demonstrate the annual percent increase in projected fuels use in the U.S for gasoline and diesel, respectively. These are projections as estimated by the EIA in their Annual Energy Outlook 2010 http://www.eia.doe.gov/oiaf/aeo/index.html. As demonstrated, gasoline projections indicate that there will be a decrease in overall gasoline and diesel consumption up to the year 2023 with fluctuations up to the year 2030. A decrease in gasoline consumption is projected while diesel consumption stays in a positive percent change. However, the EIA still projects transportation fuels use to increase, most likely signaling a large contribution for renewable fuels including advanced and cellulosic biofuels. E85 (a blend of 85% ethanol and 15% gasoline) is projected to increase in 2030 by 23.3 percent.

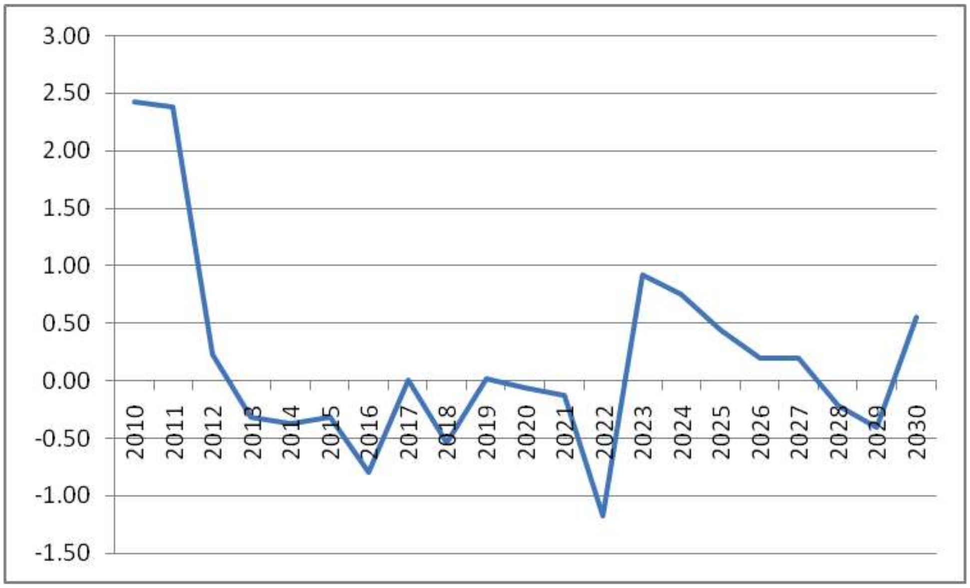

Figure 6.3 Projected Annual Percent Change of U.S. Gasoline Consumption
(*Source: http://www.eia.gov/emeu/states/_seds.htm*)

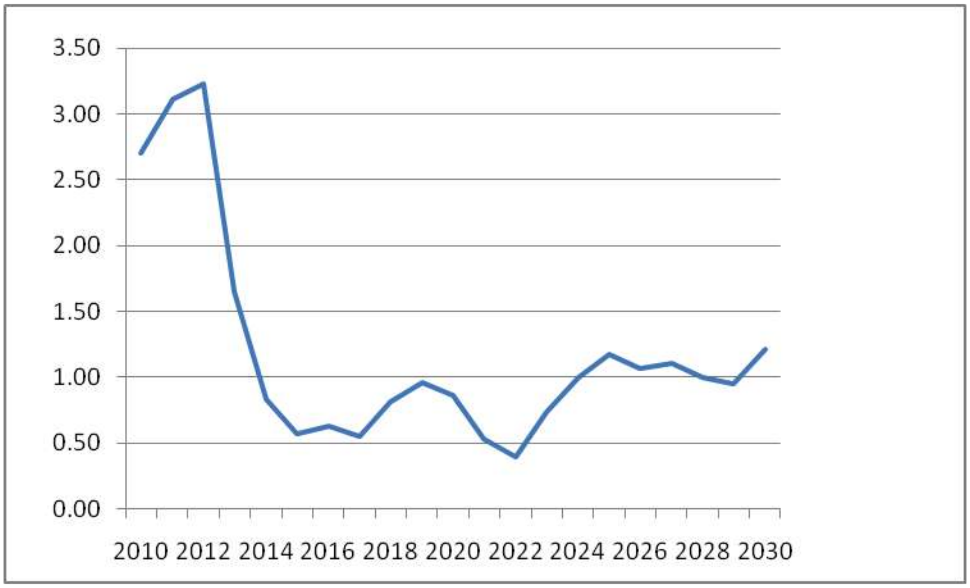

Figure 6.4 Projected Annual Percent Change of U.S. Diesel Consumption
(*Source: http://www.eia.gov/emeu/states/_seds.htm*)

This being the case, it will be important that Texas be aligned with the projected renewable fuels demands and use projections. The two major ozone nonattainment areas in Texas are the greater Houston and Dallas areas. Gasoline sold in both of these areas must be reformulated gasoline (RFG) as mandated by EPA. Fuel producers currently use a 10% ethanol blend to assist in meeting the specifications of RFG. For other areas of the state, fuel producers and importers generally use a 10% ethanol blend to achieve the EPA renewable fuel standards. Currently, Texas does not have a statewide mandate for biofuels blends for the transportation sector except for its Alternative Fuel Use Required in State Fleets. Blend scenarios and requirements in neighboring states, serviced by the Texas refinery base, may require state policymakers to respond with policies to maintain consistency with regional fuel needs.

For biodiesel, the EPA elected to carry the 500 million gallon mandate of 2009 for biomass-based diesel forward and combine it with the 650 million gallons required in 2010 by EISA. EPA communicated their intent in November 2008 when it issued the 2009 standard. Therefore, the biomass-based diesel mandate in 2010 will now be 1.15 billion gallons. Currently the production cost of bio-diesel is high due to higher oilseed prices and the loss of the $1.00 biodiesel tax credit, which the federal government allowed to expire in December 2009. A state mandate for biodiesel at low-level blends, increased over a number of years as supply warranted, would aid the industry considerably, but the cost and benefits of such a proposal should be weighed. Technology and market forces should determine conditions for the ramp-up rather than a strict legislative timeline, but, for perspective, a 2% biodiesel blend would currently require approximately 2,880,000 barrels of biodiesel or 121,000,000 gallons.

There are currently three operating corn/grain sorghum ethanol production facilities in Texas, and a fourth may soon come into production. Texas is a corn-deficit state and therefore must import a large portion of its corn to meet needs beyond the production of ethanol. The Levelland/Hockley County plant, which uses solely grain sorghum, has an operating capacity of 40 million gallons and the White Energy plant in Hereford, Texas, has a 100 million gallon per year capacity. If the state were to have an E-10 mandate throughout the state it would at this point require approximately 1.2 billion gallons of ethanol, well beyond its current production capacity. Most of the ethanol would be supplied via imports. However, as can be seen from the table above, some states have implemented lower ethanol mandates that could be increased as previously mentioned for biodiesel. Texas AgriLife Research is currently developing grain sorghum hybrids that are more drought resistant and produce higher sucrose yields per acre. Due to the state's leading effort in grain sorghum research and applications, establishing or attracting grain sorghum-based, second-generation or advanced fuel producers would support the state's agriculture sector and increase in-state ethanol production.

Since the Energy Independence and Security Act (EISA) caps the amount of ethanol from corn starch at 15 billion gallons by 2015, the remaining 21 billion gallons will come from advanced and second-generation feedstocks. Grain sorghum, sweet sorghum, sugar cane ethanol, algae biofuel, cellulosic ethanol, and non-ethanol advanced biofuels from lignocellulosic feedstocks will likely qualify into one or two of these fuel categories. A significant expenditure of both public and private sector funds for R&D directly supporting future development of biofuels was made in 2009 and will continue in future years. In the U.S., more than $2 billion was spent in 2009 on R&D activities directly related to new generation biofuels feedstocks and technology. Texas AgriLife Research alone has a $40 million research, development, and demonstration (RD&D) program addressing advanced biofuels feedstock development including both algae and lignocellulosic sources. If Texas continues to align its research activities to deployment activities of second-generation biofuels such as algae, cellulosic ethanol, and generation two drop-in fuels, as well as promote the existing biodiesel infrastructure already established, the state could reap significant contributions from these activities.

6.3 Cellulosic Biofuels Requirements

Traditional first-generation ethanol is the focus of current federal blending requirements mentioned previously; however, no states currently have mandated cellulosic ethanol blend requirements. Pennsylvania's mandate for cellulosic fuels has not been implemented due to a lack of available fuel, as stipulated in the enabling legislation. The state ethanol blend mandates mentioned previously can be fulfilled with either first generation ethanol production or second-generation (i.e., cellulosic ethanol). Unfortunately, availability of cellulosic ethanol is not sufficient to be introduced into the fuel supply chain in quantities that would be relevant to the current RFS2 demand (see Section 9). The promise of cellulosic ethanol production is that it will utilize undervalued and underutilized feedstocks, it possesses a significant positive net energy balance, and that these cellulosic feedstocks will not affect the food supply chain as the feedstocks are inedible by humans (i.e., no associated food vs. fuels issues).

6.4 Blending Requirements Economic Impacts

Blending requirements affect many sectors of the economy, not just fuels markets. The agricultural sector, job growth or loss, tax revenues on fuels with higher percentages of fuel exempt from taxation and state and national GDP must be analyzed.

According to a January 2008 study by agricultural economist John Urbanchuk, the economic impact of a 36 billion gallon Renewable Fuel Standard (RFS) is as follows for the nation:

- It will add more than $1.7 trillion to the gross domestic product between 2008 and 2022;

- It will generate an additional $436 billion of household income for all Americans during the same time period;

- It will support the creation of as many as 1.1 million new jobs in all sectors of the economy; and,

- It will generate $209 billion in new federal tax receipts.

(Source: Economic Impact of the Energy Independence and Security Act of 2007, LECG LLC.)

As stated above, a 2% biodiesel mandate in Texas would require the state use 121,000,000 gallons of biodiesel. For a statewide 10% ethanol blend it would require 1.2 billion gallons of ethanol. This may already be the current consumption rate of ethanol in Texas due to refiners using ethanol in RFG areas in Texas to address federal fuel specification requirements. In other areas of the state, use of ethanol by refiners and importers is in order to comply with federal RFS requirements. Numerous case studies have previously demonstrated that in-state production of biofuels has an overall economic surge throughout the internal biofuels supply chain as well as externally. Whether the feedstocks are grain, sugarcane, waste grease, and oils, etc., biofuels production increases construction, employment, household income, and contributes to the states' tax base and GDP. As mentioned previously, currently the production of biodiesel from soybeans does not garner favorable economics based on the loss of the $1.00 per gallon federal tax credit and the increased price of the feedstock. However, there have been significant periods historically where biodiesel has been cheaper than diesel. RIN [is this an understood term?] pricing related to the RFS may create this scenario in the future.

Texas produces substantial amounts of grain sorghum across the state. Grain sorghum is similar to corn and can be used for the production of ethanol using the same plant equipment as for corn, and it is not affected by aflatoxin. To evaluate the economic impacts of a corn ethanol facility in 2004 and 2005 the Nebraska Public Power District conducted a study of the economic impacts of a 40 million gallon per year corn ethanol facility in that state. The report indicated the following:

- The plant provides a one-time boost of $71 million to the local economy during construction.
- The plant expands the local economic base of the community by $70.2 million each year through the direct spending of $58 million.
- The plant will create at least 33 full-time jobs at the plant and a total of at least 120 jobs throughout the local economy.
- The plant increases household income for the community by $6.7 million annually.

(Source: Nebraska Public Power District, Employment and Other Economic Impacts Associated with the Construction of an Ethanol Production Facility (January 2005), and Estimated Economic Effects for the Prospective Ethanol Production Facility in Boone County, Nebraska (June 2004).

Similarly, in a 2005 study conducted by ISU economists Paul Gallagher and Dan Otto, they concluded that Iowa's developing ethanol industry benefited the state's economy on many levels. Iowa's 14 existing and planned ethanol plants at the time would contribute a total of $3.9 billion to the state's economy. They estimated that the Iowa industry as a whole would contribute $16 million annually in total state tax revenues and create a total of 5,187 direct and indirect jobs within Iowa's economy http://cornandsoybeandigest.com/mag/soybean_new_study_underscores_2/.

The current corn/milo ethanol plants in Texas as well as grain sorghum plants of a similar size may provide similar economic impacts to the local area and the region. With larger plants, the economic impact of construction and operations will be significantly larger. A 50 million gallon per year grain sorghum ethanol plant would require approximately 188,000 acres of irrigated land producing 100 bushels per acre (dryland production has a smaller yield). If solely based on grain sorghum, to produce sufficient ethanol to meet a 10% statewide mandate this would require an additional 3.8 million acres of land to be planted with grain sorghum. Because of the Texas grain deficit supply situation and irratic weather patterns, this scenario is highly unlikely, and the state would need to depend on various feedstocks to meet its ethanol production demand. However, its agricultural sector would see a significant economic increase.

Due to the extensive amount of experience Texas has with sugar cane and the potential for sweet sorghum, both of these feedstocks could be utilized for in-state ethanol production. Overall, the sugar industry in Texas provides over 8,000 jobs, a significant amount of employment. Sugar cane production in Florida provides over 25,000 jobs while in Hawaii it provides 900 jobs. Although the main emphasis of these operations is sugar, in Louisiana, another sugar cane growing state, considerations are underway to produce both ethanol and sugar as a way to meet that state's biofuels production capacity http://www.greencarcongress.com/2008/06/columbian-group.html. Similarly, a Texas-based sugar cane ethanol plant would provide its sugar cane growers an alternative option for their sugar juice during the years that sugar prices are low. It could also establish sweet sorghum as a new feedstock for ethanol, thus providing an additional feedstock besides sugar cane. Job demand for a dual ethanol and sugar facility could nearly double the number of jobs in that facility.

The majority of biofuels plants are located in rural communities where the local economy is dominated by agriculture. Ethanol production is a manufacturing sector industry that pays above average wages. Further, since most grain ethanol plants source the majority of their feedstock from, and sell their co-product (distillers grains) to, farmers within a relative close proximity to the plant, the majority of the economic impact stays in the local economy.

6.5 Summary

The demand for energy in the U.S. is projected to continue to increase. Similarly, the demand for biofuels within the United States is projected to continue as the nation looks to decrease its dependence on imported oil. Numerous states have passed biofuels legislation mandating differing blends of biofuels to increase a state's economy and position in agriculture, fuels production, employment opportunities and the state's GDP.

At this time, the state does not have enough information to suggest implementing a blending mandate. Until such time the benefits of a blending mandate can be demonstrated to outweigh the costs, market mechanisms such as fuel tax exemptions on the portion of renewable fuel blended into gasoline or diesel seem more appropriate ways to stimulate supply and demand. Further, the state should look at ways to promote existing infrastructure in meeting national requirements such as the Renewable Fuel Standard. Such efforts could include getting biodiesel blends more widely approved for pipeline distribution.

Beyond mandates, policies that ensure continued use of Texas-based supply to meet national and international demand for biofuels should be further investigated and promoted by the Texas Bioenergy Policy Council. The Policy Council should play a key role, under their existing authority, of reviewing federal policies like pipeline regulation, export restrictions, and production incentives in order to assess the needs of existing infrastructure and industries in Texas.

7.0 DEVELOPMENT AND USE OF THERMOCHEMICAL TECHNOLOGIES TO PRODUCE ALTERNATIVE FEEDSTOCK AND IDENTIFY TEXAS-BASED EFFORTS

Developing biomass into a sustainable, domestic source of affordable energy, transportation fuels, biodiesel and commodity chemicals requires the flexibility to use a wide variety of biomass resources. Therefore, several bioenergy and biofuel companies and the Biomass Program in the U.S Department of Energy (DOE) have been conducting collaborative research and development (R&D) to develop and explore biomass conversion technologies. The emphasis on these research efforts is to focus on processing, upgrading and utilization issues that will result in an optimal system for final products. Work also increasingly focuses on the production of value-added chemicals from the products of conversion technologies and addresses the fractionation, isolation, recovery, and application issues related to this. The major objective of this section is to evaluate the development and use of cost competitive thermochemical process technologies to produce alternative feedstocks for process heat and power, fuels, hydrogen, and value added chemicals from a range of biomass feedstocks, and identify Texas-based efforts.

7.1 Thermochemical Conversion Technologies

Thermochemical conversion technologies are effectively applied to biomass or biomass-derived feedstocks. The process uses heat and chemistry to convert feedstocks into a liquid, solid, or gaseous intermediate. These intermediate products can directly be used as raw fuels or products, or may be further refined or upgraded to products such as ethanol, other alcohols, renewable gasoline, renewable diesel, renewable jet fuel, ethers, synthetic natural gas, chemical products, or high-purity hydrogen, or may be used directly for heat and power generation. It is important to recognize that some of these products are direct substitutes for fossil-fuel-based intermediates and products and therefore, can likely use portions of the existing fossil fuel processing and distribution infrastructure.

An advantage of thermochemical conversion technologies is that it can, in principle, convert nearly all the biomass feedstock into energy, fuels, and value added products, even those components that are difficult to process by chemical or biological means, such as residues. In addition, they can convert the lignin-rich non-fermentable residues from biochemical conversion processes. These processes provide a means to optimize biorefinery operations by utilizing residues or waste streams that might otherwise be landfilled or used for low-value products. Major thermochemical processes include gasification and pyrolysis, which both involve the conversion of solid or liquid organic matter to gases, organic vapors, water and residual solids at elevated temperatures. The other alternatives to generate energy from biomass using thermochemical pathways are directly-fired or conventional steam boiler system and co-firing.

7.1.1 Direct Fired or Conventional Steam Boiler System

Direct fired or conventional steam boiler system is mostly applied for the woody biomass-to-energy plants, whereby biomass feedstocks are directly burned to produce steam leading to generation of heat, electricity or both. In a direct-fired system, the processed biomass is added to a furnace or a boiler to generate heat by the exothermic process of combustion, and air is supplied at the base. *Hot combustion gases* are passed through a heat exchanger in which water is boiled to create steam.

7.1.2 Co-Firing

Small portions of woody or herbaceous biomass feedstocks such as bermudagrass, switchgrass, or hybrid poplar can be used as a fuel source in existing energy systems based on fossil fuels-based materials. In the co-firing process, biomass input up to 15% can be processed with current fossil fuel technologies;

mixing syngas, landfill gas or biogas with natural gas prior to combustion; blending diesel with biodiesel and gasoline with bioethanol; and using flexible fuel engines in vehicles. This process is a relatively low cost and low risk means of adding biomass capacity, particularly in economies in transition and developing countries.

Adding biomass feedstocks to coal or other fossil fuels also releases lower amount of carbon dioxide, and decreases in nitrogen and suphur oxides content. Thus, this process provides a good platform from environmental benefits to more viable and sustainable renewable energy practices.

7.1.3 Gasification

The gasification process occurs under reducing conditions with sub-stoichiometric amounts of oxygen. In the gasification process, carbon-based feedstocks are partially oxidized, or reformed with a gasifying agent (air, oxygen, or steam), which produces high yields of *synthesis gas*, or *syngas* (primarily carbon monoxide and hydrogen) and other gases rich in methane, ethane, or hydrogen. Syngas can be carried out with most biomass feedstocks without regard to the structures of the biomass components

Process reactions occur within the gasifier at extreme conditions with temperatures in excess of 2,000 ^{o}F and pressures between 400 pounds per square inch (psi) gauge (psig) and 1,000 psig. The chemistry involved in gasification process is complex and includes the following reactions in Table 7.1 (*Source: Stiegel, G.J., Massood R. and Howard G.M. (2006): The Gas Turbine Handbook, Section 1.2 – Integrated Gasification Combined Cycle, National Energy Technology Laboratory*).

Biomass gasification has been a subject of commercial interest for several decades. Interest in biomass gasification increased substantially in the 1970s because of uncertainties in petroleum supplies, with most of the development occurring in small scale systems. In the 1980s, government and private industry sponsored R&D for large scale, medium-energy gasifier systems, primarily to gain a better understanding of reaction chemistry and scale-up issues. In the 1990s combined heat and power was identified as a potential near-term opportunity for biomass gasification because of incentives and favorable power market drivers. R&D concentrated on integrated gasification combined cycle (IGCC) and gasification co-firing demonstrations, which culminated in a number of commercial-scale systems. Biomass gasifiers currently in operation can be divided into three major categories:

- Moving Bed or Downdraft
- Entrained Flow, and
- Fluidized Bed

Schematic diagrams of such systems are shown in Figure 7.1 (Source: Philips, J. (2006): The Gas Turbine Handbook, Section 1.2.1 – Different Types of Gasifiers and Their Integration with Gas Turbines, National Energy Technology Laboratory).

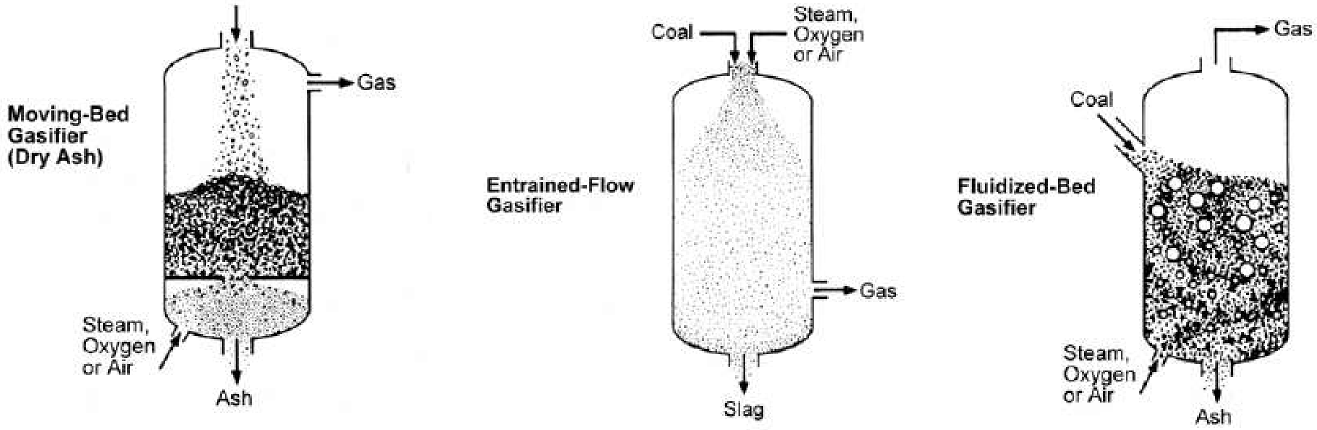

Figure 7.1 Types of Gasification Process

In a ***moving bed or downdraft gasifier***, biomass feedstocks are fed into the top of the vessel and move downward, contacting steam and oxygen/air counter-currently. As the feedstocks moves down the reactor, it is gasified. Due to the counter-current configuration, the heat of reaction from the gasification reactions is able to preheat the feedstocks before it enters the gasification zone. As a result, the temperature of the syngas exiting the gasifier is significantly lower than the temperature required for complete conversion of the feedstocks.

In an ***entrained flow gasifier***; finely ground feedstock is injected co-currently with the oxygen and steam. The feedstock heats rapidly and reacts with the oxygen/air. The residence time in this gasifier is significantly shorter than that of a moving bed gasifier. Because of this short residence time, entrained flow gasifiers must be operated at high temperature to ensure high conversion of carbon-based feedstocks. To achieve this high temperature, most entrained flow gasifiers utilize pure oxygen rather than air.

A ***fluidized bed gasifier*** is a well-stirred reactor where a consistent mixture of fresh biomass feedstock particles is continuously mixed with older partially, and fully, gasified feedstock particles. The flow of steam and oxygen/air into the gasifier controls the mixing and must not be so high as to entrain the fresh feedstock out of the bed. As the feedstock particles are gasified, however, they will become small enough that they will be entrained out. The mixing in the vessel also serves to maintain a uniform temperature throughout the bed.

Biomass gasification technology for conversion of feedstocks to syngas has been developed and scaled up from the laboratory to the pilot plant to full-scale systems. *It has been commercialized for heat and power, fuels, and syngas-derived chemicals*. Figure 7.2 shows a potential thermochemical gasification basic process flow for converting biomass to ethanol or hydrocarbons. This figure includes the potential for integration with biochemical conversion.

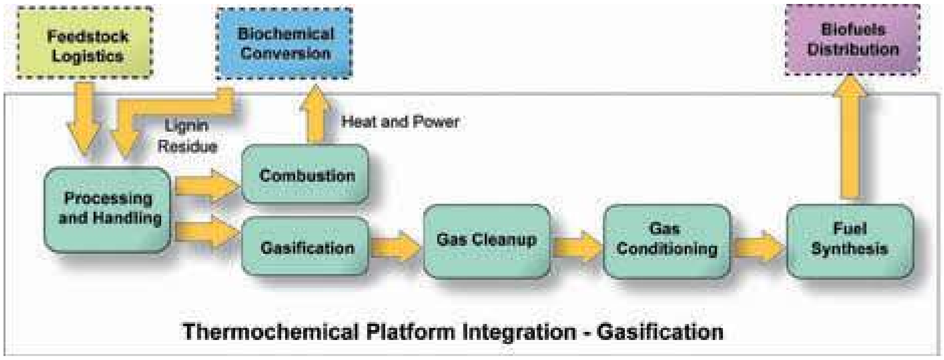

Figure 7.2 Thermochemical Platform Integration – Gasification
(Source: U.S. DOE Energy Information Administration – Thermochemical Conversion)

As shown in Figure 7.2, value added products would take three forms: heat and power, fuels, and chemicals and materials. Within each category a diversity of products can be derived from process outputs. Most of these products are manufactured today from fossil energy resources such as petroleum or natural gas. Using biomass to create these products provides an alternative to the use of fossil energy, and ultimately reduces our dependence on imported oil and gas. In addition, these products are critical to our everyday lives. They not only fuel our vehicles, but are used to create several consumer goods such as plastics, paints, pharmaceuticals, and detergents.

The gaseous product (syngas) from biomass gasification process, besides being used for heat and power, and fuels and chemicals generation, can be methanated to produce what is known as substitute natural gas (SNG) via the following reactions using appropriate catalysts:

$CO + H_2O \leftrightarrow H_2 + CO_2$
$CO + 3H_2 \leftrightarrow CH_4 + H_2O$

Various methanator designs with gas cleanings have been employed and the final SNG has a calorific value of about 38 MJ/m^3 (*Source: Slesser, M., and Lewis, C, 1979. Biological Energy Resources. E & F N Spon, London*).

Instead of SNG, syngas can also be converted to methanol, a liquid fuel *via* the following reaction:

$CO + 2H_2 \leftrightarrow CH_3OH$

For this reaction various types of catalysts have successfully been employed and the conversion technology is now commercially available (*Source: Diebold, J. & Stevens, D. 1989)*. Methanol can in turn be processed further to formaldehyde (*Source: Brink, D.L. 1981)* and a range of other chemicals.

Research into producing biomethanol from woody biomass continues, and several different processes have been evaluated (*Source: Adams, J.F. and Sims, R.E.H. 2002*). Successful conversion of around 50% of the original chemical energy stored in the biomass to methanol has been obtained at a cost estimate of around $US0.90 per liter of methanol ($US34/GJ) (*Source: Sailer, G., Funk, G. and Krumm, W. 1998*). In Sweden production of methanol from either short rotation *Salix* or forest residues was estimated to cost only $0.22/liter whereas bioethanol would cost $0.54/liter (*Source: Elam N., Ekstrom, C. and Ostman, A. 1994*). At these costs, using woody biomass feedstocks for heat and power generation would be a preferable alternative (*Source: Rosa L.P., and Ribeiro, S.K. 1998*). In addition since the volumetric energy density (MJ/1) of biomethanol is around 50%, that of fuel and bioethanol around 65%, then larger storage tanks would be needed to give the same vehicle range between refills.

Besides methane and methanol, with appropriate catalysts and reaction conditions, ammonia can also be produced from the gaseous product (syngas) of gasification. In this process an appropriate quantity of nitrogen has to be added. The roster of commercial chemicals from syngas also includes (*Source: Fourie, J. H. (1992)*:

- aromatics
- alcohols
- ketones
- oxidized and crystallized waxes
- creosotes
- cresylic acids
- ethers
- α-olefins and polyolefins,
- phenol, and
- ethylene and propylene

The synthesis of Fischer-Tropsch hydrocarbons is another method for production of hydrogen, ammonia, methanol, alcohols, aldehydes (oxosyntheses), ethylene, and propylene from biomass feedstocks via syngas. (*Source: Werpy T. and Peterson T. (2004).*

7.1.4 Pyrolysis

Pyrolysis is a name given to the thermochemical process that offers a flexible and attractive way of converting solid biomass into an easily stored and transportable fuel, which can be successfully used for the production of renewable gasoline, jet fuel, or diesel. Depending on the process conditions the major product could be *bio-oil*, a liquid fuel, or substantial quantities of *bio char*, a solid fuel, or *syngas*, a non-condensible gaseous product. The actual proportion of each of the above three products will be dependent on the type and nature of the biomass input, the type of pyrolyser used, as well as on the details of the pyrolysis process adopted. This process transforms the biomass into high quality fuel without creating ash or energy directly. Figure 7.3 shows a typical thermochemical pyrolysis basic process flow for the conversion of biomass feedstock to fuel synthesis.

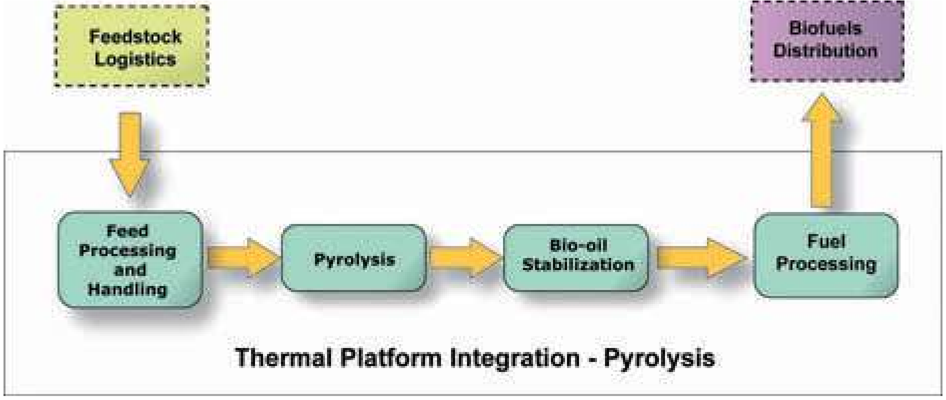

Figure 7.3 Thermochemical Platform Integration – Pyrolysis
(Source: U.S. DOE Energy Information Administration – Thermochemical Conversion)

In the pyrolysis process, biomass input is subjected to high temperatures in the absence of air or oxygen. Generally when the process is carried out at low temperatures and a slow heating rate, char yield is maximized. Conversely, at high temperature, low heating rate and extended gas residence time, the gas yield is maximized. Bio-oil yield on the other hand varies in oxygen content or viscosity according to the biomass input, and is maximized at medium temperatures (450 - 600°C), rapid heating rates and abbreviated residence times. Bio oil is a renewable liquid fuel and can offer major advantages over solid biomass and gasification due to the ease of handling, storage and combustion in an existing power station when special start-up procedures are not necessary.

Wood residues, forest residues and bagasse are important short term feed materials for pyrolysis being aplenty, low-cost and good energy source. Straw and agro residues are important in the longer term; however straw has high ash content which might cause problems in the pyrolysis process.

Several pyrolysis processes have been developed to pilot, demonstration and commercial scale based solely on thermochemical conversion to examine the possibilities for conversion of biomass feedstocks to liquid products. Some of these studies include (*Source: Boerrigter, H., Den Uil, H. and Calis, H.-P. (2002*):

Six circulating fluidized bed plants have been constructed by Ensyn Technologies, with the largest having a nominal capacity of 50 t/day operated for Red Arrow Products Co., Inc. in Wisconsin.
DynaMotive (Vancouver, Canada) demonstrated the bubbling fluidized bed process at 10 t/day of biomass and is scaling up the plant to 100 t/day.
BTG (The Netherlands) operates a rotary cone reactor system at 5 t/day and is proposing to scale the plant up to 50 t/d.
Fortum has a 12 t/day pilot plant in Finland. The yields and properties of the generated liquid product, bio oil, depend on the feedstock, the process type and conditions, and the product collection efficiency.
Biomass Program researchers use both vortex (cyclonic) and fluidized bed reactors for pyrolyzing biomass. The fluidized bed reactor of the Thermochemical Users Facility at the National Renewable Energy Laboratory is a 1.8 m high cylindrical vessel of 20 cm diameter in the lower (fluidization) zone, expanded to a 36 cm diameter in the freeboard section.

The extraction and recovery of chemicals from biomass pyrolysis liquids is rapidly growing in interest as the natural catalysts in most biomass forms are enhanced or removed to emphasize production of specific chemicals. In addition, these chemicals are recovered by physical and/or chemical processing and subjected to catalytic processing to improve the product quality or yield or derive higher value chemicals. The list of these chemicals from biomass pyrolysis includes (*Source: Bridgwater A. (1996)*:

- levoglucosan
- calcium acetate
- hydroxyacetaldehyde
- glyoxal
- olefins, gasoline
- phenols, ethers, anisole
- aromatics, ethers
- food flavorings
- oxychemicals
- 2-furaldehyde
- alkanes and alkenes
- fatty acids
- acetol

Outputs from biomass or biomass-derived feedstocks and thermochemical conversion technologies vary widely depending on the source of the biomass (five-six carbon sugars, lignin, ash, extractives, and proteins) and the processes used to isolate different components (gases such as CO, CO_2, H_2, H_2O, CH_4). To optimize the profitability and economic viability of the biorefinery, utilization of all process outputs is necessary. Products R&D emphasize value-added products that utilize all components of the biomass feedstocks, while minimizing environmental impacts and effectively integrating heat and power requirements within the biorefinery.

7.1.5 Thermochemical Conversion Technology and Research Challenges and Barriers

The following is a summary of the potential technology and research challenges and barriers for biomass thermochemical conversion technologies:

Feeding Dry Biomass:

- No significant barriers in the near term
- Processing and handling, dry biomass feeding, densification, specifications development, and chemical contaminants removal in the longer term

Feeding or Drying high Moisture Content Biorefinery Streams:

- The costs and trade-off of drying or feeding wet biorefinery residues
- Innovative dryer designs for utilizing low-value process heat

Gasification of Wood, Biorefinery Residue Streams and Low Sugar Content Biomass:

- Developing an understanding of gasification options and their chemistries for high-lignin feedstocks and residues, high-moisture organic residues, and low sugar content biomass

Pyrolysis of Biomass:

- Control the pyrolytic pathways to bio-oil intermediates to increase product yield, selectivity, and recovery
- New methods to clean and stabilize the bio-oil intermediate
- Improved hydro-treating catalysts and techniques for processing the bio-oil

Syngas Cleanup and Conditioning:

- Gas cleaning and conditioning technology for a near-term need
- The interactions for efficient cleanup and conditioning of syngas in conjunction with optimal lifetimes of the catalyst(s)

Fuels Catalyst Development:

Gasification route:

- The commercial success of mixed alcohol synthesis

- Capital and operating costs of improved catalysts with increased productivity and selectivity to higher alcohols

Pyrolysis route:

- Additional improvements in pyrolytic processing with or without catalysts to yield higher quality bio-oil
- The development of robust catalysts for the upgrading of pyrolysis oil in production of liquid transportation fuels
- Improvement to the robustness of hydro-cracking catalysts for producing hydrocarbon biofuels via pyrolysis
-

Validation of Syngas Quality:

- Validation of syngas quality for the production of liquid fuels via catalytic synthesis

Sensors and Controls:

- Effective process control to maintain plant performance and regulate emissions at target levels
- Improvements in commercial control systems for thermochemical processes and systems

7.2 Microbial Syntheses

Microbial processing by direct fermentation of primary biomass derivatives can be used to produce fuels, and synthesize a large number of organic chemicals. The cellular components that facilitate these processes are enzymes, the protein catalysts produced by the microorganisms.

It is evident that most of the common chemicals synthesized are commercially available from non-biomass sources. The molecular structures of the products range from simple compounds, such as ethanol, to complex compounds, such as the penicillins, to polymeric products, such as the polyhydroxybutyrates. Suitable substrates for the fermentation process are generally monosaccharides and disaccharides and their original sources such as molasses and starch and cellulose hydrolysates. A wide range of biomass feedstocks is used for commercial fermentation systems. Examples are:

- glucose for many different chemicals and products
- beet sugar molasses for citric acid
- hydrolyzed starch for citric acid, itaconic acid, and xanthan gum
- thinned starch for ionophores and alkaline proteases
- vegetable oil for terramycin
- corn steep liquor for penicillin, and
- soybean meal for vitamin B12

In microbial process, the microorganism is grown in a culture medium that contains the carbon source (substrate), a nitrogen source (usually ammonia, urea, or ammonium salts), and minor and trace nutrients and growth factors such as vitamins and amino acids, if necessary. The majority of the excreted chemicals are oxygenated compounds that contain carbonyl, carboxyl, or hydroxyl groups. During the fermentation process, part of the substrate is converted to cellular biomass, usually a small amount for anaerobic processes and a larger amount for aerobic processes. By-products such as CO_2 from aerobic processes and oligosaccharides and other water-soluble products are also formed.

Many common organic chemicals can be manufactured by employing live microorganisms; fermentation ethanol is the best example. Certain microorganisms are also capable of performing syntheses that are very difficult to carry out by conventional thermochemical conversion technologies. The compounds produced in these cases are usually characterized by complex, chiral structures such as those of the antibiotics. Combinations of microbial and conventional thermochemical technologies are sometimes employed for multistep syntheses when neither method alone is satisfactory.

7.2.1 Anaerobic Digestion

Anaerobic digestion (AD) is an effective biological process to convert the organic fraction of waste streams to methane (CH_4) and carbon dioxide (CO_2) rich biogas suitable for energy production in the absence of oxygen. AD is a common waste-to-energy technology for various types of combined and separated organic waste streams.

The technology has been used for over 100 years and thousands of AD systems have been installed in Europe and the U.S. since the 1970s. Since the 1990s, better designed, more successful projects have come on-line in the U.S. Several environmental conditions such as moisture content, temperature, and pH levels in an enclosed reactor can successfully be controlled to maximize biogas generation and waste reduction. The biogas by-product generated during the digestion process can be used on-site as a supplement/replacement for natural gas, to generate electricity, or within a combined heat and power (CHP) system to provide both heat and electricity. An additional option is to upgrade the biogas to natural gas pipeline quality and then inject into the natural gas network or even use as a vehicle fuel.

As shown in Table 7.2, the efficiency and rate of AD technology is generally controlled by the factors to maximize the process performance:

The general pathways of AD technology, as shown in Figure 7.4, have a multi-phase process. The first phase of the process involves the conversion of biodegradable organic materials in the waste stream to soluble compounds and volatile fatty acids. The soluble matter is then converted to biogas in the second step. Depending on the waste stream and the system design, biogas typically consists of up to 70% methane; the remaining composition is primarily carbon dioxide, trace gases such as hydrogen sulfide, nitrogen, and water. Although all AD processes follow the same pathway, design and operation of this technology varies widely, depending on the process controlling factors and site-specific conditions.

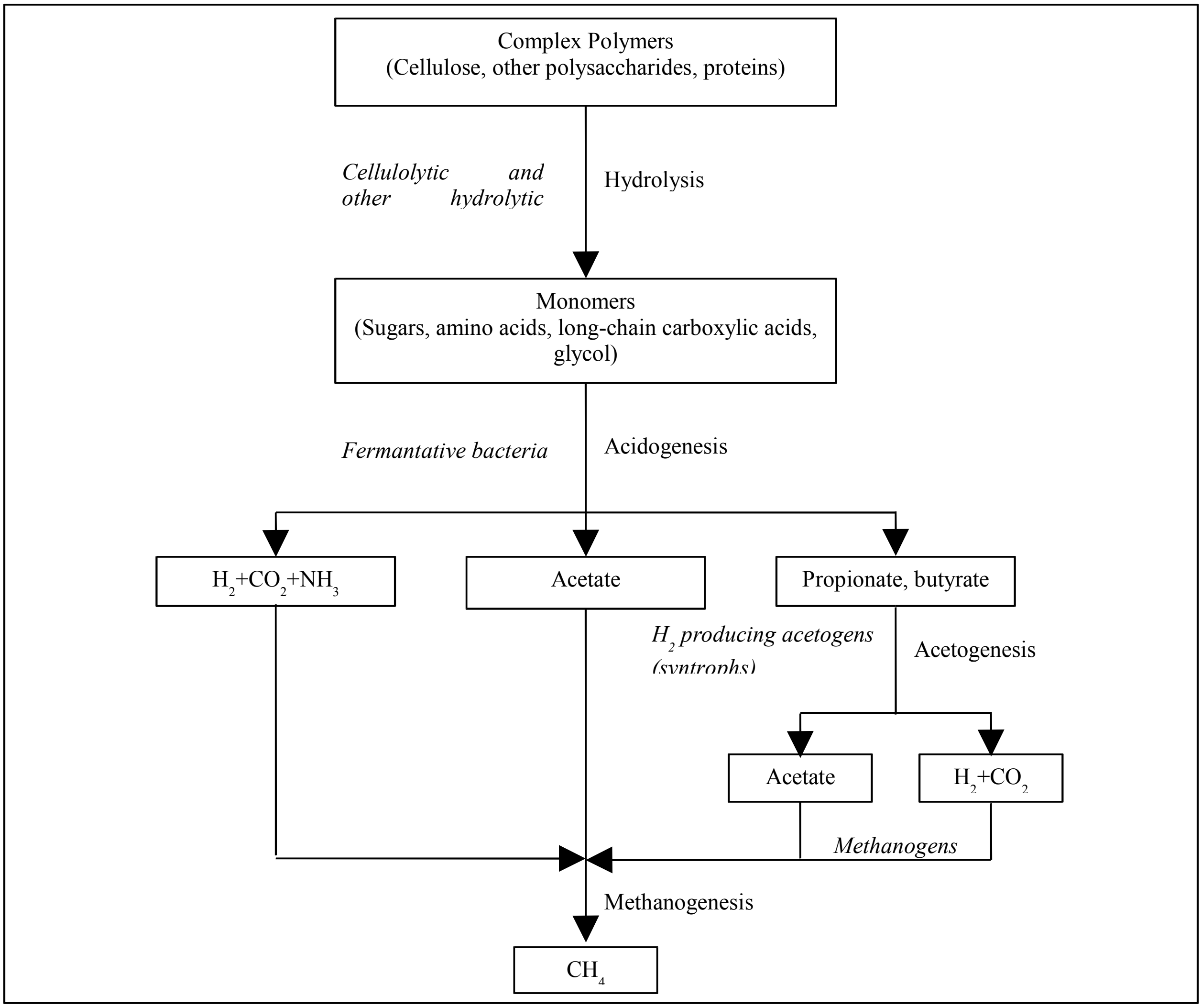

Figure 7.4 General Pathways of Anaerobic Digestion (*Source: McCarty, 1964*)

Recent developments in AD technology have shown that varied waste streams range from food, yard, and commercial wastes to agricultural residues. In many countries, organic waste streams including manures and crop residues that are derived from food production are the largest source of wastes. The best use of these wastes is land application for nutrient recycling to crops, but lack of adequate land for optimum nutrient use and odor control has necessitated the need for suitable treatment and disposal methods. Conversion of these waste streams into a renewable energy resource has been the focus of intensive progress for more than two decades. Where costs are high for waste disposal, and the effluent has economic value, AD technology and biogas production can reduce overall operating costs.

7.3 Summary

Interest in the production of energy, fuels, and chemicals from low cost and renewable feedstocks has gained attention in the past decade, as the cost of liquid hydrocarbon fuels has increased with a rise in crude oil prices and as concerns have mounted about either a depleting fossil fuel resource or at least one that requires increased investment and advanced technology. Concurrently, thermochemical and sugar-base conversion technologies have benefitted from reduced overall production costs and increased commercial viability. Similar to a petroleum refinery, much of the feedstock in this process is consumed in the production of commodity-scale fuels, while bio-based chemicals and materials make up a smaller, but higher-valued product stream.

Current R&D efforts and activities are focused on developing an understanding of the gasification processes and their chemistries for woody biomass feedstocks, low-quality agricultural residues, and lignin-rich biorefinery residues.

In addition, pyrolysis of similar feedstocks is being pursued at a lower level of effort. The activities in this process include basic studies of catalytic and chemical mechanisms for improving quality and yields of bio-oil catalysis for stabilizing the intermediate and catalytic upgrading of bio-oil to biofuel blending stocks. National laboratories, industry, and universities perform this core research, which addresses many of the technical barriers that must be overcome for research and development to proceed to the next level.

The Policy Council recognizes that both of these processes need further R&D to attain widespread commercial application and will pursue their development through technology developments. The Policy Council also recognizes that such direct conversion processes also necessitate consideration of the most attractive environmental and economic solution, and thus need to consider the direct use of biomass for power and heat, in addition to thermochemical upgrading routes to liquid fuels. Exploration and production of unconventional natural gas and oil reservoirs has substantially increased our domestic energy resources, lowering the price of natural gas. Supplies are predicted to be substantial for years to come; given this, any alternative bioenergy process needs to be cost effective with regard to pricing realities of existing domestic fuel sources.

8.0 FEASIBILITY AND ECONOMIC DEVELOPMENT OF THE REQUIREMENTS FOR PIPELINE-QUALITY, RENEWABLE NATURAL GAS

The intent of this section is to include a feasibility assessment of pipeline-quality renewable natural gas generated from potential bioenergy feedstocks.

As described in *Section 7.0*, numerous byproducts can be generated from thermochemical conversion technologies (e.g., gasification or pyrolysis) and microbial mediated processes (e.g., anaerobic digestion). One common product of these processes is the generation of various forms of gas. As previously described the product of gasification is a syngas and the product of anaerobic digestion is biogas or biomethane. Biogas can also be generated from the microbial mediated process such as decomposition in municipal solid waste landfills, publically owned treatment works (POTW), waste water treatment plants, and of course from the anaerobic degradation or decomposition of every carbon based organisms or agricultural products that are no longer living. Essentially, syngas or biogas can be generated from the degradation or destruction of any of the feedstock discussed in *Section 1.*

Once generated the syngas or biogas can be captured and utilized using various processes. Low quality or quantity gases can be vented or flared (burned) before off gassing to the atmosphere. However, the syngas or biogas can be used to generate energy or other products. The most common include the generation of heat via a boiler for example or power (e.g., electricity) via an internal combustion (IC) engine for example. The generation of both heat and power via cogeneration is referred to as combined heat and power (CHP). This can also be conducted using an IC engine, microturbine, or if the volume and quality is sufficient via a gas turbine (Figure 8.1). Cogeneration is significantly more efficient as once the gas is consumed the heat given off of the engine can be scavenged and utilized. The biogas generated, particularly from anaerobic digestion is often of low to medium quality gas having a low to medium concentration of combustible gas (e.g., methane) and several impurities that may have to be separated from the gas. This low to medium quality gas may range from 500 to 700 British thermal units (BTU) per standard cubic feet (scf) of gas. Assuming it is gas generated from an anaerobic digester the concentration of methane is normally between 50 and 65 percent. The remainder of biogas includes numerous impurities such as carbon dioxide (CO_2), water (H_2O), hydrogen sulfide (H_2S), and other volatile organic compounds. This low to medium quality gas can be utilized in properly fitted CHP, boiler, kiln, greenhouse, or supplemented with natural gas or propane to dilute the impurities. Over time, if not diluted, these impurities, namely the hydrogen sulfide, however, can corrode most metal components and piping and thus degrade operations. As a result, the impurities are generally treated or conditioned to decrease their concentration and increase the purity of the combustible portion of the biogas.

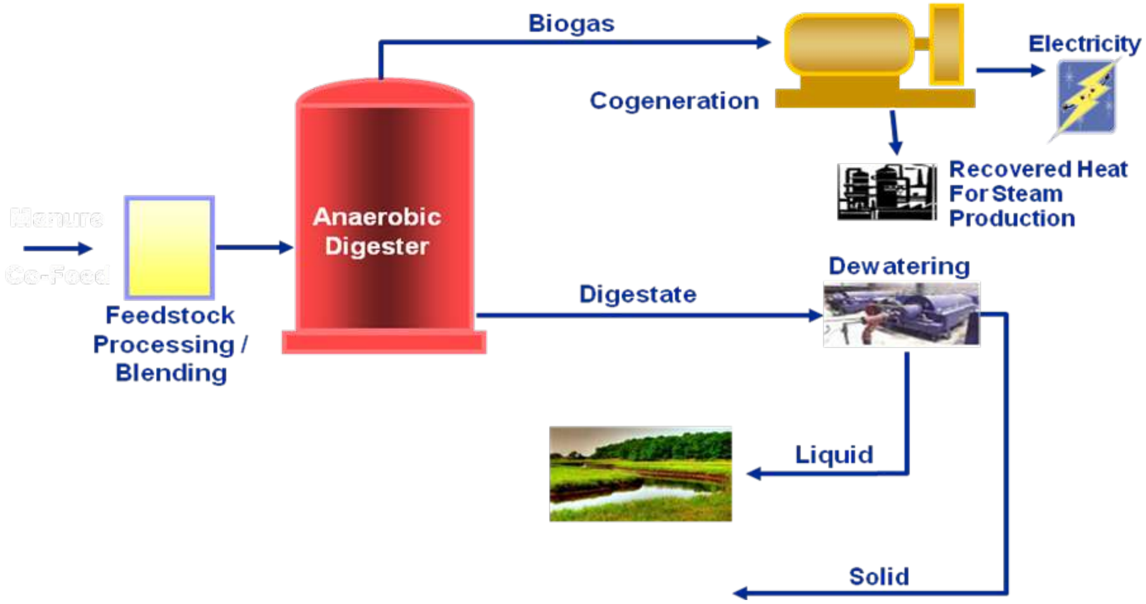

Figure 8. 1 Schematic of biogas generation and utilization from a digester (Tetra Tech)

To achieve high quality or high-grade biogas (850 to 1,000 Btu/scf) these impurities need to be removed or treated and cleaned from the gas. This is essential if the biogas generated is to be used for pipeline quality renewable quality gas. Whether it is injected into the natural gas grid or planed to be used as a vehicle fuel (e.g., compressed natural gas or liquefied natural gas) gas cleanup is essential.

There are more than 25 projects across the US that are generating pipeline quality biogas. Many of these are derived from landfill gas and anaerobic digestion projects. According to EPA in 2009 the following states had operating projects: Arkansas (1), California (2), Georgia (2), Kansas (1), Louisiana (1), Michigan (2), New York (1), Ohio (3), Pennsylvania (3), Tennessee (1), Texas (3), and Wisconsin (1) (Source: Chris Voell, EPA AgStar & Landfill Methane Outreach Program). According to EPA in 2009 the following utilities were accepting pipeline renewable natural gas: OnCor, Michigan Gas Utilities, Duke Energy, National Fuel Company, Keyspan Energy, Arkansas Gas Association, Equitable Gas, Equitrans, Dominion, Municipal Gas of Georgia, Gulf South Pipeline, Proliance Energy, and Pacific Gas & Electric (PG&E).

Admittedly, most of these projects are those from landfill gas collection systems largely due to the consistent quantity and quality of gas generated. However, several bioenergy projects based upon livestock manure are generating pipeline quality natural gas as well.

In 2008, a centralized digester developed by Environmental Power Corporation (EPC), also known as Microgy, located in Stephenville, Texas, reached full-capacity production levels of pipeline-quality natural gas. The large-scale facility receives manure from multiple farms in the region, digests the manure in controlled and monitored complete mix digesters, and purifies the resulting gas to pipeline quality. Manure solids having 8-10% total solids and co-substrates are loaded into one of eight 900,000 gallon digesters followed by source separation and composting on site. Design capacity of the digester includes handling of manure of up to 10,000 cows and 1 billion cubic feet of biogas per year at 650,000 million Btu (MMBtu). The Lower Colorado River Authority agreed to buy up to 2,000 MMBtu per day through September 2008. In October 2008, the facility started selling 8,000 MMBtu per day to PG&E in

California under a 10-year contract (source: http://www.epa.gov/agstar/profiles/huckabay.html). There are many other biogas projects around the country. For example, in Fennville Michigan, Scenic View Dairy - Fennville II, a dairy farm operating an anaerobic digester from manure from 2200 dairy and 1450 heifers, generates 150 standard cubic feet per minute (scfm) of biogas (136 million BTU/day) and injects it at 125-145 pounds per square inch (psig) into Michigan Gas Utilities' grid at pipeline quality.

Numerous technical, administrative, regulatory, and economic factors need to be considered in determining the feasibility of such a project and policy. The technological challenges of generating pipeline quality gas include, but are not limited to, conditioning and treatment of the gas to remove impurities or contaminants to levels acceptable by gas transmission companies and end users. The gas then needs to be increased in pressure to match the specification of the pipeline and metered properly. There are an increasing number of technologies available to address the technological challenge of gas cleanup. A gas cleanup and compression process that Tetra Tech conducted on a site in California is shown in Figure 8.2. It illustrates the conversion of biomethane generated from 4500 milking dairy cows using a bio-catalyzed scrubber (Figure 8.3) and carbon polishing to remove H_2S to 0 parts per million. This was followed by a pressure swing adsorption (PSA) system to separate CO_2 from the methane (Figure 8.4), condensation steps to remove the moisture from the gas, compression steps and cooling to bring to enriched gas up to the pipeline quality temperature (less than 100 degree Fahrenheit) and pressure (650 psi) required to inject it into the grid.

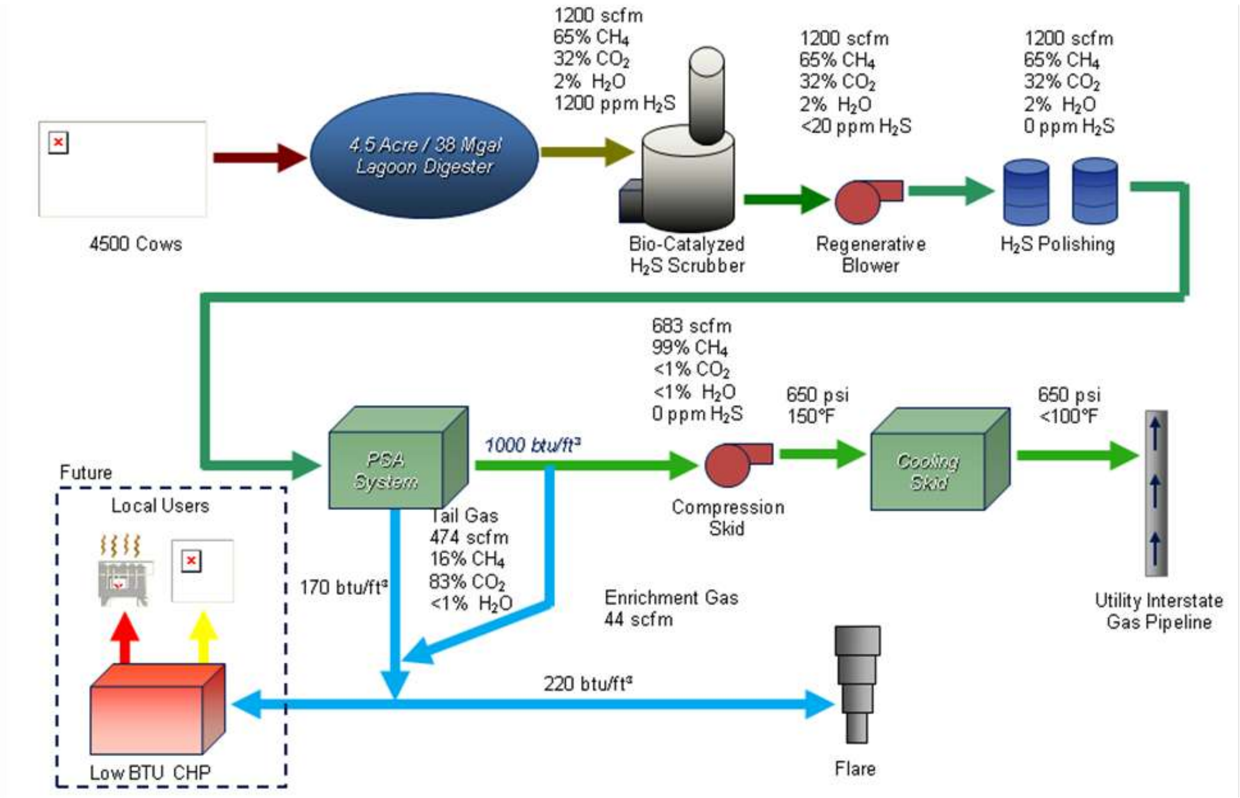

Figure 8.2 Example Process Flow Diagram

For Gas Cleanup and Compression (courtesy of Tetra Tech)

Figure 8.3 Hydrogen Sulfide Scrubber (courtesy of Tetra Tech)

Figure 8.4 Pressure Swing Absorption System (courtesy of Tetra Tech)

Beyond the conversion of biogas to pipeline quality, syngas can also be converted to renewable gases and liquids. Via a number of advanced conversion processes syngas can be converted to hydrogen (and fuels and chemicals), methanol (and various chemicals), ethanol, and via the Fischer-Tropsch to diesel, gasoline, napthalenes, and waxes. These are not addressed in this section but are worth noting as options for syngas conversion.

The logistics of injecting into the grid including grid connections, regulatory approvals, energy sales agreements, right away access agreements, and operational tasks (e.g., active monitoring/testing) can be challenging. The cost of transporting and connecting to the gas grid via a proper pipeline network can be costly, so these factors need to be addressed carefully.

Finally, regulatory negotiating and approvals also need to be considered. All of these factors are costly and therefore need to be considered. The aforementioned Tetra Tech project in California was located within several miles of the utility grid, so these costs were minimized and allowed the project to be viable due to the PG&E desire to see the project to execution. It was based upon 4500 milking cows generating approximately 1200 psi of biogas having a concentration of 65% methane; therefore, economies of scale were important. Finally, the natural gas purchase price is critical in determining the economic feasibility. There are no simple or straightforward calculations to determine the viability of a project, and each case scenario must be reviewed carefully.

Additional challenges include that federal tax credits do not recognize the value of renewable natural gas. Currently the federal biogas tax credit only applies to the generation of electricity. The tax credit calls for 1.9 cents per kilowatt hour ($5.66 per MMBtu) for electricity produced from on-site biogas (Natural Gas Vehicles for America). All other biogas uses (including the biomethane in vehicles and producing electricity off site) do not qualify. Therefore, if the biogas is not used to generate electricity on-site it does not qualify for the tax credit. This is unfortunate as several biogas developers' business plans have called for injection of the biogas into the natural gas grid and extracting it at another location to produce electricity. Further, federal agencies have focused on liquid cellulosic and non-cellulosic renewable biofuels and have proposed reverse auctions for subsidies but not on biogas generation. The American Biogas Coalition (ABC) has been created to support the generation of biogas for use of electricity generation as well as renewable natural gas on the grid. http://www.americanbiogascouncil.org/ Through the efforts of this group, there is an expectation that renewable pipeline quality biogas can be utilized more in the future.

9.0 STUDY THE DEVELOPMENT OF FEDERAL POLICY AND REGULATORY DEVELOPMENTS

9.1 U.S. Federal Bioenergy Fuels Policy

Although ethanol has been used as a fuel in the U.S. since 1908 it was not until the 1970s that a large increase in its use as a fuel was manifested. Two occurrences which contributed were the oil embargo of the 1970s by Middle Eastern countries and the Iran-Iraq war. As a result in 1978 the U.S. passed the National Energy Act which provided a federal tax exemption for gasoline that was blended with 10 percent ethanol. This reduced the cost of ethanol to the rack price of gasoline at the time. The value of the tax exemption at the time was 40 cents per gallon of ethanol. By 1980, 25 states had exempted alcohol blended gasoline from state taxes.

Similarly, due to increased petroleum prices in the mid 2000s, biodiesel production increased significantly from 2004 to 2008, but with subsequent drops in oil prices, increased costs in soybeans and no extension of the federal tax credit for biodiesel, this trend diminished in 2009 to just over 500 million gallons.

Numerous federal legislations followed that would promote the use of ethanol and biodiesel in the country's fuel supply. The following is a summary of the most relevant federal legislation.

The Energy Tax Act of 1978 – part of the National Energy Act, imposed taxes and tax credits designed to shift consumption from oil and gas toward energy conservation by promoting fuel efficiency and altenatives.

The Energy Security Act of 1980 – provided financial assistance for the construction of ethanol plants.

The Omnibus Reconciliation Act of 1980 – legislated import tariffs on gasohol blends imported into the U.S.

The Budget Reconciliation Act of 1990 – established the federal excise tax credit at 54 cents per gallon of ethanol until the year 2000 (now termed the Volumetric Ethanol Excise Tax Credit or VEETC). It provided a credit of 10 cents per gallon for the first 15 million gallons for small producers (< 30 million gallon capacity, now 60 million gallon capacity).

The Clean Air Act (1990) – mandated oxygenated fuels. Requirements for reformulated gasoline (RFG) and wintertime oxygenated fuels in 39 major carbon monoxide non-attainment areas and require year-round use of oxygenates in nine severe ozone non-attainment areas in 1995.

The Energy Policy Act of 1992 – established incentives for the use of alternative-fuel vehicles by federal, state and private fleets with the use of B20 biodiesel blends qualifying for designation as an alternative fuel.

Alternative Motor Fuels Act (1992 and 1998) – contain provisions for mandating oxygenated fuels in federal fleets and provides for alcohol fuel to be made available to the public at locations where the federal vehicles are fueled.

The Surface Transportation Act of 1998 – extended the 54 cent federal tax credit for ethanol until 2007, diminishing one cent per year for the years 2001, 2003 and 2005.

March 1999 – California Executive Order Banning MTBE – this executive order began the disappearance of MTBE as an oxygenate in the U.S. fuel system, creating a larger demand for ethanol.

American Jobs Creation Act of 2004 – included the Volumetric Ethanol Excise Tax Credit (VEETC) which extended tax incentives for ethanol and biodiesel. It also ensured that the Highway Trust Fund revenues were not significantly affected by increased ethanol use. Additionally, it provided a credit of \$1.00 per gallon of biodiesel made from oil crops and animal fats and a \$0.50 per gallon credit for biodiesel made from recycled fats and oils, to the blenders. The incentive is taken at the blender level, which generally means petroleum distributors.

The 2005 U.S. Energy Bill – introduced the Renewable Fuel Standard (RFS) requirement. The purpose is to increase the renewable fuels content in the nation's fuel supply. Requires 7.5 billion gallons of ethanol and biodiesel use by 2012. It was signed in September of 2006. This is known as RFS1. Biodiesel tax credit was extended through 2008.

The Energy Independence and Security Act (EISA) of 2007 – also known as RFS2, this is an omnibus energy policy law that consists mainly of provisions designed to increase energy efficiency and the availability of renewable energy. For biofuels, the law sets a modified standard that starts at 9.0 billion gallons of renewable fuels in 2008 and rises to 36 billion gallons by 2022. Of the latter total, 21 billion gallons is required to be obtained from cellulosic ethanol and other advanced biofuels. The pivotal change brought about by EISA is the qualification of a renewable fuel based upon its ability to meet a greenhouse gas emission reduction threshold. The RFS2 regulations contain four separate categories of fuels, each with their own feedstock and performance criteria. Each category has its own mandate of annual volumetric use and a corresponding schedule for increases through 2022. It extended the biodiesel tax credit to 2009.

E15 Blends – On November 4, 2010, EPA formally issued its decision to allow an increase in ethanol percentage volumetric blend with gasoline from 10% to 15% for use in newer model automotive engines, specifically 2007 and newer. Increasing the ethanol blend, beyond existing manufacturer-approved amounts (E10), has auto and small engine manufacturers concerned that motor drivability and performance issues would suffer or fail. EPA's decision was delayed by extensive testing undertaken by the Department of Energy (DOE) to evaluate the effects of increased ethanol blends on newer engines. The EPA will decide whether to allow E15 to be used in vehicles built between 2001 and 2006 after it receives further testing data from the Department of Energy. Several parties are challenging that decision in court.

9.2 Renewable Fuels Standard 2 (RFS2)

With regard to the EISA, starting in 2016, all of the increase in the RFS2 target must be met with advanced biofuels, defined as cellulosic ethanol and other biofuels derived from feedstock other than corn starch with explicit carve-outs for cellulosic biofuels and biomass-based diesel. The EPA Administrator is given authority to temporarily waive part of the biofuels mandate, if it is determined that a significant renewable feedstock disruption or other market circumstance might occur. In its first such action, the EPA dramatically lowered the cellulosic biofuel mandate for 2010 from 100 million to 6.5 million gallons, the reason being that the original targeted volumes are not able to be achieved commercially at this time. This level will remain in 2011 despite being scheduled to increase to 250 million gallons in the original mandate.

Fuels produced from biorefineries that displace more than 80% of the fossil-derived processing fuels used to operate a biofuel production facility will qualify for cash awards. Many of the RFS inquiries and requirements can be found at;
http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=1db5a6191f97d4a6fab91d4c922e39d6&tpl=/ecfrbrowse/Title40/40cfr80_main_02.tpl

Figure 9.1 shows the projected required volumes of the four targeted renewable fuels by the EPA.

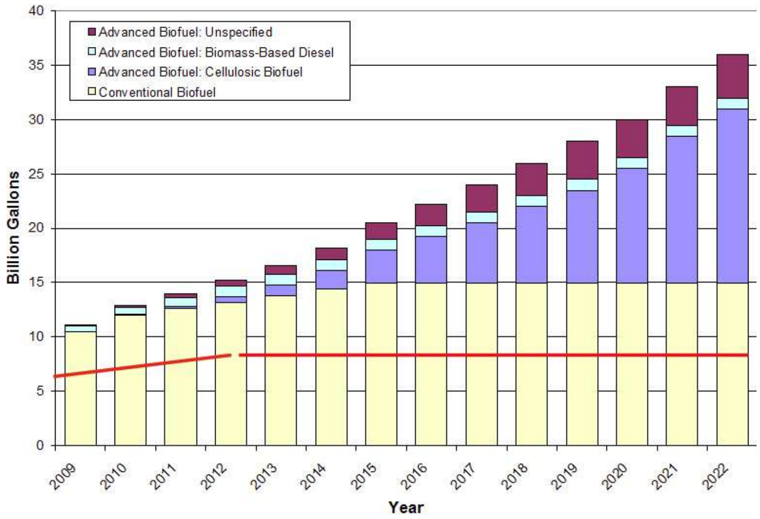

Figure 9.1 RFS2 Renewable Fuels Volumes

(*Source: America Advances to Performance-Based Biofuels: The Advanced Renewable Fuel Standard / RFS2, February 26, 2010, Clayton McMartin and Graham Noyes)*

Figure 9.1 shows the targeted volumes of renewable fuel as per the EISA and the EPA. *(Source: U.S. EPA).* In the case of Biomass-Based Diesel, EPA elected to carry the 500 million gallon mandate forward and combine it with the 650 million gallons required in 2010 by EISA. EPA communicated their intent in November of 2008 whenever they issued the 2009 standard. Therefore, the Biomass-Based Diesel mandate in 2010 will now be 1.15 billion gallons. The 2010 mandates are currently in litigation.

Renewable fuels used by refiners and sellers of gasoline and diesel will need to prove compliance of the RFS2 requirements. To track this, the EPA has established a Renewable Identification Numbers program or RINs. Under RFS2, RINS are provided to renewable fuels producers by the EPA for each lot or defined bulk volume of renewable fuel produced and these follow the product throughout the value chain. Each of these obligated parties must demonstrate compliance at the end of the year by submitting a sufficient number of RIN credits to satisfy their pro-rata share of the overall mandate. Their pro-rata share is based on the volume of gasoline they produced or imported in that year, divided by the total anticipated U.S. consumption for that year, and multiplied by the total renewable fuel mandate. RFS2 expands this pool to include diesel production or import for use in on-road and non-road, locomotive and marine applications.

9.2.1 Biofuels Definitions under RFS2

The four fuels identified by RFS2 include the following. Under these definitions not only will the feedstock define the fuels but so will the technology due to the GHG requirements.

*Cellulosic Biofuel_*
- Renewable fuel produced from cellulose, hemicellulose, or lignin. May include cellulosic ethanol, biomass to liquids diesel liquids diesel
- Lifecycle threshold: 60% reduction in GHGs with respect to gasoline and diesel

Biomass-Based Diesel
- May include biodiesel (Fatty Acid Methyl Esters) and renewable diesel if fats/oils not co-processed with petroleum. Includes soy based biodiesel.
- Lifecycle threshold: 50% reduction in GHGs with respect to gasoline and diesel

Advanced Biofuels
- Essentially anything but corn starch ethanol
- Includes cellulosic biofuels and biomass based diesel
- Lifecycle threshold: 50% reduction in GHGs with respect to gasoline and diesel

(Other) Renewable Fuel
- Corn starch ethanol and other renewable fuels not meeting the criteria for the other categories. Ethanol plants that commenced construction prior to enactment of EISA meet the 20% requirement. New corn ethanol plants using new technologies that show 20% GHG reductions to qualify
- Lifecycle threshold: 20% reduction in GHGs with respect to gasoline and diesel

These (Other) renewable fuels meet or exceed the (20%) emissions reductions:
- corn based ethanol plants using new efficient technologies
- biodiesel made from waste grease, oils, and fats
- sugarcane based ethanol

9.2.2 Current Status of the VEETC for Ethanol

As mentioned previously, the American Jobs Creation Act of 2004 extended the current excise tax exemption or blender's credit known as the Volumetric Ethanol Excise Tax Credit (VEETC). VEETC provides oil companies with an economic incentive to blend ethanol with gasoline. This tax credit does not require that the ethanol be domestically produced. Any ethanol imported from Brazil can qualify the gasoline blender with the same VEETC as ethanol purchased from a producer in Iowa. To address this, a tariff is imposed on imported ethanol to the U.S. (discussed below).

As of January 1, 2009, the original tax credit totaling 51 cents per gallon on pure ethanol (5.1 cents per gallon for E10, and 42 cents per gallon on E85) was reduced to 45 cents per gallon. VEETC is currently authorized through December 31, 2010.

On March 25, 2010, Representative Pomeroy (D-ND) and Representative Shimkus (R-IL) along with 27 other members of Congress introduced H.R. 4940, a bill that would extend VEETC at 45 cents per gallon for five years. An identical bill (S. 3231, the Grow Renewable Energy from Ethanol Naturally (GREEN)

Jobs Act of 2010) has been introduced in the Senate. Without the extension of the ethanol tax incentive, multiple studies indicate there would be a displacement of domestically-produced ethanol with foreign ethanol, most likely from Brazil. Increasing imports from countries such as Brazil would result in a cut in domestic production – roughly 4 billion gallons or 40 percent as estimated by a Renewable Fuels Association (RFA) study.

A more recent bill, the Domestic Manufacturing and Energy Jobs Act of 2010 sponsored by Rep. Sander Levin (D-MI), which has been in consideration since July 2010by the U.S. House Ways and Means Committee, would reduce the VEETC to 36 cents per gallon and would extend the credit for only one year. The bill would also extend the 54 cent tariff on imported ethanol for one year. As of the writing of this report, ethanol industry representatives feel optimistic about the extension of the VEETC, but the final numbers are uncertain.

9.2.3 Import Tariffs on Ethanol

The Omnibus Reconciliation Act of 1980 legislated import tariffs on ethanol or gasohol blends imported into the U.S. Its purpose is to assure that the VEETC tax exemptions are not going to overseas producers. Currently the tariff is higher than the amount of the VEETC. At present, the VEETC is $0.45/gallon, but the tariff is a 2.5 percent tax plus $0.54/gallon. The total tariff is approximately $0.60/gallon, which is 33% beyond the VEETC. There is currently a strong push from UNICA (Brazil's sugar cane ethanol lobbying group), the U.S. oil industry, the beef and dairy cattle industry and environmental groups for the elimination of the import tariff.

9.3 Federal Biodiesel Incentives

The early drivers pushing the interest in biodiesel were the rising cost of petroleum, the desire to stimulate rural economic development through value-added agricultural applications, and the desire to reduce our dependence on foreign oil for trade balance and national security reasons. The latter two are still drivers today and the former will again be a driver once petroleum prices rise again.

Environmentally, the benefits of biodiesel for pollution reduction are significant and well-documented. Biodiesel is also a value-added agricultural-based product that is appropriate and available to meet the low-sulfur diesel requirements established by the Environmental Protection Agency. It should be noted, however, that EPA currently takes the position that biodiesel blends have the potential to increase NOx emissions. In Texas, NOx emissions are of concern because they are precursors to ozone formation. Diesel fuel, including biodiesel blends less than 100% biodiesel, are subject to the Texas Commission on Environmental Quality's Texas Low Emission Diesel requirements to reduce NOx emissions. These standards apply only to 110 counties in the eastern part of the state. There is continued debate on whether biodiesel increases NOx emissions and there are several recent studies that show NOx neutrality or even NOx reductions, particularly when used in newer diesel engines.

The federal and certain state governments have previously passed legislative mandates requiring compliance with renewable energy standards and alternative fuel requirements; these mandates, such as the landmark federal Energy Policy Act of 1992 and the Renewable Fuels Standard mentioned above encouraged public and private sector fleet operators to utilize biodiesel blends and flex-fueled vehicles. The current market has been largely built on sales to fleet operators and the Department of Defense. On December 31, 2009, Congress let the $1.00 per gallon federal tax incentive for biodiesel expire which has caused the biodiesel industry to diminish operations to approximately 20% of capacity while various plants sit idle. Several pieces of legislation were amended throughout 2010 to re-instate the $1.00 per gallon credit, but most failed or the amendment was stripped out prior to passage.

Unlike ethanol, biodiesel is not protected by a secondary import tariff that offsets the value of its tax incentive.

9.4 Texas Biofuel Incentives

Various Texas legislative measures for biofuels have been passed to assist the biofuels industry. A summary of these follow;

Biofuels Promotion - The Texas Bioenergy Policy Council and the Texas Bioenergy Research Committee were established to promote the goal of making biofuels a significant part of the energy industry in Texas by January 1, 2019. The Policy Council is tasked with the following: 1) provide a vision for unifying the state's agricultural, energy, and research strengths in a successful launch of a cellulosic biofuel and bioenergy industry; 2) foster development of cellulosic and biobased fuels; 3) pursue the creation of a next-generation biofuels energy research program at a university in the state; 4) pursue federal and other funding to position the state as a bioenergy leader; 5) study the feasibility and economic development effect of a blending requirement for biodiesel or cellulosic fuels; 6) pursue the development and use of thermochemical process technologies to produce alternative chemical feedstocks; and 7) study the feasibility of the requirements for renewable natural gas. (*Reference* ***Senate Bill*** *1016, 2009, and* ***Texas Statutes****, Agriculture Code 50D)*.

Alternative Fuel Use Required in State Fleets - State fleets with more than 15 vehicles, excluding emergency and law enforcement vehicles, may not purchase or lease a motor vehicle unless the vehicle uses compressed natural gas, liquefied natural gas, liquefied petroleum gas, methanol or methanol-gasoline blends of 85% or greater (M85), ethanol or E85, biodiesel or B20 and higher blends, or electricity including plug-in hybrid electric vehicles. Waivers may be granted for fleets under the following circumstances: 1) the fleet will operate primarily in areas where neither the state agency or a supplier can reasonably be expected to establish adequate fueling for these fuels, or 2) the agency is unable to obtain equipment or fueling facilities necessary to operate alternative fuel vehicles at a cost that is no greater than the net costs of using conventional fuels. By September 30, 2010, covered state agency fleets must consist of at least 50% vehicles that use alternative fuels as listed above and use these fuels not less than 80% of the time the vehicle is driven. Furthermore, state agencies authorized to purchase passenger vehicles or other ground transportation vehicles for general use must ensure that at least 25% of the vehicles purchased during any state fiscal biennium, other than exempted vehicles, meet or exceed federal Tier II, Bin 3 emissions standards. Covered state agencies may meet these requirements through the purchase of new vehicles or the conversion of existing vehicles. (*Reference* ***House Bill*** *432, 2009, and* ***Texas Statutes****, Government Code 2158.001, 2158.0013, and 2158.003 to 2158.009)*.

Ethanol and Biodiesel Blend Tax Exemption - The biodiesel, renewable diesel, methane, or ethanol portion of blended fuel containing taxable diesel is exempt from the diesel fuel tax. The blend must be clearly identified on the retail pump, storage tank, and sales invoice in order to be eligible for the exemption. *(Reference* ***Texas Statutes****, Tax Code 162.204)*. Since ethanol is not typically blended with diesel, this exemption has little effect on the promotion of ethanol.

Ethanol, Biodiesel, and Renewable Diesel Production Incentive Program - Ethanol and biodiesel producers were subject to a fee of $0.032 per gallon of ethanol or biodiesel produced in each registered production facility, collected by the Texas Department of Agriculture, should they choose to participate in the program initally designed for up to ten years participation. Participation in the program made the producer eligible for a grant in the amount of $0.20 per gallon of ethanol, biodiesel, or renewable diesel produced. Funding was available for only 18 months and has not been subsequently funded since 2006-

07 fiscal biennium. *(Reference **House Bill** 2582, 2009, and **Texas Statutes**, Agriculture Code 16.001 and 16.005).*

The Texas Emissions Reduction Plan (TERP) was established by the 77th Texas Legislature in 2001, through the enactment of Senate Bill (SB) 5. Its statutory authority is to reduce nitrogen oxides (NO_X) emissions from older heavy-duty on-road vehicles and non-road equipment by providing grants and rebates for voluntary upgrades and replacements. While this program does not incentivize alternative fuels directly, the purchase of a fleet capable of alternative fuel consumption could increase demand for alternative fuels.

The **New Technology Research and Development Program** - provides grants for alternative fuel and advanced technology demonstration and infrastructure projects under the New Technology Research and Development (NTRD) Program, which provides incentives to encourage and support research, development, and commercialization of technologies that reduce pollution. The NTRD Program is administered by the Texas Commission on Environmental Quality and could increase demand for alternative fuels. *(Reference Texas Statutes, Health and Safety Code 386).*

Texas Clean Fleet Program - Beginning in 2010, the Texas Commission on Environmental Quality (TCEQ) will administer the Texas Clean Fleet Program, which encourages owners of fleets containing diesel vehicles to permanently remove the vehicles from the road and replace them with alternative fuel or hybrid electric vehicles which could increase demand for alternative fuels. Grants will be available to fleets to offset the incremental cost of such replacement projects. An entity that operates a fleet of at least 100 vehicles and places 25 or more qualifying vehicles in service for use entirely in Texas during a given calendar year is eligible to participate in the program. Qualifying alternative fuel or hybrid electric vehicle replacements must: result in a reduction of emissions of nitrogen oxides or other pollutants, as established by the TCEQ, by at least 25% as compared to baseline levels; meet established minimum fuel economy guidelines; and meet other requirements as established by TCEQ. Neighborhood electric vehicles do not qualify under this program. This program expires August 31, 2017. *(Reference - Senate Bill 1759, 2009, and Texas Statutes, Health and Safety Code 391)*.

Natural Gas Fuel Rates and Alternative Fuel Promotion - Through its natural gas program, the Texas General Land Office (GLO) makes competitively priced natural gas available to school districts and other state and local public entities for use in natural gas vehicles. The GLO has also established an alternative fuels program to aggressively promote the use of alternative energy sources, especially for those fuels abundant in Texas, which could increase demand for renewable natural gas.

The Heavy-Duty Vehicle and Equipment Grant Program - Administered by the North Central Texas Council of Governments, in partnership with the Texas Commission on Environmental Quality and the U.S. Environmental Protection Agency. The program seeks to reduce emissions from heavy-duty engines in the Dallas-Fort Worth region, as well as educate public and private entities on the availability of clean fuels and vehicle technologies, which could increase demand for alternative fuels. Grant funding is available in three emphasis areas: local government, construction equipment and idle reduction projects. Both public and private sector entities may apply for grants for the replacement or repower/retrofit of construction equipment, or for the purchase and installation of on side and on-board idle reduction technologies. Local governments may apply for additional project types. All projects must have a nitrogen oxide emissions reduction component. Projects will be selected on a modified first come first served basis.

Alternative Fuel Vehicle (AFV) Grants, Houston and Galveston - Congestion Mitigation and Air Quality (CMAQ) Program Grants are available through the Houston-Galveston Area Council, via the Greater Houston Clean Cities Coalition, for up to 75% of the incremental cost of purchasing new original equipment; manufactured clean fuel vehicles; clean fuel vehicle conversions/repowers; or establishing publicly accessible alternative fueling infrastructure, which could increase demand for alternative fuels. This grant is for government and private entities in the eight-county Houston-Galveston non-attainment area.

9.5 Texas Feedstocks and RFS2 Requirements

Texas, with its large land mass and agricultural sector, has the potential to produce a significant amount of biofuels. The key will be the economic productivity of these fuels from the targeted feedstock. In Texas, the feedstocks (listed below) can be categorized for each fuel; however the technology process will also need to meet the GHG requirements. Thus a Life Cycle Assessment (LCA) will be needed to demonstrate the required GHG reduction.

Cellulosic Biofuel

- Agricultural residues – corn stover, sorghum bagasse, sugarcane bagasse, cotton gin waste, rice hulls, wheat straw
- Perennial grasses – Switchgrass, elephant grass
- Miscanthus
- Woody Biomass Feedstocks (Eucalyptus, Pine, Poplar, others)

Biomass-Based Diesel - Any biomass capable of being converted to diesel. The feedstock from which biomass based diesel is listed below (list is not exclusive):

- Algae
- Camelina
- Castor
- Cottonseed
- Fats and greases
- Jatropha
- Rapeseed
- Safflower
- Soybean
- Sunflower

Advanced Biofuel

- Sugarcane
- Sorghum (being considered by the U.S. EPA)
- Any cellulosic biofuel feedstock
- Any biomass based biodiesel feedstock
- (Other) Renewable Fuel
- Corn (with new advanced technology demonstrating 20% GHG reductions)
- Grain Sorghum (with new advanced technology demonstrating 20% GHG reductions)

10.0 GENOMICS-BASED RESEARCH AND DEVELOPMENT AND IDENTIFY TEXAS-BASED EFFORTS

The intent of this section is to identify Texas-based efforts focused on genomics-based research and development for the production of biofuels. Optimized biocatalysts are required to make sugar, starch and biomass-to-fuels technologies economically viable. As such, numerous companies are vying to develop or co-develop unique biocatalysts that are capable of fermenting sugars into renewable fuels. These include cellulosic ethanol, cellulosic butanol, renewable drop in fuels and biodiesel. Other companies are focused on organisms which will convert the biomass directly into fuels, through a process called direct microbial conversion. Genomics-based efforts are also being developed to obtain more easily converted feedstocks. What follows is a list of some of the most relevant companies currently developing genetically modified biocatalysts and modified plant or crop strains for application to the biofuels industry.

10.1 Ethanologens

Besides lignin, lignocellulosic biomass is comprised of cellulose (a six-carbon sugar – "C6") and hemicellulose (five-carbon sugars such as xylose and arabinose – "C5"). Various challenges exist which must be overcome before cellulosic ethanol can compete with fossil-based gasoline. To be competitive biocatalysts utilized in cellulosic ethanol technologies must be able to convert both C6 and C5 sugars to biofuel, they must be able to tolerate impurities and inhibitors which may be present in the resulting sugar streams or gases and they must have increased tolerance to biofuel product concentrations. Biocatalysts able to ferment sugars to ethanol are of most interest due to the existing fuel ethanol industry. Conventional corn ethanol almost exclusively utilizes native (non-genetically modified) yeast from the genera *Saccharomyces*. These yeasts are able to ferment C6 sugars such as glucose, which is the main sugar in corn starch, but are not able to ferment C5 sugars. Therefore, new genetically modified as well as non-GMO ethanologens are being developed that will be able to ferment C6 and C5 sugars, simultaneously or in cascade mode.

Selected leading companies developing new ethanologens for the second and third generation biofuels industry are listed in Table 10.1. Two of the companies are targeting organisms capable of performing what's termed "consolidated bioprocessing". These are Mascoma and Qteros. Consolidate bioprocessing is thought to be one of the more economical methods for cellulosic ethanol conversion. The concept is to develop or obtain an organism that is capable of not only producing cellulases required for hydrolyzing cellulose but at the same time the organism is able to ferment those resulting sugars directly to ethanol. The cost reductions from consolidated bioprocessing come from integration of these two unit processes into one. The process obviates the need to purchase extraneous cellulases and there is no requirement for purchasing or licensing of an ethanologen. If achieved, the cost reductions could be significant. *Clostridium* species are ideal for this as they are strict anaerobes (no need for aeration mixing) and some species such as *Clostridium thermocellum* are known for having a complex cellulose degrading mechanism. Both Mascoma and Qteros are developing *Clostridium* species.

Green Tech America, Incorporated and Verenium are developing ethanologens that will convert monomeric C6 and C5 sugars to ethanol. The organisms are capable of fermenting sugars resulting from pretreatment of the biomass followed by cellulase hydrolysis of cellulose, thus requiring the need for extraneous cellulases. In 2006 Green Tech America was founded by Dr. Nancy Ho, a research professor in the Department of Chemical Engineering at Purdue University (http://www.greentechamerica.com). The company possesses U.S. Patent number 5,789,210 entitled "Recombinant Yeast for Effective Fermentation of Glucose and Xylose". In a 2004 study Sedlak and Ho demonstrated that *Saccharomyces* yeast, 424A(LNH-ST), which contained cloned xylose-metabolizing genes stably integrated into the yeast chromosome in high copy numbers, could efficiently ferment glucose and xylose present in corn fiber and corn stover hydrolysates into ethanol. (*Source: Sedlak, M., and N. W. Ho. 2004. Characterization of the effectiveness of hexose transporters for transporting xylose during glucose and xylose cofermentation by recombinant Saccharomyces yeast. Yeast* ***21:****671–684*). The organism continues to be developed and has been tested by various laboratories and companies that include NREL, Iogen and the large Chinese conglomerate COFCO. Verenium is the result of the ethanologen technology originally licensed by BC International. The organisms are derived from the laboratories of Dr. Lonnie Ingram of the University of Florida. Dr. Ingram has worked extensively in the cloning of fermenting genes from heterologous organisms into the Enterobateriacea *Escherichia coli* and *Klebsiella* spp. BP Biofuels acquired Verenium's cellulosic biofuels technology, including two facilities, in July 2010. Verenium will continue its enzyme research and business, including its biofuels enzymes products.

Zeachem is a Lakewood, Colorado based company that has developed technology which indirectly produces ethanol using a bioconversion process linked to a thermo-chemical process. The targeted feedstock for this technology is woody biomass. The biomass is converted to soluble sugars which are then converted to acetic acid using a common acetogen. The acetic acid is later esterified and subsequently formed into ethanol via hydrogenation. The process' energy is supplied by the residual lignin obtained from the biomass. Groundbreaking ceremonies for the first Zeachem pilot plant facility in Boardman, Oregon occurred in June of 2010.

Syngas to ethanol is another technology which has been under development for many years. Two leading companies are leading the effort in its commercial development. The process gasifies the biomass feedstock which produces syngas, mostly carbon monoxide and hydrogen. The syngas is cleaned and fed to anaerobic organisms in liquid medium capable of fermenting the syngas to ethanol. Coskata and INEOs Bio lead this technology's development.

10.2 Butanologens

In the last few years several companies have begun to develop, modify and improve organisms able to ferment sugars to butanol. There are several advantages that butanol offers over ethanol as an alternative fuel. Butanol does not possess the affinity to water that ethanol has, thus it is able to be pipelined without the precautions you would have with anhydrous ethanol. Ethanol is currently pipelined in Brazil, but in a hydrous state (95% ethanol, 5% water). Butanol can be blended with gasoline without concerns of phase separation. It has higher energy content than ethanol and has no effect on the Reid Vapor Pressure when blended with gasoline. Companies within the U.S and Europe are looking to develop organisms capable of fermenting high yield butanol.

Commercial production of butanol via fermentation is performed anaerobically by *Clostridium* species and has been known for many years. During World War I in Manchester, England, Chaim Weizmann performed basic research on the fermentation of *Clostridium acetobutylicum* for the production of acetone, butanol and ethanol. The main fermentation protocols are still in use today. Feedstocks for the commercial microbial production of butanol include starch, molasses, sucrose, wood hydrolysates and pentoses. *Clostridium*, however, is fastidious and difficult to work with as it grows slowly.The stoichiometric ratios of butanol production are less than ideal and it is difficult to genetically engineer. More recently with the push for renewable fuels, a few companies have begun to develop eukaryotic and prokaryotic biocatalysts able to produce butanol. Currently there is little publicly available information on these companies. Leading companies include Gevo, Cobalt Technologies in the U.S. and Dupont and British Petroleum in Europe. Gevo (http://www.gevo.com) is an Englewood, Colorado-based company that is developing butanol-fermenting microorganisms and butanol product recovery processes. Gevo's technology relies on the production of butanol via yeast fermentation. Microorganisms such as *E. coli* or

Saccharomyces sp. generally do not have a metabolic pathway to convert sugars such as glucose into n-butanol, but it is possible to transfer an n-butanol producing pathway from an n-butanol producing strain, (e.g., *Clostridium*) into a bacterial or eukaryotic heterologous host, such as *Escherichia coli* or *Saccharomyces* sp., and use the resulting recombinant microorganism to produce n-butanol.

Important to this process is the ability of the recombinant organism to contain genes and express enzymes that catalyze the conversion of acetyl-CoA to n-butanol. Gevo has acquired the ability to do this in various yeasts which include *Saccharomyces* and possibly *Kluveromyces*. An extensive list of information and claims are found in the following patent website. http://www.wipo.int/pctdb/en/wo.jsp?WO=2008080124&IA=US2007088705&DISPLAY=DESC.

Cobalt Technologies located in Mountain View, California relies on the pretreatment of biomass utilizing nitric acid followed by butanol production by *Clostridium spp.* The company has been able to raise significant development funds from over seven different equity partners. In 2008 DuPont and British Petroleum teamed up to work on the molecular engineering of biocatalysts for the production of 1-butanol, 2-butanol and isobutanol. The current technology provides a recombinant *Escherichia coli* host which produces butanol or 2-butanone and comprises a genetic modification that results in reduced production of AcrA, AcrB, or both AcrA and AcrB, which are two endogenous proteins (export proteins) known to be components of a multidrug efflux pump in *Escherichia coli*. Such cells have an increased tolerance to butanol or 2-butanone as compared with cells that lack the genetic modification. Host cells of the invention may produce butanol or 2-butanone naturally or may be engineered to do so via an engineered pathway.

10.3 Biodiesel and Renewable Diesel

Several companies are concentrating on making changes to native algae or designing unique oil producing algae. Other technologies are being developed to produce renewable diesel using bacteria and yeast. Of special mention are Synthetic Genomics, Algenol, Amyris, and LS9.

Synthetic Genomics Inc. (SGI) is a venture founded by J. Craig Venter, a world renowned geneticist mostly known for leading the effort to be the first to completely sequence the human genome. In collaboration with ExxonMobil, SGI is identifying and developing algae strains that can achieve high bio-oil yields at lower costs. Algenol is in the process of commercializing the use of a hybrid blue-green algae (cyanobacteria) to make “ethanol, and high-value organic green-chemicals directly from carbon dioxide, water and sunlight” according to their website. They have opended operations in Fort Myers, Florida and are considering a similar project in Freeport, Texas in conjunction with Dow Chemical. Emeryville, California based Amyris is a seven-year old company looking to utilize *Saccharomyces spp*. to ferment sugars to renewable diesel. One cost benefit to the process is that product recovery is simple and can be performed without capital intensive equipment such as distillation. Amyris has recently received a government commitment of funds for up to $24.3 million from the U.S. Department of Energy and has numerous funding partners. The DOE grant is meant to help Amyris expand its existing Emeryville plant to produce a diesel substitute by fermenting biomass from sweet sorghum (up to 1,370 gallons per year), and secondarily, have capacity to churn out substitutes for petroleum-based products like lubricants and polymers. Just recently the company has obtained an off-take agreement with Shell for the production of its renewable diesel, already approved for use by the EPA.

10.4 Plant and Crop Genetics

Improvements in plant genetics for biofuels production are key to the economic development of the industry. Various companies and university researchers have leveraged previously established plant genetic tools to the improvements of first generation or dedicated energy crops. Objectives of these companies and researchers include increasing cellulose yields in plants, increasing plant yields per acre, as well as increasing and understanding drought tolerance in plants and the development of less recalcitrant feedstocks, among others.

Texas AgriLife Research and Ceres continue to work on a research and commercialization agreement for the development of high biomass sorghum. The sorghum is intended for biofuels and bio-power production. Dr. William (Bill) Rooney of Texas A&M has developed sorghum strains that can grow up to 20 feet in length and could produce more than 2,000 gallons of ethanol per acre -- or more than four times the current starch-to-ethanol process.

10.5 List of Genomics-Based R&D Companies and Texas-based Efforts

The following table (Table 10.1) demonstrates some of the more relevant companies and Texas-based efforts (not inclusive) currently developing biocatalysts or performing plant genetics improvements for the biofuels industry. The Texas-based efforts are mostly from the university sector with the exception of Terrabon.

10.6 Summary

Improvements in biocatalysts and plant genetics will be a key to making biofuels technologies economically viable. Numerous companies are vying to leverage technology advancements to make the required improvements in the targeted strains. Many of these are outside of Texas. The state of Texas has a distinguished advantage in several areas that can be exploited to push some of these improvements forward.

First and foremost, the Texas AgriLife Research has 7 academic departments and 12 regional research centers working on a wide range of bioenergy topics. Energy Cane and Energy sorghum are receiving significant attention at Texas AgriLife Research for consideration throughout the world as a viable biofuel feedstock alternative to current food crops. Similarly, the utilization of the algae cultures in the UTEX algae collection at the University of Texas – Austin, in conjunction with the expertise on campus -- as well as the Texas AgriLife Research in the Texas A&M system -- should continue to be funded. These organizations should continue to look for opportunities that contribute to the required current and future needs of bioenergy industries.

11.0 STRATEGIES TO ESTABLISH A NEXT-GENERATION BIOFUELS ENERGY RESEARCH PROGRAM

One way to increase the state's opportunities in the current and future thrust in the renewable energy sector is the establishment of a dedicated university-based research program or consortium. Established research consortia are an attractive resource to federal agencies and the private sector looking to fund advanced research in the various renewable energy industries, particularly if they have unique facilities and expertise. They can provide a one-stop shop for the state's research objectives or act as a central liaison to a network of research conducted across the state.

11.1 Current Biofuels R&D in Texas Universities

Projects are ongoing in the Texas A&M System, Texas Tech University System, and The University of Texas System and are shown in Table 11.1. The list was obtained by performing web-based research on those campuses. One of the intentions of this task was to rank, via down selection, the biofuels energy research being conducted in the major state universities to be included. Due to the limited research listed in Table 5.1, we suggest that all of the efforts identified be considered for inclusion in some fashion by a research consortium.

It is evident from the current research being conducted at Texas universities that there is an emphasis on two major research areas. These are biofuel feedstock research and algae research. These appear to be natural progressions of historical departmental strengths found within these campuses. Of special mention is the work being conducted on sorghum, energy cane, and oilseeds at the Texas AgriLife Research. Numerous academicians and researchers have been studying various facets of sorghum and sugar cane as an agricultural crop due to its potential advantages as a biofuels feedstock. Some countries, including the U.S., consider these to be a non-food crop resource for fuel ethanol. Thus, the extensive knowledge of sorghum and sugar cane genetics, hybrid crop research, agronomic, and production logistics at Texas AgriLife Research can serve as a significant foundation next-generation biofuels energy research hub.

The research into second-generation feedstocks being conducted at the Texas A&M Agriculture and Engineering BioEnergy Alliance is also of critical importance. Chevron Technology Ventures, a division of Chevron USA, Inc., is supporting research initiatives over a four-year period through the Texas A&M BioEnergy Alliance which is a formal partnership combining the A&M System's two premier research agencies in agriculture and engineering. These are the Texas AgriLife Research and the Texas Engineering Experiment Station. Although the results from the research performed under this effort may eventually be owned by Chevron, the facilities and expertise should be considered as part of the consortium or program.

Texas Tech University has done substantial research on existing agricultural feedstocks in the west Texas and panhandle regions of the state that include: cotton, livestock manure, and row crop residue. The university has also led in many areas of innovation into the cultivation and propagation of oilseed crops that are uniquely tolerant to heat, drought, and limited inputs. This research is easily transferred to the production of oilseeds, like canola, castor, and mustard, for use as biodiesel or other high-value oils that are able to accommodate multiple feedstocks without compromising the characteristics or performance of the final product.

The University of Texas – Austin has within its ranks one of the most recognized experts on the biosynthesis of cellulose. Researchers have conducted extensive research on the synthesis of cellulose at the micro-molecular level. This expertise could be brought to bear (if not already) on the modification of lignocellulosic structure to make biomass feedstocks more amenable to pretreatment. This research could certainly be a valid addition to such a consortium. Additionally, since up to 35% of lignocellulose is comprised of lignin, lignin research being conducted and sponsored by Chevron at the UT Permian Basin campus would be of interest.

Numerous research projects are investigating the use and development of microalgae for biofuels applications in both university systems. This bodes well for such a consortium as Texas has a significant algae collection (UTEX), abundant sunlight, land, CO_2 and shoreline. The one limiting factor would be water. However as reported in Section 5 and in the accompanying table of this report, Texas AgriLife Research (with General Atomics) is working on a unique project to produce JP-8 fuel for the Department of Defense in western Texas using brackish water as the water source. It appears that it would be key to unify the algae efforts and assets within the universities to establish a Research Group or Team in the consortium that would align all of these efforts. Distances from locations or university policies may or may not be an issue in this regard. That should be determined by the organizing entity and the universities.

Though not included in this report, Rice University and Baylor University have contributed significant resources to both state and national policy development through research on federal biofuel policy, production methods of renewable fuels using more abundant and sustainable biomass inputs such as unused agricultural and forestry residues, municipal wastes and high-yielding, sustainable energy crops, and chemical development of improved biocatalysts and bioprocesses.

11.2 Establishing a Biofuels Research Consortium

11.2.1 Infrastructure and Capacity Building

It will initially also be required that the organizing entity understands what facilities and infrastructure currently exists within its university campuses and colleges. This should minimally include the departments of agriculture, crop sciences, biology, microbiology, molecular biology, and engineering. If a broader vision is the target (i.e., to include wind power, etc.) then other departments will need to be evaluated. To establish a next-generation biofuels energy research program it will be important to know answers to the following questions:

- What are the current and planned research activities of the faculty members and staff?
- What and where are the existing feedstock genetics program laboratory assets?
- Is there an existing facility to perform integrated biomass conversion testing?
- If not, what type(s) and what scale of feedstock pretreatment facilities exist and where?
- Are there facilities available for hydrolysis or gasification of biomass?
- Are there facilities for fermentation testing of biocatalysts? What kind and at what scale?
- What and where are the algae research facilities?
- What are the computing and communications (teleconferencing) capabilities of the campus (es)?
- These and other questions should be undertaken to access the available infrastructure and to establish what the infrastructure gaps are. It will also assist in establishing what campuses and research efforts should be aligned.

Once research activities are known it will be necessary to understand what technical gaps exist on the campuses and if required, devise plans to acquire the needed technical expertise. The defined scope of the consortium will dictate what technical capabilities the consortium will require.

11.2.2 Strategy to Establish

Establishing a strategy for a next-generation biofuels energy research consortium program will require the organizing entity to know and understand numerous issues. Some of these include:

- Envisioning what the mid- and long-term focus of the research consortium will be
- Knowing fully the research currently being conducted and at which campus
- Understanding the facilities and infrastructure capabilities of each campus location
- Knowing the expertise of the academic staff and where these disciplines reside
- Understanding where synergies with researchers, engineers and infrastructure may exist
- Looking beyond the university campuses and identifying government, NGOs and private sector entities willing to collaborate on establishing a consortium

The strategy to establish a consortium should rely on the various points mentioned above as well as the wishes of the organizing entity. Various examples exist in which states have decided to utilize their universities and align renewable energy research interests in order to increase the state's knowledge base, increase job opportunities and attract the renewable energy industry. One such example is that of the "Colorado Renewable Energy Collaboratory" in the state of Colorado (http://www.coloradocollaboratory.org/index.html). A "collaboratory" is defined as a system in which scientists, engineers and academicians are able to interact and communicate using computing systems over long distances without walls. Assisted by the state, the Collaboratory is comprised of three universities and one national laboratory. These are Colorado State University, the Colorado School of Mines, the University of Colorado, and the National Renewable Energy Laboratory (NREL). Within this organization six centers have been established to assist researchers, students and industry to collaborate on public and privately financed projects. These centers include:

- Colorado Center for Biorefining and Biofuels
- Center for Revolutionary Solar Photoconversion
- SolarTAC (Solar Technology Acceleration Center) – Research Partnership
- Center for Research and Education in Wind
- Carbon Management Center
- Energy Efficiency and Management Center

The organizations stay current on research within each center and have meetings throughout the year to present their findings. Private sector involvement is critical for research funding and commercial application. The range of disciplines is broad, as demonstrated by the centers above and may be too expensive for what is currently planned for Texas. However, this could be considered an example of enabling unification of more than one institute. The institutes are located within a 60-mile radius in the

Colorado Front Range area. However, for Texas, distance should not be considered a barrier if teleconferencing systems are available.

The Bioenergy Bridge at Penn State University is an example of a single university system established to assist in the development of the state's agricultural and energy sector (http://www.bioenergybridge.psu.edu/). It is a university/private/public consortia aimed at solving the critical issues related to creating a sustainable bioindustry for the production of fuels, power and high value bio-based products. It is structured to rely heavily on private sector involvement for the funding of the organization.

In another example, the University of California – Davis campus has established the "Energy Institute" in order to aggregate its renewable energy assets under one roof. The Energy Institute's goal is "to develop fundamental understanding and new technologies for generating, converting, storing, moving, and using energy and innovative strategies for implementing a sustainable energy system." The institute works with other institutes, laboratories and programs across the campus and worldwide. It has an external advisory board and an internal campus steering committee and it aligns numerous research efforts. Fields of discipline under this institute include energy efficiency, bioenergy, transportation energy, energy and the environment, molecular energy sciences, nuclear energy and fusion sciences.
(http://energy.ucdavis.edu/home.cfm?id=ENR,28)

Therefore, the proposed biofuels consortium in Texas can be comprised of a number of campuses, institutes and industries willing to collaborate. Whichever model is most appropriate, of primary importance for establishing the consortium is to identify the vision of that consortium. Will it be strictly biofuels and bioenergy based or is it much broader than that? Texas being the largest wind power producer in the U.S. may consider adding to the consortium a wind energy component, though the National Institute For Renewable Energy at Texas Tech University has been recently established for that purpose.

11.2.3 Establishing the Business Plan

Whether or not the organizing entity is to collaborate with the private sector it will be key that the entity establish a business and marketing plan for the consortium. This will define the mission, vision, scope, management, research activities, campuses, laboratories and demonstrate to the private sector (if included) the research and the benefits it can derive as a contributor to the consortium. The private sector may be required if the goal of the consortium is to be a self-funding organization. This business plan description is written to include collaborations with the private sector.

For the purpose of this report we propose to call the consortium the **Texas Biofuels Research Consortia.** The business plan will define and describe the best approach to establish and economically sustain the consortia. Initial work to be conducted prior to the business plan should accomplish these four major tasks:

1. Mission and Vision of the Texas Biofuels Research Consortia – the organizing entity will need to work diligently to define the mission and vision of the consortia. This should initially be based on the existing strengths of the campuses and colleges currently conducting next-generation biofuels energy research. Other considerations for establishing the mission and vision may include the existing and future energy needs of the state, the existing agricultural sector in the state, federal and state energy policies, and future plans of the various universities to be considered.

2. Texas Biofuels Research Consortia Faculty and Facilities Evaluations – assess the existing research facilities, equipment and staff that are envisioned to be included in the consortia. This should describe in detail the current research being conducted and available facilities at the targeted universities to be considered as part of the consortia. Synergies in colleges or research disciplines to be aligned should be defined and described. As mentioned, communications between the campuses will be important therefore, teleconferencing systems should be utilized.

3. Strengths, Potential Weaknesses and Integration of Facilities, Infrastructure and Resources – the initial vision of the consortia should drive the required facilities, infrastructure and technical expertise required. Facility strengths and upgrades should be described. Strengths and deficiencies in infrastructure should also be reported. Technical gaps and additional staff required to achieve completeness of the consortia's needs should be noted.

4. Texas Biofuels Research Consortia Business and Marketing Plan – after the first three tasks have been completed the organizing entity should develop a Texas Biofuels Research Consortia Business and Marketing Plan. The following contents are recommended to develop as part of the business plan:

Description of the Texas Biofuels Research Consortia
Mission, vision and business strategy

Management and Operational Strategy
Describe the management organization and philosophy, board of directors and the experience and capabilities of key individuals and organization divisions. Some of those to be included are:

- Management Team
- Board of Commissioners/Directors
- Alliances and Professional Relationships
- Current Project Structure and Teams
- General Management Structure
- Operational Structure
- Facilities and Services Marketing Structure
- Management, Operations, and Services Marketing Support Requirements

Technology and Research Capabilities
This section will describe each of the targeted technology areas to be leveraged and the associated faculty. The following are possible disciplines of research for a next-generation biofuels energy research program. We have concentrated on these disciplines based on the current research on-going in the universities discussed above.

For Lignocellulosic Research:

- Plant genetics
- Plant production and biomass yield improvements
- Biomass harvesting and transport
- Biomass storage
- Biomass handling and feeding
- Pretreatment of biomass

- Enzyme discovery and characterization
- Solid-Liquid Separations
- Fermentation (conventional and syngas)
- Combustion, Pyrolysis and Gasification
- Chemical Catalysis
- Biopower and Hydrogen Production
- Byproduct Recovery and Utilization
- Engine and Vehicle Testing
- Process engineering of unit processes
- Thermochemical technologies

For Algae Research:
- Strain isolation
- New strain identification
- Algal genetics
- Land-based algae production research
- Photobioreactor design and improvements
- Algae product yield improvements
- Lowering or eliminating operational cost barriers (see Task 5)
- Heterotrophic algae research
- Thermochemical oil conversion
- Process engineering of unit processes

Systems Integration

This section should describe how each of the campuses, colleges or research areas could be systematically integrated into the consortia.

Available Services and Facilities (for external use)

This section should describe the proposed services to be available as well as provide detailed descriptions of the facilities to be utilized by interested parties.

Training Facilities

The Texas Biofuels Research Consortia should serve as a training facility for undergraduate students, graduate students and private and public-sector personnel. The program could serve as a platform for workforce development of the emerging renewable energy industry through undergraduate and graduate research, short-courses, and certificate and degree programs.

Marketing Strategy

This section should describe the various planned marketing scenarios that will be required to sustain the consortia. The utilization of member fees, foundation grants and funding, pay-as-you-go services, research funding and other concepts should be considered, if appropriate.

Funding Development Program

The state may be required to provide development funding for the program or consortia initially. In the mid to long-term the consortia should strive to be self-funding, Therefore, the founding strategy should target integration of university colleges or departments which would attract outside funding due to its uniqueness or expertise. Funding opportunities to target should include federal as well as corporate funding sources.

Financial Operations Model
Minimally, a five-year financial model should be developed to demonstrate the budget requirements to include facilities, infrastructure staff and other funding requirements of the consortia. This should include proforma balance sheets, income statement, cash flow statement, with monthly expenditures and staffing for the first 24 months of the project.

11.3 Summary

Our findings suggest that the current university biofuels energy research efforts at Texas universities are mainly focused on lignocellulosic biomass production, biomass and lignin conversion, cellulose synthesis and algae-based fuels research. Establishing a next-generation biofuels energy research program or consortium should be premised on the currently ongoing next generation research. It should look to integrate these efforts as a “virtual” consortia, to avoid costly expenses. It should look to distinguish itself through its uniqueness, as other programs and centers have already been established that may have similar assets. The current sorghum, oilseed and algae research being conducted would be an initial starting point for that.

A business and marketing plan for the consortia should be developed. The business plan will serve to guide the organizing entity, define the vision of the consortia, demonstrate the required financial requirements and address how it will be funded. Additionally, the business plan will reveal to the private sector the planned dedication of the program and it will demonstrate the benefits they can derive from working with the consortia.

12.0 STRATEGIES TO PROCURE FEDERAL AND OTHER FUNDING TO AID TEXAS IN BECOMING AN INDUSTRY LEADER

12.1 Federal Sources of Funding for Bioenergy R&D

There are various federal agencies that sponsor research, development and deployment of bioenergy projects. The two primary agencies tasked with developing the biofuels and bioenergy portfolio for the United States are the U.S. Department of Energy and the U.S. Department of Agriculture. Although the U.S. has been funding biofuels research over several decades it was not until President Bill Clinton signed Executive Order 13134 on August 12, 1999, that federal funding increased significantly for biofuels and bioenergy research and development.

The emphasis of the Executive Order was to "develop a comprehensive national strategy, including research, development, and private sector incentives, to stimulate the creation and early adoption of technologies needed to make biobased products and bioenergy cost-competitive in large national and international markets."

The order established the "Interagency Council on Biobased Products and Bioenergy." The Council is comprised of the secretaries of agriculture, commerce, energy, and the interior, the administrator of the U.S. Environmental Protection Agency, the director of the Office of Management and Budget, the assistant to the president for science and technology, and the director of the National Science Foundation. This council is instructed to prepare annually a strategic plan for the President outlining overall national goals in the development and use of biobased products and bioenergy and a budget. This basically obligates the two largest funding sources for this type of research, the DOE and USDA, to work together and fund research and commercialization projects to meet the renewable fuels and energy requirements as per federal legislation as interpreted and administered by the EPA.

In order to position the state of Texas and its higher learning institutions to be competitive for the DOE and USDA funds, it is required that these organizations understand the desired outcomes for bioenergy and biofuels funded research from each of these federal agencies. In simple terms the DOE's main thrust is energy security and diminishing the utilization of imported oil. The DOE Office of Energy Efficiency and Renewable Energy (EERE) has established a strategic goal to meet the requirements of the Energy Independence and Security Act (EISA). The Biomass Program in the DOE is the main funding source for DOE's bioenergy programs. The Biomass Program supports four key priorities of the EERE strategic plan:

- Dramatically reduce dependence on foreign oil
- Promote the use of diverse, domestic and sustainable energy resources
- Reduce carbon emissions from energy production and consumption
- Establish a domestic bio-industry

The major research focus of the Biomass Program for the foreseeable future is the commercialization of cellulosic ethanol technologies as cellulosic ethanol is seen as the most promising renewable bulk commodity fuel able to displace petroleum use in the transportation sector. Other advanced cellulosic biofuels conversion technologies are also supported. The DOE strategy focuses on the full supply chain, from growth of the biomass to fuel utilization. The goals have time and production cost metrics that will need to be considered. For more information, state and university personnel are encouraged to read DOE's Biomass Multi-Year Program Plan; http://www.eere.energy.gov/biomass/pdfs/mypp.pdf

For USDA, the state or universities should familiarize themselves with the vision of the newly established National Institute of Food and Agriculture (NIFA). Formed mainly from the Cooperative State Research, Education, and Extension Service, NIFA is the USDA's extramural research funding agency for biofuels and bioenergy research. Of particular emphasis for the state or universities is NIFA's focus on **rapidly improving the amount and quality of plant-based feedstocks that will be the source of biofuels**, as President Barack Obama has set renewable energy goals for the nation, including 60 billion gallons a year from biofuels by 2030. See http://www.csrees.usda.gov/index.html for more details.

Universities should also be aware of the USDA's Biopreferred Program. The program promotes and funds research to develop renewable, environmentally-friendly biobased products. The university can forge alliances with the private sector and request funds to sponsor developmental work for such products. These can include products from industrial and construction products to housewares and cleaning supplies. http://www.biopreferred.gov/

It is also recommended that the state and its researchers familiarize themselves with the *Roadmap for Biomass Technologies in the United States* prepared by the Biomass Technical Advisory Committee as it lists the targeted research to be funded by USDA and DOE. Research sections include Feedstock Systems, Processing and Conversion, Transportation, Storage, and Distribution Infrastructure, End-Use Markets and Crosscutting Processes and Technologies. Research programs at the universities should target these main objectives.
http://www.brdisolutions.com/Site%20Docs/Roadmap/OBP_roadmapv2_web.pdf

Other federal funding opportunities may be found at the EPA and the DOD's Defense Advanced Research Project Agency (DARPA). DARPA is the research arm of the U.S. military. It sponsors research which is considered out-of-the-box. It is comprised of various offices including the Strategic Technology Office. This office is in charge of funding biofuels research for the military. The military is looking to replace many of its fossil-based fuels with renewable fuels as required by law. There is currently a mandate for the military to reduce energy consumption by 30 percent by 2015 and they must also grow their use of renewable energy sources by 25 percent by 2025. See http://www.newbernsj.com/news/biofuel-89852-crops-military.html.

Algae research is being strongly supported by DARPA, including some of the algae research being conducted at Texas AgriLife Research and the University of Texas (see Section 10). Continuing and expanding outreach to DARPA to suggest unique approaches for military biofuel production may draw their interest to other areas and programs in the state capable of generating high-value fuels. DARPA is able to fund projects it considers unique at any time. Therefore, if researchers believe they have breakthrough R&D that can be applied to the demands of DARPA they should contact the DARPA offices.

12.2 Non-Federal Sources of Funding

The International Energy Agency is an organization consisting of a collection of research areas of focus which are funded collaboratively. The United States is one of many member states which participate. Bioenergy is one of the leading areas and there are numerous researchers conducting work on the topic worldwide. http://www.iea.org/

The European Biofuels Technology Platform is an agency funded by the European Union (EU) member states. Its mandate is to fund biofuels research within the EU in order to accelerate the deployment of sustainable biofuels technologies. Usually the prime contractor will be an organization or company in a member state. However, the State of Texas and its universities should investigate where research efforts may align well with their European counterpart to gain access into this well-funded organization. http://www.biofuelstp.eu/overview.html#mission

The National Biodiesel Board (NBB) and the Renewable Fuels Association (RFA) are trade organizations that in some cases fund research. The amount of research funded by these agencies is not substantial but may fit within the current university research conducted in the State. The NBB reportedly funds biodiesel crops and algae research while the RFA funds starch crop research for biofuel production and biofuel vehicle testing. http://www.biodiesel.org/
http://www.ethanolrfa.org/

12.3 Biofuels Program Funding Sources

Following is a table (Table 12.1) that identifies programs and offices that are responsible for funding bioenergy R&D. It identifies the funding sources, key personnel and contact information, R&D areas and cross references this to Texas-based programs and R&D interests to match funding needs with the most appropriate sources of funding. For 2011, there are significant R&D budget increases for the DOE's Office of Science and the National Science Foundation.
http://www.whitehouse.gov/administration/eop/ostp/rdbudgets/2011

12.4 Summary

Numerous sources of funding exist to perform basic and applied biofuels and bioenergy research. If a state research center has a unique capability which attracts the interest of large funding agencies such as the USDA and the DOE, these agencies could be a source of funding for multiple years. For all agencies noted we would encourage the state or its universities to contact the appropriate contact persons from each identified program above. This outreach should be a discovery experience to become familiar with the funding vision from each agency or office and to understand the upcoming research to be funded. These agencies will typically discuss their goals, procurement needs and areas of interest *before* a solicitation is released. Once a solicitation is released it is difficult to obtain any strategic advantage.

Networking before solicitations are released is critical so that the most appropriate solicitations are targeted. The state would then be able to position their research personnel or teams to be competitive for those funding opportunities. In some cases the funding agencies will require that the research teams be comprised of public-private partnerships as this is intended to lead to quicker commercialization of technologies and processes. Therefore, in some cases, outreach to the private sector should also be considered if not already being conducted.

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14.0 GLOSSARY

Agricultural biomass – A subset of biomass produced directly from agricultural activities, including cereal grains; sugar crops; oilseeds; other arable crops and crop by-products such as straw; vegetative grasses; farm forestry (e.g. willow and poplar); and livestock by-products, for example, manure and animal fats.

Alcohol fuels – A general term which denotes mainly ethanol, methanol and butanol, usually obtained by fermentation, when used as a fuel.

Alternative chemical feedstock means a feedstock that is produced by a thermochemical process that converts alternative sources of fuel, including biomass, or other renewable sources, to a raw material to be used in the chemical manufacturing process.

Animal waste – The dung, feces, slurry or manure which is used as the raw material for a biogas digester.

Ash content – The weight of ash expressed as a percentage of the weight before burning of a fuel sample burned under standard conditions in a laboratory furnace. The higher the ash content, the lower the energy value of the fuel.

Bagasse – The fibrous residue from sugarcane which remains after the juice has been extracted. It constitutes about 50 per cent of cane stalk by weight and with a moisture content of 50 per cent its calorific value varies from 6.4 to 8.60 GJ/t. It is widely used to generate electricity and also as animal feed, in ethanol production, for pulp and paper, paperboard, furniture, etc.

Bark – A general term for all the tissues outside the cambium in sterns of trees; the outer part may be dead, the inner part is living.

Biobased product – The term ‘biobased product,’ as defined by Farm Security and Rural Investment Act (FSRIA), means a product determined by the U.S. Secretary of Agriculture to be a commercial or industrial product (other than food or feed) that is composed, in whole or in significant part, of biological products or renewable domestic agricultural materials (including plant, animal, and marine materials) or forestry materials.

Biodiesel – Fuel derived from vegetable oils or animal fats that can be used in existing engines or blended with diesel fuel. It is produced when a vegetable oil or animal fat is chemically reacted with an alcohol. Section 16.001 of the Texas Agriculture Code defines biodiesel as means a motor fuel that:

1. Meets the registration requirements for fuels and fuel additives established by the United States Environmental Protection Agency under Section 211 of the federal Clean Air Act (42 U.S.C. Section 7545);
2. Is mono-alkyl esters of long chain fatty acids derived from vegetable oils and animal fats;
3. Meets the requirements of ASTM specification D-6751;

4. Is intended for use in engines that are designed to run on conventional, petroleum-derived diesel fuel; and
5. Is derived from agricultural products, vegetable oils, recycled greases, biomass, or animal fats or the wastes of those products or fats.

Biorefinery – A facility that processes and converts biomass into value-added products. These products can range from biomaterials to fuels such as ethanol or important feedstocks for the production of chemicals and other materials. Biorefineries can be based on a number of processing platforms using mechanical, thermal, chemical, and biochemical processes.

Biofuels – Fuels made from biomass resources, or their processing and conversion derivatives. Biofuels include ethanol, biodiesel, and methanol.

Biogas – The fuel produced following the microbial decomposition of organic matter in the absence of oxygen. It consists of a gaseous mixture of methane and carbon dioxide in an approximate volumetric ratio of 2:1. In this state the biogas has a calorific value of about 20–25 MJ/m3 but this can be upgraded by removing the carbon dioxide.

Biomass – Any organic material, of plant and animal origin, derived from agricultural and forestry production and resulting by-products, and industrial and urban wastes, used as feedstocks for producing bioenergy and biomaterials.

Biomass conversion process – The methods which convert biomass into energy or fuel can be classified as:

- biochemical, which includes fermentation and anaerobic digestion
- thermochemical, which includes pyrolysis, gasification and liquefaction.

Bioenergy **–** Renewable energy produced from biomass when used to produce heat and/or power and transport fuels. Bioenergy produced from agricultural biomass includes biofuels such as bioethanol, mainly derived from cereal grains and sugar, and biodiesel from vegetable oils and animal fats; biopower in the form of electricity; and bioheat generated from processing mainly agro-forestry products (e.g willow), crop and livestock by-products (e.g. straw and manure) and grasses (e.g. elephant grass).

Biomass energy potential – This term refers to the total biomass energy generated per annum. This represents all the energy from crop residues, animal wastes, the harvestable fuel crops and the annual increase in the volume of wood in the forests.

Biomaterials – Renewable industrial raw materials and derived processed products produced from biomass. Biomaterials produced from agricultural biomass mainly include industrial oils for paints, inks, etc. from oilseed crops; starch and sugar from, for example, cereals, potatoes, sugar beet and sugarcane, used to produce polymers, detergents, paper, etc.; fibers from crops such as cotton and hemp; and high-value low-volume products derived from a variety of crops, and used in the production of, for example, cosmetics, flavorings, and healthcare products.

Biopower – The use of biomass feedstock to produce electric power or heat through direct combustion of the feedstock, through gasification and then combustion of the resultant gas, or through other thermal conversion processes. Power is generated with engines, turbines, fuel cells, or other equipment.

Bioproducts – Includes both bioenergy and biomaterials.

By-products – Includes solid, liquid and gaseous products derived from human activities.

Calorific value – A measure of the energy content of a substance determined by the quantity of the heat given off when a unit weight of the substance is completely burned. It can be measured in calories or joules; the calorific value is normally expressed as kilocalories/kg or MJ/kg.

Density – The weight of unit volume of a substance. In the case of wood several different densities can be referred to:

- basic density (the weight of dry matter in unit volume of freshly felled wood);
- air-dry density (the weight of unit volume of oven-dried wood);
- stacked density (the weight of wood at stated moisture content – fresh, air-dry, etc. – contained in a stack of unit volume).

Energy content – The intrinsic energy of a substance, whether gas, liquid or solid, in an environment of a given pressure and temperature with respect to a data set of conditions. Any change of the environment can create a change of the state of the substance with a resulting change in the energy content. Such a concept is essential for the purpose of calculations involving the use of heat to do work.

Energy efficiency – The percentage of the total energy input that does useful work and is not converted into low-quality, essentially useless, low temperature heat in an energy conversion or process.

Ethanol fuel (bioethanol) – Fermentation ethanol obtained from biomass-derived sources (usually sugar cane, corn, lignocellulosic biomass, etc.) used as a fuel. Ethanol is also obtained from syngas. Section 16.001 of the Texas Agriculture Code defines fuel ethanol as meaning an ethyl alcohol that:

1. Has a purity of at least 99 percent, exclusive of added denaturants;
2. Has been denatured in conformity with a method approved by the Bureau of Alcohol, Tobacco, Firearms, and Explosives of the United States Department of Justice;
3. Meets the requirements of ASTM D4806, the standard specification for ethanol used as a motor fuel; and
4. Is produced exclusively from agricultural products or by-products or municipal solid waste.

Feedstock – A product used as the basis for manufacture of another product.

Fuel – Denotes energy sources which have hitherto provided the bulk of the requirements of modern industrial society (e.g. petroleum, coal, and natural gas; wood is excluded from this category). The term is almost synonymous with *commercial energy*.

Mill Residue – Bark and woody materials that are generated in primary wood-using mills when round-wood products are converted to other products. Examples are slabs, edgings, trimmings, sawdust, shavings, veneer cores and clippings, and pulp screenings. Includes bark residues and wood residues (both coarse and fine materials) but excludes logging residues.

Moisture content – The moisture content is the amount of water contained in a biomass or fuel.

Non-woody biomass **–** The term includes mostly agricultural crops, shrubs and herbaceous plants.

Photosynthesis – A term used commonly to denote the process by which plants synthesize organic compounds from inorganic raw materials in the presence of sunlight. All forms of life in the universe require energy for growth and maintenance. It is therefore the process whereby green plants use the sun's energy to produce energy-rich compounds, which may then be used to fix carbon dioxide, nitrogen and sulphur for the synthesis of organic material.

Renewable resources – Natural resources produced by photosynthesis, or derived from products of photosynthesis (e.g. energy from plants), or directly from the sun (e.g. solar energy) utilized by humans in the form of plant or animal products.

Renewable energy – Refers to an energy form the supply of which is partly or wholly generated in the course of the annual solar cycle. The term covers those continuous flows that occur naturally and repeatedly in the environment (e.g. energy from the sun, the wind, from plants, etc.). Geothermal energy is also usually regarded as a renewable energy source since, in total; it is a resource on a vast scale.

Renewable Diesel – Section 16.001 of the Texas Agriculture Code defines renewable diesel as a motor fuel that:

1. Meets the registration requirements for fuels and fuel additives established by the United States Environmental Protection Agency under Section 211 of the federal Clean Air Act (42 U.S.C. Section 7545);
2. Is a hydrocarbon;
3. Meets the requirements of ASTM specification D-975;
4. Is intended for use in engines that are designed to run on conventional, petroleum-derived diesel fuel; and
5. Is derived from agricultural products, vegetable oils, recycled greases, biomass, or animal fats or the wastes of those products or fats.

Woody biomass – Comprises the total mass of roots, stem, limbs, tops, and leaves of all trees and shrubs (live and dead) in the forest, woodland, or rangeland environment. In practice, woody biomass generally refers to woody material that historically has a low value and is not suitable for traditional higher value forest products such as lumber, plywood, paper and pulp, furniture and other wood products. Woody biomass is one of the most important forms of biomass energy.

Yield – For plant matter yield is defined as the increase in biomass over a given time and for a specific area, and must include all biomass removed from the area. The yield or annual increment of biomass is expressed in dry tones per year.

APPENDIX A
USDA - Texas Agricultural Statistics Districts

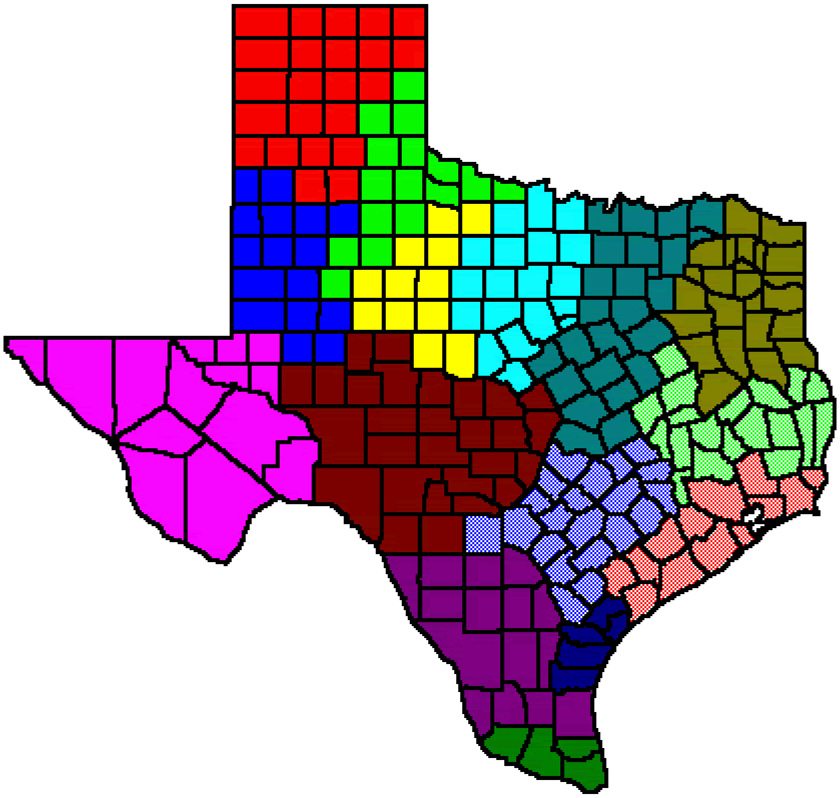
USDA United States Department of Agriculture
National Agricultural Statistics Service

Texas Field Office of USDA's National Agricultural Statistics Service

You are here: Home / Statistics by State / Texas / Charts & Maps

Texas Agricultural Statistical Districts

Read our narrative description of these districts.



Key	Code	Numeric Name	Geographic Name
🟥	11	District 1-North	Northern High Plains
🟦	12	District 1-South	Southern High Plains
🟩	21	District 2-North	Northern Low Plains
🟨	22	District 2-South	Southern Low Plains
■	30	District 3	Cross Timbers
■	40	District 4	Blacklands
■	51	District 5-North	North East Texas
▨	52	District 5-South	South East Texas
🟪	60	District 6	Trans-Pecos
🟫	70	District 7	Edwards Plateau
▨	81	District 8-North	South Central
■	82	District 8-South	Coastal Bend
▨	90	District 9	Upper Coast
🟪	96	District 10-North	South Texas
🟩	97	District 10-South	Lower Valley

http://www.nass.usda.gov/Statistics_by_State/Texas/Charts_&_Maps/distmap2.htm

Description of the Texas Agricultural Statistical Districts

Summary: Texas is divided into 15 agricultural statistical districts. These district are geographically referred to as Northern High Plains, Southern High Plains, Northern Low Plains, Southern Low Plains, Cross Timbers, Blacklands, North East Texas, South East Texas, Trans-Pecos, Edwards Plateau, South Central, Coastal Bend, Upper Coast, South Texas, and Lower Valley.

Northern High Plains: The Northern High Plains district is located in the most northern part of the panhandle. The 23 counties included in this district are Armstrong, Briscoe, Carson, Castro, Dallam, Deaf Smith, Floyd, Gray, Hale, Hansford, Hartley, Hemphill, Hutchinson, Lipscomb, Moore, Ochiltree, Oldham, Parmer, Potter, Randall, Roberts, Sherman, and Swisher.

Southern High Plains: The Southern High Plains district is located in the lower west side of the panhandle. The 16 counties included in this district are Andrews, Bailey, Cochran, Crosby, Dawson, Gaines, Glasscock, Hockley, Howard, Lamb, Lubbock, Lynn, Martin, Midland, Terry, and Yoakum.

Northern Low Plains: The Northern Low Plains district is located in the southeast side of the panhandle. The 16 counties included in this district are Borden, Childress, Collingsworth, Cottle, Dickens, Donley, Foard, Garza, Hall, Hardeman, Kent, King, Motley, Wheeler, Wichita, and Wilbarger.

Southern Low Plains: The Southern Low Plains district is located to the immediate southeast of the panhandle, just below the Northern Low Plains. The 12 counties included in this district are Baylor, Coleman, Fisher, Haskell, Jones, Knox, Mitchell, Nolan, Runnels, Scurry, Stonewall, and Taylor.

Cross Timbers: The Cross Timbers district is located to the east of the Southern Low Pains with the state of Oklahoma bordering on the north. The 19 counties included in this district are Archer, Brown, Callahan, Clay, Comanche, Eastland, Erath, Hood, Jack, Mills, Montague, Palo Pinto, Parker, Shackelford, Somervell, Stephens, Throckmorton, Wise, and Young.

Blacklands: The Blacklands district is located to the right of Cross Timbers with the state of Oklahoma bordering on the north and stretching south to the central part of the state. The 25 counties included in this district are Bell, Bosque, Collin, Cooke, Coryell, Dallas, Delta, Denton, Ellis, Falls, Fannin, Grayson, Hamilton, Hill, Hunt, Johnson, Kaufman, Lamar, Limestone, McLennan, Milam, Navarro, Rockwall, Tarrant, and Williamson.

North East Texas: The North East Texas district is located at northeastern part of the state. The state of Oklahoma borders the district on the north with Arkansas and Louisiana states bordering on the east. The 24 counties included in this district are Anderson, Bowie, Camp, Cass, Cherokee, Franklin, Gregg, Harrison, Henderson, Hopkins, Houston, Marion, Morris, Nacogdoches, Panola, Rains, Red River, Rusk, Shelby, Smith, Titus, Upshur, Van Zandt, and Wood.

South East Texas: The South East Texas district is located just south of North East Texas and to the southeast of the Blacklands. Louisiana state borders the district on the east. The 19 counties included in this district are Angelina, Brazos, Freestone, Grimes, Hardin, Jasper, Leon, Madison, Montgomery, Newton, Polk, Robertson, Sabine, San Augustine, San Jacinto, Trinity, Tyler, Walker, and Waller.

Trans-Pecos: The Trans-Pecos district is located in the most western tip with the state of New Mexico bordering on the north and the country of Mexico bordering on the south. The 14 counties included in this district are Brewster, Crane, Culberson, Ector, El Paso, Hudspeth, Jeff Davis, Loving, Pecos, Presidio, Reeves, Terrell, Ward, and Winkler.

Edwards Plateau: The Edwards Plateau district is centrally located. Districts surrounding are (moving clockwise from the west) Trans-Pecos, Southern High Plains, Southern Low Plains, Cross Timbers, Blacklands, South Central, South Texas, and the country of Mexico. The 28 counties included in this district are Bandera, Blanco, Burnet, Coke, Concho, Crockett, Edwards, Gillespie, Irion, Kendall, Kerr, Kimble, Kinney, Lampasas, Llano, McCulloch, Mason, Menard, Reagan, Real, San Saba, Schleicher, Sterling, Sutton, Tom Green, Upton, Uvalde, and Val Verde.

South Central: The South Central is located to the east of Edwards Plateau. Districts surrounding South Central (moving clockwise from the west) are Edwards Plateau, Blacklands, South East Texas, Upper Coast, Coastal Bend, and South Texas. The 21 counties included in this district are Austin, Bastrop, Bee, Bexar, Burleson, Caldwell, Colorado, Comal, De Witt, Fayette, Goliad, Gonzales, Guadalupe, Hays, Karnes, Lavaca, Lee, Medina, Travis, Washington, and Wilson.

Coastal Bend: The Coastal Bend district is located in the central part of the coast line that bends. Districts surrounding the Coastal Bend (moving clockwise from the west) are South Texas, South Central, Upper Coast, and the Gulf of Mexico. The five counties included in this district are Aransas, Kleberg, Nueces, Refugio, and San Patricio.

Upper Coast: The Upper Coast district is located north of the Coastal Bend with Louisiana bordering on the east and the Gulf of Mexico bordering on the south. The 13 counties included in this district are Brazoria, Calhoun, Chambers, Fort Bend, Galveston, Harris, Jackson, Jefferson, Liberty, Matagorda, Orange, Victoria, and Wharton.

South Texas: The South Texas district is located south of Edwards Plateau and South Central with Lower Valley just below. Bordering on the east is the Coastal Bend district and the Gulf of Mexico with the country of Mexico bordering on the west. The 15 counties included in this district are Atascosa, Brooks, Dimmit, Duval, Frio, Jim Hogg, Jim Wells, Kenedy, La Salle, Live Oak, McMullen, Maverick, Webb, Zapata, and Zavala.

Lower Valley: The Lower Valley district is located at the most southern tip of the state. The South Texas district borders it on the north, with the country of Mexico bordering on the left, and the Gulf of Mexico bordering on the right. The four counties included in this district are Cameron, Hidalgo, Starr, and Willacy.

http://www.nass.usda.gov/Statistics_by_State/Texas/Charts_&_Maps/distmap1.htm

APPENDIX B
Texas Bioenergy Crop Summary

Bioenergy Feedstock	#	Crop	Latin Binomial	Soil pH	Soil	Rainfall Requirement	Maximum Temperature	Minimum Temperature	Latitude/Longitude	Approximate Region	Average Dry Matter Yield Dryland	Logistical Challenges to Planting/Managing	Challenges to Sustainability*	Sustainability in Texas	Selling Points	Drawbacks	Primary** Information Source Used
Cellulosic Biomass		**Annual grasses**															
	1	Daylight Sensitive Sorghum	*Sorghum bicolor*	5.8-8.5	Well adapted, well drained loams ideal	16-30"	Not limiting	Warm season	Not limiting	All state	4,000-20,000 lb/ac	Annual planting	Fossil fuel inputs: fertilizer, seeding	High	C4; long growing season	Yearly reseeding	Bassam, 2010
	2	Energy Cane	*Saccharum spp.*	5 - 8.5	Well drained, deep	>23"	Not limiting	Not limiting	Not limiting	E, S, & Coast	28,000-43,000 lb/ac	Vegetative propagation	Occupies prime ag land	Good	Water-use efficient		Rainbolt & Gilbert, 2008
	3	Giant Reed	*Arundo donax*	6.1-7.8	Moist	>28"	Not limiting	Warm season	Latitude not limiting	E & C (N & S)	7,000-15,000 lb/ac	Slow vegetative prop.		High	C4; requires few inputs	Invasive	
	4	Miscanthus	Miscanthus spp.	5.5-7.5	Moist	>40"	Not limiting	Not limiting	Latitude not limiting	S/SE	6,000-40,000 lb/ac	Vegetative prop.	Rainfall requirements high/C3	Poor soils in SE	Cold tolerant	Invasive; heavy soils	
	5	Sweet Sorghum	*Sorghum bicolor*	5.8-8.5	Well adapted, well drained loams ideal	>16"	Not limiting	1500-2500 degree days	8 mo without frost	All state	4,000-5,500 lb/ac	Annual planting	High inputs	High	Saline soil tolerant/ water efficient	Yearly planting/inputs	FAO, 2010
		Perennial grasses															
	6	Bahiagrass	*Paspalum notatum*	5.5-6.5	Sandy, well drained	>30"	Not limiting	28°C	Latitude not limiting	E	3,000 - 5,500 lb/ac	Slow to establish	Excellent but requires some N	High	Low fertility requirement	Invasive	Redfearn & Nelson, 2003
	7	Bermudagrass	*Cynodon dactylon* /others	6.5-8.0	Well drained	>25"	Not limiting	Not limiting	Latitude not limiting	E & C (both N & S)	5,000-12,000 lb/ac	Highly productive cultivars are vegetative prop.	Requires fertilizer inputs	High	Flexible uses/tolerant	Invasive	Muir et al., 2009
	8	Big Bluestem	*Andropogon gerardii*	>6.0	Moist	>32"	Not limiting	Not limiting	Latitude not limiting	NC	6,000-10,600 lb/ac	Weak seedlings		High	Native	Dispersed production	Boe et al., 2004
	9	Indian Grass	*Sorghastrum* spp.	>6.0	Well drained	>25"	Not limiting	Not limiting	Latitude not limiting	E & C (both N & S)	4,000-10,000 lb/ac	Expensive seed		High	Native	Dispersed production	Mitchell & Vogel, 2004
	10	Little Bluestem	*Schizachyrium scoparium*	>6.0	Well drained	>14-40"	Not limiting	Not limiting	WHZ 2-9	All state	1,000-4,000 lb/ac		Excellent but low yields	High	Drought tolerant	Dispersed production	Boe et al., 2004
	11	Old world bluestems	*Bothriochloa* spp. etc.	6.8-8.0	Well drained loams ideal	>25"	Not limiting	Not limiting	Not limiting	NC & NW	2,500-10,000 lb/ac	Slow establishment	Some N required	High	Drought & winter hardy	Kleberg' and 'KR' cultivars are extremely invasive	Coleman et al., 2004; Noble Foundation
	12	Switchgrass	*Panicum virgatum*	>6.0	Upland types-well drained; Lowland types heavy	20-48"	Not limiting	Not limiting	All lat up to 99o long	E, N, S	3,500-18,000 lb/ac	Weak seedlings	Excellent but requires some N	High	Widely adapted	Diificult to establish	Kiniry et al, 2005
		Other															
	13	Atriplex	*Atriplex* spp.	7-8.5	Saline	>20"	Not limiting	20o	<30o N	S	3,000-6,500 lb/ac	Unknown management		Medium	Saline tolerant	Limited freeze tolerance	Aganga et al. 2003; Goodin and Newton, 1984
	14	Kenaf	*Hibiscus cannabinus*	7.0	Neutral, well drained	>6"	Not limiting	>32o	Latitude not limiting	NC & SC	>4,000-15,000 lb/ac	Requires fertilizer	Annual requiring yearly reseeding	High	Drought tolerant; daylight sensitive	Continuous cropping discouraged	Bassam 2010 & Muir
Woody Feedstocks	**1**	Cedar (Juniper)	Juniperus spp.	>7.0	Well drained	Not limiting	Not limiting	Not limiting	Not limiting	Central	Unknown	Dispersed production	Harvest radius to conversion plants	High	Alkaline soil tolerant; woody feedstock a byproduct of land clearing	Highly invasive; dispersed	Adams, 2008
	2	Eucalyptus	Eucalyptus spp.	-	-	-	-	32°C (freeze intolerant)	-	-	-	-	Climate inappropriate	Low		Frost susceptible	
	3	Hybrid Poplar	*Populus spp.*	5.5-7.8	Moist, deep	15"	< 100C	Not limiting	Not limiting	E, NC, & Panhandle	6-22 Mg/ha/yr	Grown from cutting	Climate inappropriate	Moderate	Improves water quality	No adaptation to Texas	Felix et al., 2008; Pearson et al., 2008
	4	Mesquite	*Prosopis glandulosa*	neutral	Medium	18-40"	Not limiting	Not limiting	Not limiting	C & W (both N&S)	5,000-9,000 lb/ac	Long term investment	Harvest radius to conversion plants	High	Adapted and hardy	Dispersed	Ansley et al., 2009
	5	Pine	*Pinus spp.*	>4.0	Sandy, well drained	>7"	Not limiting	Not limiting	Not limiting	All state	1,000-6,000 ft3/ac	Time to harvest		High			Mann, 1971
	1	Algae	*Multiple Genus*	n/a	n/a	None	n/a	n/a	Not limiting	Coast	5000-15000 g oil/ac/yr	Raceway construction, access to water and CO2	Amount of fresh water required if fresh water species are grown	High	Can use salt water, May be a CO2 sink from power/municipal plants, Does not compete with arable land	Cost-effective methods unproven on large scale	Edwards, 2008
	2	Camelina	*Camelina sativa*	6.5-8.0	Medium to light	9"	Not limiting	Not limiting	Not limiting	All state; S & C because of alkaline soil	400-1000 lb/ac		50 kg N/ha for lower yield; 100 kg N/ha for higher yield	High for spring varities	Widely adapted		James Grichar, data not published; Meakin, 2007
	3	Castor	*Ricinus communis*	Acid to alkaline	Loamy, medium texture, well drained	15"	Not limiting	Not limiting	Not limiting	Not limiting	300-800 lb shelled/ac		50 lb N/ac; not a legume; can be weedy or invasive	Moderate because poisonous compound	Widely adapted	Seed is poisonous to livestock and humans (Ricin); bean is friable	Meakin, 2007
	4	Cottonseed	*Gossypium hirsutum*	5-8	Most soils	23"	Not limiting	Warm-season	Not limiting	Central & E	90 lb seed/inch of water	Boll weevil, cotton root rot	Byproduct; 5 lb N/ inch water	High			Colleague; Cotton Incorporated

Bioenergy Feedstock	#	Crop	Latin Binomial	Soil pH	Soil	Rainfall Requirement	Maximum Temperature	Minimum Temperature	Latitude/Longitude	Approximate Region	Average Dry Matter Yield Dryland	Logistical Challenges to Planting/Managing	Challenges to Sustainability*	Sustainability in Texas	Selling Points	Drawbacks	Primary** Information Source Used
Oil Crops	5	Flaxseed	*Linum usitatissimum*	5.8-7	Deep fertile loams, heavy clay	15"	Not limiting	Not limiting	Not limiting	Karnes,Jim Wells, Bee, Wilson, Atascosa, Live Oak and Nueces. As more cold tolerant varieties were developed, the acreagespread into the southern Blackland Prairie counties.	22-42 bu/ac	Availability of adapted seed	Competes with a plant source of omega 3 fatty acids for humans	High			James Grichar, Data not published; Meakin, 2007
	6	Jatropha	*Jatropha curcus*	6-8.5	Well drained	24-60"	Not limiting	Frost susceptible	35o Lat	n/a	400-8,000 lb/ac	N needed	Climate challenges	Low	None	Indeterminate	FAO 2010
	7	Palm	*Elaeis guineensis*	4-7	Most; tolerates periodic flooding	75"	>90°F	75°F	Tropical	Valley with irrigation	10,000 lb/ac	5-6 months for fruit to ripen; fruit ripens at different times through the season	Climate inappropriate, hand harvest	Low		Hand harvest	FAO, 2002
	8	Peanut	*Arachis hypogea*	4.5-8.5	Sandy	>27"	Not limiting	Frost susceptible	Not limiting	west	500-8,000 (nuts)	Diseases/pathogens	High inputs: Ca, irrigation, pesticides	high	47-50% oil	Competes for human food	Simpson 2010
	9	Rapeseed	*Brassica napus*	5.5-8.0	Medium texture, well drained	15"	Not limiting	Not limiting	Not limiting	C & S for spring type; Panhandle for winter cultivars	500-3500 lb/ac		Processing plants not in Texas; 80-100 lb N/ac; heavy user of sulfur	High	Will tolerate some soil salinity	Pods prone to shatter	James Grichar data not published; Meakin, 2007
	10	Safflower	*Carthamus tinctorius*	6-7.8	Deep, fertile, well-drained; tolerates salinity	15"	Not limiting	Not limiting	Not limiting	W, Panhandle, S	600- 4,000 lb/ac		Minimal herbicides; 40 lb N/ac for dryland 80 for irrigated; Market in place in Abilene, TX	High			James Grichar, Data not published; Meakin, 2007
	11	Sesame	*Sesamum indicum*	5.6-7.8	Well drained, fertile	19"	Not limiting	Not limiting	Not limiting	S & C	800-1,200 lb/ac		40-80 lb N, 20 lb P2O5 and 20 lb K2O per acre	High		Some types shatter	James Grichar, Data not published; Oplinger et al., 1990
	12	Soybean	*Glycine max*	6.5-7	Well drained	19"	Not limiting	Not limiting	Not limiting	Panhandle, C, & E	14-63 bu/ac		Competes with food source	High	Leguminous		Specht et al., 1999; Boerma, 2004
	13	Sunflower	*Helianthus annuus*	6.1-7.8	Sand to clay	19"	Not limiting	Not limiting	Not limiting	Valley, S, Panhandle	1,100 to 2,000 lb/ac	Invasive	Processing plants in Midwest, P & K similar to corn & soybean = 50 lb P, 100 lb K/ac; < 75 lb N/ac	High		Inefficient water user	Meakin, 2007
Agricultural Waste and Co-products	1	Animal Fats	*Bovine spp.*	n/a	n/a	n/a	n/a	n/a	n/a	Panhandle	n/a	n/a	n/a	n/a	n/a		Directory of livestock harvest plants
	2		*Gallus spp.*	n/a	n/a	n/a	n/a	n/a	n/a	E	n/a	n/a	n/a	n/a	n/a		Directory of livestock harvest plants
	3	Corn Stover	*Zea mays*	5.4-7.8	Moist, fertile	23"	Not limiting	Not limiting	Not limiting	C, S, & E	11,000 lb/ac		Fertilizer and removal of stover does not provide for return of organic matter to the soil	High	Byproduct		ICM, 2007
	4	Cotton Gin Trash	*Gossypium hirsutum*	5-8	Most soils	23"	Not limiting	Not limiting	Not limiting	Central & E	90 lb seed/inch of water	Boll weevil, cotton root rot	Byproduct; 5 lb N/ inch water	High			Colleague; Cotton Incorporated
	5	Manure	TetraTech to report														
	6	Mill Waste	Pinus spp.	n/a	n/a	n/a	n/a	n/a	n/a	East	8 m tons/yr		Dependent on lumber industry	High	Already available	Mechanics of log residue	Forest Service, 2009
	7	Peanut Stover	*Arachis hypogea*	4.5-8.5	Sandy	>27"	Not limiting	Frost susceptible	Not limiting	west	1,000-5,000 hay	n/a	Compete for soil organics	high	Byproduct	Pesticide & fungicide residue/ compete with cattle feed	Trostle ,2008
	8	Rice Hulls	*Oryza sativa*	4.5-6.6	Fertile clays	>25" for rice	Not limiting	Monthly average <8°C	Not limiting	S & Coast	1,700-2,000 lb/ac	Heavy soils		High	Competes with livestock feed co-product		LSU Rice Production BMP
	9	Rice Straw	*Oryza sativa*	4.5-6.5	Fertile clays	>25" for rice	Not limiting	Monthly average <8°C	Not limiting	S & Coast	7,000-14,000 lb/ac	Heavy soils	Compete for soil organics	High	Alternative to burning off the field prior to planting		LSU Rice Production BMP
	10	Sugar Cane Bagasse	*Saccharum* spp.	5.0-8.5	Moist, fertile	50" for cane	Not limiting	Freeze-free	36.7° N to 31°S	Valley	25% of crop	n/a	Competes for sugar mill energy	Medium	Byproduct	Very few	FAO, 1988
	11	Wheat Straw	*Triticum aestivum*	6.0-7.5	Fertile loams & clays	>15" for wheat	Not limiting	Not limiting	Not limiting	Statewide	4,000-6,000 lb/ac	None	Compete for soil organics	High			Kerstetter & Lyons, 2001
	1	Barley	*Hordeum vulgare*	6.0-7.8	Well drained; sandy-loam to clay	>8"	Not limiting	Not limiting	Not limiting	Statewide	37-110 bu/ac	None	None	High	Drought and saline tolerant	Displaces grains	Harman et al., 1990
	2	Corn	*Zea mays*	5.4-7.8	Moist, fertile	>23"	Not limiting	Not limiting	Not limiting	C, S, & E	75-120 bu/ac	None	Fertilizer and competition with human and livestock food and feed	High	Byproduct	High inputs, especially water; afflotoxin is a problem	Texas Corn Producers

Bioenergy Feedstock	#	Crop	Latin Binomial	Soil pH	Soil	Rainfall Requirement	Maximum Temperature	Minimum Temperature	Latitude/Longitude	Approximate Region	Average Dry Matter Yield Dryland	Logistical Challenges to Planting/Managing	Challenges to Sustainability*	Sustainability in Texas	Selling Points	Drawbacks	Primary** Information Source Used
Grain and Food Crops	**3**	Sorghum	*Sorghum bicolor*	5.8-8.5	Well adapted, well drained loams ideal	16-30"	Not limiting	Warm season	Not limiting	All state	40-60 bu/ac	Annual planting		High	C4; long growing season	High inputs	Bassam, 2010
	4	Sugarbeets	*Beta vulgaris*	6.5-7.5	Sandy, deep	>19"	Not limiting	Not limiting	30-60°	NC, E, & Panhandle	18-26 short ton/ac			High		High inputs	Sugarbeet Research & Production Guide
	5	Sugar Cane	*Saccharum* spp.	5.0-8.5	Moist, fertile	50"	Not limiting	Freeze-free	36.7° N to 31°S	Valley	20,000 lb/ac	Needs 2 seasons w/o freeze	High inputs required		Byproduct	Limited to 3 counties	USDA, 2010
	6	Rice	*Oryza sativa*	4.5-6.5	Fertile clays	>25"	Not limiting	Monthly average <8°C	Not limiting	S & Coast	7,000-8,000 lb/ac	Heavy soils	Large amounts of irrigation for flooding	High	Efficient conversion	High inputs	LSU Rice Production BMP
	7	Wheat	*Triticum aestivum*	6.0-7.5	Fertile loams & clays	>15"	Not limiting	Not limiting	Not limiting	Statewide	40-70 bu/ac	None	Competes with human food	High		High inputs	Small Grains Variety Testing Information, TAMU

***Crops with potential as sustainable biofuel feedstocks will grow in Texas without irrigation, with a relatively low amount of fertilizer, and are not anticipated to negatively impact human food or livestock feed.**

**Multiple sources used in all cases.

Table 1
Bioenergy Crop Summary
Texas Bioenergy Study

Feedstock	#	Crop	Latin Binomial	Approximate Region	Average Dry Matter Yield Dryland	Sustainability* in Texas	Primary** Information Source Used
Cellulosic Biomass		**Annual grasses**					
	1	Daylight Sensitive Sorghum	*Sorghum bicolor*	All state	4,000-20,000 lb/ac	High	Bassam, 2010
	2	Energy Cane	*Saccharum spp.*	E, S, & Coast	28,000-43,000 lb/ac	Good	Rainbolt & Gilbert, 2008
	3	Giant Reed	*Arundo donax*	E & C (N & S)	7,000-15,000 lb/ac	High	
	4	Miscanthus	Miscanthus spp.	S/SE	6,000-40,000 lb/ac	Poor soils in SE	
	5	Sweet Sorghum	*Sorghum bicolor*	All state	4,000-5,500 lb/ac	High	FAO, 2010
		Perennial grasses					
	6	Bahiagrass	*Paspalum notatum*	E	3,000 - 5,500 lb/ac	High	Redfearn & Nelson, 2003
	7	Bermudagrass	*Cynodon dactylon* /others	E & C (both N & S)	5,000-12,000 lb/ac	High	Muir et al., 2009
	8	Big Bluestem	*Andropogon gerardii*	NC	6,000-10,600 lb/ac	High	Boe et al., 2004
	9	Indian Grass	*Sorghastrum* spp.	E & C (both N & S)	4,000-10,000 lb/ac	High	Mitchell & Vogel, 2004
	10	Little Bluestem	*Schizachyrium scoparium*	All state	1,000-4,000 lb/ac	High	Boe et al., 2004
	11	Old world bluestems	*Bothriochloa* spp. etc.	NC & NW	2,500-10,000 lb/ac	High	Coleman et al., 2004; Noble Foundation
	12	Switchgrass	*Panicum virgatum*	E, N, S	3,500-18,000 lb/ac	High	Kiniry et al, 2005
		Other					
	13	Atriplex	*Atriplex* spp.	S	3,000-6,500 lb/ac	Medium	Aganga et al. 2003; Goodin and Newton, 1984
	14	Kenaf	*Hibiscus cannabinus*	NC & SC	>4,000-15,000 lb/ac	High	Bassam 2010 & Muir
Woody Feedstocks	**1**	Cedar (Juniper)	Juniperus spp.	Central	Unknown	High	Adams, 2008
	2	Eucalyptus	Eucalyptus s	-	-	Low	
	3	Hybrid Poplar	*Populus spp.*	E, NC, & Panhandle	6-22 Mg/ha/yr	Moderate	Felix et al., 2008; Pearson et al., 2008
	4	Mesquite	*Prosopis glandulosa*	C & W (both N&S)	5,000-9,000 lb/ac	High	Ansley et al., 2009
	5	Pine	*Pinus spp.*	All state	1,000-6,000 ft3/ac	High	Mann, 1971
Oil Crops	**1**	Algae	*Multiple Genus*	Coastal areas, near municpal wastewater systems, over brackish or saline water resources	5000-15000 g oil/ac/yr	High	Edwards, 2008
	2	Camelina	*Camelina sativa*	All state; S & C because of alkaline soil	400-1000 lb/ac	High for spring varities	James Grichar, data not published; Meakin, 2007
	3	Castor	*Ricinus communis*	Not limiting	300-800 lb shelled/ac	Moderate because poisonous compound	Meakin, 2007
	4	Cottonseed	*Gossypium hirsutum*	Central & E	90 lb seed/inch of water	High	Colleague; Cotton Incorporated
	5	Flaxseed	*Linum usitatissimum*	Karnes,Jim Wells, B	22-42 bu/ac	High	James Grichar, Data not published; Meakin, 2007
	6	Jatropha	*Jatropha curcus*	n/a	400-8,000 lb/ac	Low	FAO 2010
	7	Palm	*Elaeis guineensis*	Valley with irrigatio	10,000 lb/ac	Low	FAO, 2002
	8	Peanut	*Arachis hypogea*	west	500-8,000 (nuts)	high	Simpson 2010
	9	Rapeseed	*Brassica napus*	C & S for spring type; Panhandle for winter cultivars	500-3500 lb/ac	High	James Grichar data not published; Meakin, 2007
	10	Safflower	*Carthamus tinctorius*	W, Panhandle, S	600- 4,000 lb/ac	High	James Grichar, Data not published; Meakin, 2007
	11	Sesame	*Sesamum indicum*	S & C	800-1,200 lb/ac	High	James Grichar, Data not published; Oplinger et al., 1990
	12	Soybean	*Glycine max*	Panhandle, C, & E	14-63 bu/ac	High	Specht et al., 1999; Boerma, 2004
	13	Sunflower	*Helianthus annuus*	Valley, S, Panhandle	1,100 to 2,000 lb/ac	High	Meakin, 2007
Agricultural Waste and Co-products	**1**	Animal Fats	*Bovine spp.*	Panhandle	n/a	n/a	Directory of livestock harvest plants
	2		*Gallus spp.*	E	n/a	n/a	Directory of livestock harvest plants
	3	Corn Stover	*Zea mays*	C, S, & E	11,000 lb/ac	High	ICM, 2007
	4	Cotton Gin Trash	*Gossypium hirsutum*	Central & E	90 lb seed/inch of water	High	Colleague; Cotton Incorporated
	5	Manure	TetraTech to report				
	6	Mill Waste	Pinus spp.	East	8 m tons/yr	High	Forest Service, 2009
	7	Peanut Stover	*Arachis hypogea*	west	1,000-5,000 hay	High	Trostle ,2008
	8	Rice Hulls	*Oryza sativa*	S & Coast	1,700-2,000 lb/ac	High	LSU Rice Production BMP
	9	Rice Straw	*Oryza sativa*	S & Coast	7,000-14,000 lb/ac	High	LSU Rice Production BMP
	10	Sugar Cane Bagasse	*Saccharum* spp.	Valley	25% of crop	Medium	FAO, 1988
	11	Wheat Straw	*Triticum aestivum*	Statewide	4,000-6,000 lb/ac	High	Kerstetter & Lyons, 2001
Grain and Food Crops	**1**	Barley	*Hordeum vulgare*	Statewide	37-110 bu/ac	High	Harman et al., 1990
	2	Corn	*Zea mays*	C, S, & E	75-120 bu/ac	High	Texas Corn Producers
	3	Sorghum	*Sorghum bicolor*	All state	40-60 bu/ac	High	Bassam, 2010
	4	Sugarbeets	*Beta vulgaris*	NC, E, & Panhandle	18-26 short ton/ac	High	Sugarbeet Research & Production Guide
	5	Sugar Cane	*Saccharum* spp.	Valley	20,000 lb/ac		USDA, 2010
	6	Rice	*Oryza sativa*	S & Coast	7,000-8,000 lb/ac	High	LSU Rice Production BMP
	7	Wheat	*Triticum aestivum*	Statewide	40-70 bu/ac	High	Small Grains Variety Testing Information, TAMU

***Crops with potential as sustainable biofuel feedstocks will grow in Texas without irrigation, with a relatively low amount of fertilizer, and are not anticipated to negatively impact human food or livestock feed.**

****Multiple sources used in all cases.**

Table 2
Texas Bioenergy Study

Fuel	#	Crop	Latin Binomial	Approximate Region	Average Dry Matter Yield Dryland	Logistical Challenges to Planting/Managing	Logistical Challenges to Harvesting	Logistical Challenges to Processing	Logistical Challenges to Transportation	Solutions	Selling Points
Cellulosic Biomass		**Annual grasses**									
	1	Daylight Sensitive Sorghum	*Sorghum bicolor*	All state	4,000-20,000 lb/ac	Annual planting	None	Lack of conversion facility	None for hay; Haylage or silage is difficult to transport	In the case of silage wet material could be ensiled at the processing facility	Equipment readily available
	2	Energy Cane	*Saccharum spp.*	E, S, & Coast	28,000-43,000 lb/ac	Vegetative propagation	None	Lack of conversion facility	None for hay; Haylage or silage is difficult to transport	In the case of silage wet material could be ensiled at the processing facility	Equipment readily available
	3	Giant Reed	*Arundo donax*	E & C (N & S)	7,000-15,000 lb/ac	Slow vegetative prop.	None	Lack of conversion facility	None for hay; Haylage or silage is difficult to transport	In the case of silage wet material could be ensiled at the processing facility	Equipment readily available
	4	Miscanthus	*Miscanthus* spp.	S/SE	6,000-40,000 lb/ac	Vegetative prop.	Heavy soils	Lack of conversion facility	None for hay; Haylage or silage is difficult to transport	In the case of silage wet material could be ensiled at the processing facility	Equipment readily available
	5	Sweet Sorghum	*Sorghum bicolor*	All state	4,000-5,500 lb/ac	Annual planting	None	Lack of conversion facility	None for hay; Haylage or silage is difficult to transport	In the case of silage wet material could be ensiled at the processing facility	Equipment readily available
		Perennial grasses									
	6	Bahiagrass	*Paspalum notatum*	E	3,000 - 5,500 lb/ac	Slow to establish	None	Lack of conversion facility	None for hay; use as silage unlikely	Scale up to build processing plant	Equipment readily available and distribution system for hay in place
	7	Bermudagrass	*Cynodon dactylon* /others	E & C (both N & S)	5,000-12,000 lb/ac	Highly productive cultivars are vegetative prop.	None	Lack of conversion facility	None for hay; use as silage unlikely	Scale up to build processing plant	Equipment readily available and distribution system for hay in place
	8	Big Bluestem	*Andropogon gerardii*	NC	6,000-10,600 lb/ac	Weak seedlings	None	Lack of conversion facility	None for hay; use as silage unlikely	Scale up to build processing plant	Equipment readily available and distribution system for hay in place
	9	Indian Grass	*Sorghastrum* spp.	E & C (both N & S)	4,000-10,000 lb/ac	Expensive seed	None	Lack of conversion facility	None for hay; use as silage unlikely	Scale up to build processing plant	Equipment readily available and distribution system for hay in place
	10	Little Bluestem	*Schizachyrium scoparium*	All state	1,000-4,000 lb/ac	Slow establishment	None	Lack of conversion facility	None for hay; use as silage unlikely	Scale up to build processing plant	Equipment readily available and distribution system for hay in place
	11	Old world bluestems	*Bothriochloa* spp. etc.	NC & NW	2,500-10,000 lb/ac	Slow establishment	None	Lack of conversion facility	None for hay; use as silage unlikely	Scale up to build processing plant	Equipment readily available and distribution system for hay in place
	12	Switchgrass	*Panicum virgatum*	E, N, S	3,500-18,000 lb/ac	Weak seedlings	None	Lack of conversion facility	None for hay; use as silage unlikely	Scale up to build processing plant	Equipment readily available and distribution system for hay in place
		Other									
	13	Atriplex	*Atriplex* spp.	S	3,000-6,500 lb/ac	Unknown management	None	Lack of conversion facility	None for hay; use as silage unlikely	Scale up to build processing plant; research to determine BMP*	Equipment readily available and distribution system for hay in place
	14	Kenaf	*Hibiscus cannabinus*	NC & SC	>4,000-15,000 lb/ac	Annually seeded; requires fertilizer	None	Lack of conversion facility	None for hay; use as silage unlikely	Scale up to build processing plant; research to determine fit in crop rotation	Equipment readily available and distribution system for hay in place
Woody Feedstocks	**1**	Cedar (Juniper)	*Juniperus* spp.	Central	Unknown	Dispersed production	Dispersed	Lack of central processing or conversion facility; harvest interval is not consistent	Harvest radius to conversion plants	Evaluate location of conversion plant to balance transportation with fuel output	Already removed for brush control in rangelands; removal increases water availability
	2 **3**	Eucalyptus Hybrid Poplar	*Eucalyptus* spp. *Populus spp.*	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	4	Mesquite	*Prosopis glandulosa*	C & W (both N&S	5,000-9,000 lb/ac	Long term investment	Dispersed	Lack of central processing or conversion facility; harvest interval is not consistent	Harvest radius to conversion plants	Evaluate location of conversion plant to balance transportation with fuel output	Already removed for brush control in rangelands; removal increases water availability

Fuel	#	Crop	Latin Binomial	Approximate Region	Average Dry Matter Yield Dryland	Logistical Challenges to Planting/Managing	Logistical Challenges to Harvesting	Logistical Challenges to Processing	Logistical Challenges to Transportation	Solutions	Selling Points
	5	Pine	*Pinus spp.*	All state	1,000-6,000 ft^3/ac	Time to harvest	None	None	None	This resource is already utilized in E TX	This resource is already utilized in E TX
Oil Crops	**1**	Algae	*Multiple Genus*	Coastal areas, near municpal wastewater systems, over brackish or saline water resources	5000-15000 g oil/ac/yr	Raceway construction; access to water, nutrients, and CO_2	Cost-effective methods unproven on large scale	Cost-effective methods unproven on large scale	None	Investment in research	Can use salt water, May be a CO2 sink from power/municipal plants, Does not compete with arable land
	2	Camelina	*Camelina sativa*	All state; S & C because of alkaline soil	400-1000 lb/ac	Annual planting	None	Local processing not available	None	Investment in research	Does not compete with food or feed
	3	Castor	*Ricinus communis*	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	4	Cottonseed	*Gossypium hirsutum*	Central & E	90 lb seed/inch of water	Boll weevil, cotton root rot; annual planting; irrigated in much of TX	None	Local processing not available	None	Investment in research	Does not compete with food or feed
	5	Flaxseed	*Linum usitatissimum*	Karnes,Jim Wells,	22-42 bu/ac	Availability of adapted seed; annual planting	None	Local processing not available	None	Investment in research	Adapted to most soils and climates
	6	Jatropha	*Jatropha curcus*	n/a	400-8,000 lb/ac	N needed	Indeterminate	Local processing not available	None	Investment in research	Does not compete with food or feed
	7	Palm	*Elaeis guineensis*	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	8	Peanut	*Arachis hypogea*	west	500-8,000 (nuts)	Diseases/pathogens; annual p	Few	Local processing not available	None	Investment in research	High oil content
	9	Rapeseed	*Brassica napus*	C & S for spring type; Panhandle for winter cultivars	500-3500 lb/ac	Annual planting	Pod shatter	Local processing not available	None	Investment in research	Will tolerate some soil salinity
	10	Safflower	*Carthamus tinctorius*	W, Panhandle, S	600- 4,000 lb/ac	Annual planting	Market in Abilene, TX	Local conversion plant not available	None	Investment in research	Market in place in Abilene, TX; very drought hardy
	11	Sesame	*Sesamum indicum*	S & C	800-1,200 lb/ac	Annual planting	Some types shatter	Local processing not available	None	Investment in research	Drought hardy and high oil content
	12	Soybean	*Glycine max*	Panhandle, C, & E	14-63 bu/ac	Diseases/pathogens; annual p	None	Local processing not available	None	Investment in research	Legume-no additional N fertilizer required
	13	Sunflower	*Helianthus annuus*	Valley, S, Panhandle	1,100 to 2,000 lb/ac	Invasive	None	Local processing not available	None	Investment in research	Well adapted to Texas; many commercial cultivars available
Agricultural Waste and Co-products	**1** **2**	Animal Fats	*Bovine spp.* *Gallus spp.*	Statewide	Not applicable	Not applicable	Specialty Processing	Specialty Processing	none		
	3	Corn Stover	*Zea mays*	C, S, & E	11,000 lb/ac	Crop residue is important for soil nutrient cycling, tilth, and soil stabilization	None	Lack of conversion facility	None	Research to develop BMP	Does not compete with human consumption
	4	Cotton Gin Trash	*Gossypium hirsutum*	Central & E	90 lb seed/inch of water	Competes with livestock feed source	None	Lack of conversion facility	None		Does not compete with human consumption
	5	Manure	not applicable	Statewide	Not applicable	Not applicable			very low total solids makes it costly to transport	processing at CAFO	
	6	Mill Waste	*Pinus* spp.	All state	Dependent on mill	None	None	None	None	This resource is already utilized in E TX	This resource is already utilized in E TX
	7	Peanut Stover	*Arachis hypogea*	W	1,000-5,000 hay	Competes with livestock feed source and soil organics	None	Lack of conversion facility	None	Scale up to build processing plant	This should not be fed to livestock if treated with fungicide; it is sold to aid profits and this would allow that income to peanut farmers without livestock consumption

Table 2
Texas Bioenergy Study

Fuel	#	Crop	Latin Binomial	Approximate Region	Average Dry Matter Yield Dryland	Logistical Challenges to Planting/Managing	Logistical Challenges to Harvesting	Logistical Challenges to Processing	Logistical Challenges to Transportation	Solutions	Selling Points
	8	Rice Hulls	*Oryza sativa*	S & Coast	1,700-2,000 lb/ac	Heavy soils limit equipment access	Heavy soils	Lack of conversion facility	None	Scale up to build processing plant	No additional inputs after rice harvest, processing, and hull transport for conversion
	9	Rice Straw	*Oryza sativa*	S & Coast	7,000-14,000 lb/ac	Heavy soils limit equipment access	Heavy soils	Lack of conversion facility	None	Scale up to build processing plant	Alternative to burning off the field prior to planting
	10	Sugar Cane Bagasse	*Saccharum* spp.	Valley	25% of crop	Competes with sugar processing energy source	None	Lack of conversion facility	None	Scale up to build processing plant	Mechanics to produce energy from sugar cane bagasse are in place at sugar mills
	11	Wheat Straw	*Triticum aestivum*	Statewide	4,000-6,000 lb/ac	Competes with livestock feed source and soil organics	None	Lack of conversion facility	None	Scale up to build processing plant	Large acerage planted; wide variety of cultivars adapted to many environments
Grain and Food Crops	**1**	Barley	*Hordeum vulgare*	Statewide	37-110 bu/ac	Competes with livestock feed and human consumption; annual planting	None	Lack of conversion facility	None	Scale up to build processing plant	High starch; not as competitive with human and animal consumption as other grains; will tolerate saline soils
	2	Corn	*Zea mays*								
	3	Sorghum	*Sorghum bicolor*	All state	40-60 bu/ac	Competes with livestock feed and human consumption; annual planting	None	Lack of conversion facility	None	Scale up to build processing plant	High starch; not as competitive with human and animal consumption as other grains
	4	Sugarbeets	*Beta vulgaris*	NC, E, & Panhandle	18-26 short ton/ac	Competes with livestock feed and human consumption; annual planting	None	Lack of conversion facility	None	Scale up to build processing plant	High starch; not as competitive with human and animal consumption as other grains
	5	Sugar Cane	*Saccharum* spp.								
	6	Rice	*Oryza sativa*								
	7	Wheat	*Triticum aestivum*								

***BMP=Best management practice.**

Table 3

Texas Bioenergy Study

Fuel with Potential in West Texas	#	Crop	Latin Binomial	Rainfall Requirement	Approximate Region	Average Dry Matter Yield Dryland	Use in West Texas
Cellulosic Feedstocks	**1**	Daylight Sensitive Sorghum	*Sorghum bicolor*	>16"	>16" rainfall	4,000-8,000 lb/ac	Cultivation
	8	Little bluestem	*Schizachyrium scoparium*	>14"	>14"	Unknown	Dual forage/bioenergy
Woody Feedstocks	**1**	Cedar (Juniper)	*Juniperus* spp.	Not limiting	Central	Unknown	Harvest from rangelands
	4	Mesquite	*Prosopis glandulosa*	18-40"	C & W (both N&S)	5,000-9,000 lb/ac	Harvest from rangelands
	5	Pine	*Pinus spp.*	>7"	All state	1,000-6,000 ft^3/ac	Harvest from rangelands; native types (i.e. not longleaf pine)
Oil Crops	**1**	Algae	*Multiple Genus*	None	Coast	5000-15000 g oil/ac/yr	Where irrigation water is salinated
	2	Camelina	*Camelina sativa*	9"	All state; S & C because of alkaline soil	400-1000 lb/ac	Growth will not be consistent every year because of water limitation; small pockets of land are suitable
	3	Castor	*Ricinus communis*	15"	Not limiting	300-800 lb shelled/ac	Not recommended because of toxicity issues.
	10	Safflower	*Carthamus tinctorius*	15"	W, Panhandle, S	600- 4,000 lb/ac	Growth will not be consistent every year because of water limitation; small pockets of land are suitable
	13	Sunflower	*Helianthus annuus*	19"	Valley, S, Panhandle	1,100 to 2,000 lb/ac	Growth will not be consistent every year because of water limitation; small pockets of land are suitable
Agricultural Waste and Co-products	**4**	Cotton Gin Trash	*Gossypium hirsutum*	23"	Central & E	90 lb seed/inch of water	Where cotton is currently grown under irrigation
	5	Manure	not applicable	not applicable	Numerous regions of the state (not affected by climatic conditions)		
	7	Peanut stover	*Arachis hypogea*	Irrigated	Where cultivated	1,000-5,000 lb/acre	Byproduct of peanut cultivation
	11	Wheat Straw	*Triticum aestivum*	>15" for dryland	Statewide	4,000-6,000 lb/ac	Where cotton is currently grown under irrigation
Grain and Food Crops	**1**	Barley	*Hordeum vulgare*	>8"	Statewide	37-110 bu/ac	Growth will not be consistent every year because of water limitation; small pockets of land are suitable; tolerates some saline water
	7	Wheat	*Triticum aestivum*	>15"	Statewide	40-70 bu/ac	Growth will not be consistent every year because of water limitation; small pockets of land are suitable

Table 5.1 Texas-based Algae Fuel Companies, Technologies and Associations

Name	Location	Partners	Technology	Production Scale	Contact	Status
Sunrise Ridge Algae Inc.	Houston, Texas	University of Texas - Austin	Wastewater algae production technology that produces feedstocks for biodiesel and other applications.	Pilot Scale	'norm.whitton@sunrise-ridge.com'	Unresponsive
Valcent Products Inc.	El Paso, Texas	Global Green Solutions	High density vertical technology for the production of algae.	Pilot Scale	Phone 1-888-506-7979	Inactive
Biocentric Energy	Orange County, Texas	Petroleum Equipment Institute	PBR manufacturer	2 acre site	http://www.biocentricenergy.com/	In planning stage
General Atomics	Pecos, Texas	Texas A&M (Texas AgriLife Research)	JP-8 fuef from algae triglycerides. Texas Ag research service - algae typing, testing of species to be used and also testing different processes.	Brackish Water Ponds	Gary Hopper Ph. 202-496-8217	Active
Science Applications International Applications	Pecos, Texas	University of Texas - Austin	Identifying the best strains of algae for producing oil from sites in Texas and from the university's algal culture collection, harvesting the algal strains, breaking the algal cells to extract oil, purifying the algal oil for jet fuel production and exploring uses and markets for waste by-products from the process.		Tim Green, Office of the Vice President for Research Ph.512 475 6596.	Active
Chevron	College Station, Texas	Texas A&M (Texas A&M Agriculture and Engineering BioEnergy Alliance)	Production of bio-oils with a focus on non-food crops	N/A		Active
PetroSun Biofuels Inc	Harlignen and Rio Hondo, Texas		Open pond algae farm	1,100 acres	Gordon LeBlanc Ph. (480) 425-4290	
Glycos Biotechnologies Inc.	Houston, Texas		Biotransformation technique that directs crude glycerin from the biodiesel process into ethanol.	N/A	Phone: (713) 869-9377 http://www.glycosbio.com/	Active
Dr. Keith Klein	Sul Ross State University, Alpine, Texas		Designing an insulated algae propagation tank that includes a parabolic mirror with a refractor that will concentrate the plant-feeding part of the light spectrum on algae and the remaining light on solar cells and a boiler.			Active
National Algae Association	The Woodlands, Texas		Provides a forum for researchers, producers and investors to advance the discussion and production of algae as a renewable energy source.	N/A		Active
UTEX Algae Culture Collection	University of Texas - Austin, Texas		The Culture Collection posseses the largest algae collection in the world. It includes approximately 3,000 different strains of living algae, representing most major algal taxa. The primary function of UTEX is to provide algal cultures at modest cost to a user community.	N/A	The Culture collection of Algae (UTEX), Ph. (512)471-4019 http://web.biosci.utexas.edu/utex/default.aspx	Active

Table 6.1 State Biofuel Mandates

State	Biofuel Mandates
California	All gasoline produced at California refineries to contain 10% ethanol by December 31, 2009. Enacted June 2007. In 2009, the California Air Resources Board approved the LCFS, which establishes standards that fuel producers and importers must meet each ye
Florida	On June 25, 2008, Governor Charlie Crist signed into law House Bill 7135, which established the Florida Renewable Fuel Standard. Under the standard, most automobile gasoline must contain 10 percent ethanol by December 31, 2010.
Iowa	25% of motor fuel to come from renewable sources (E10, E85, biodiesel by 2020). Enacted May 2006.
Louisiana	All gasoline to contain 2% ethanol; 2% of all diesel to be biodiesel. To go into effect six months after there are 50 million gallons of ethanol in annual production or 10 million gallons of biodiesel in the state, unless the Louisiana Commission on Weig
Massachusetts	Two percent biodiesel mandate suspended on July 2010 - http://www.biodieselmagazine.com/article.jsp?article_id=4266 .
Minnesota	All gasoline to contain 20% ethanol by 2013. Enacted May 2005. Mandate for use of a 5% biodiesel blend. Currently waived due to cold weather issues.
Missouri	All gasoline except premium grade gasoline to contain 10% ethanol by 2008. Enacted July 2006.
Montana	All gasoline (except 91-octane) to contain 10% ethanol. Enacted May 2005.
New Mexico	SB 489 requires that 5% of every gallon of diesel fuel sold in New Mexico comes from an agricultural source by 2012. Enacted April 2007.
Oregon	All gasoline to contain 10% ethanol after Oregon ethanol production reaches 40 million gallons per year; All diesel fuel to contain 2% biodiesel after the production of biodiesel from sources in Oregon, Washington, Idaho and Montana reaches 5 million gal
Pennsylvania	HB 1202, approved by the Governor on 7/10/08 (Act No. 78), requires gasoline to contain 10 vol% cellulosic ethanol one year after annualized in-state cellulosic ethanol production reaches 350 million gallons, 2% biodiesel for on-road compression ignition engines one year after annualized in-state production reaches 40 million gallons, 5% biodiesel (100 million gallons), 10% biodiesel (200 million gallons), and 20% biodiesel (400 million gallons). Renewable (non ester) diesel can be substituted for up to 25% of the biodiesel mandate. The biodiesel mandate is contingent on diesel vehicle manufacturers not voiding or withdrawing warranties. The cellulosic ethanol mandate would not apply to regions where it would violate or conflict with a NAAQS SIP. On 1/15/09, Governor Rendell announced that the in-state biodiesel production threshold had been met and the 2% biodiesel requirement will be effective within a year. In a report to the General Assembly dated 8/27/09, the PA Department of Agriculture announced that there is sufficient infrastructure and the 2 vol% biodiesel mandate will be effective on 5/1/10. http://www.npra.org/issues/transportation/smfs/?fa=pa
Washington	All gasoline to contain 2% ethanol by 2008. To be increased up to 10% if no adverse ozone pollution levels result and sufficient raw materials are available within the state; 2% of all diesel sold to be biodiesel by 2008. To be increased to 5% if there

Adapted from: http://www.pewclimate.org/what_s_being_done/in_the_states/map_ethanol.cfm

Table 7.1 Chemical Reactions in Gasification

$C + 1/2\ O_2 \leftrightarrow CO$	$\Delta H_f = -111.4$ MJ/kmol
$C + O_2 \leftrightarrow CO_2$	$\Delta H_f = -393.4$ MJ/kmol
$C + CO_2 \leftrightarrow 2\ CO$	$\Delta H_f = 170.7$ MJ/kmol
$C + H_2O \leftrightarrow CO + H_2$	$\Delta H_f = 130.5$ MJ/kmol
$C + 2\ H_2 \leftrightarrow CH_4$	$\Delta H_f = -74.7$ MJ/kmol
$CO + H_2O \leftrightarrow H_2 + CO_2$	$\Delta H_f = -40.2$ MJ/kmol

Table 7.2 Controlling Factors of Anaerobic Digestion Performance

Physical Factors	**Chemical Factors**
Temperature	pH
Hydraulic Retention Time	Alkalinity
Solids Retention Time	Volatile Acids
Solids Loading Rate	Nutrients
Mixing	Trace Elements
Solids Concentration	Toxic Compounds
Biomass Type	
Volatile Solids Loading	

Table 9 - Renewable Fuels Required by Federal Law

EISA Renewable Fuel Volume Requirements (billion gallons)

Year	Cellulosic biofuel requirement	Biomass-based diesel requirement	Advanced biofuel requirement	Total renewable fuel requirement
2008	n/a	n/a	n/a	9
2009	n/a	0.5	0.6	11.1
2010	0.1	0.65	0.95	12.95
2011	0.25	0.8	1.35	13.95
2012	0.5	1	2	15.2
2013	1	a	2.75	16.55
2014	1.75	a	3.75	18.15
2015	3	a	5.5	20.5
2016	4.25	a	7.25	22.25
2017	5.5	a	9	24
2018	7	a	11	26
2019	8.5	a	13	28
2020	10.5	a	15	30
2021	13.5	a	18	33
2022	16	a	21	36
2023+	b	b	b	b

[a] To be determined by EPA through a future rulemaking, but no less than 1.0 billion gallons.

[b] To be determined by EPA through a future rulemaking.

Table 10 - List of Genomics-based R&D Companies

Company	Type of Organism or Plants Being Developed	Other Products	Technology	Investors/Partners	Location
Ethanologens					
Mascoma	Clostridium, yeast		Consolidated Bioprocessing	Flagsghip Ventures, Khosla Ventures, Atlas Ventures, General Catalyst Partners, KPCB, VantagePoint Venture Partners, GM, Marathon Oil	Cambridge, MA
Coskata	Anaerobic organisms		Syngas to ethanol	GM, Total, Blackstone Clean Venture Partners, Khosla Ventures, Advanced Technology Ventures, Globespan Capital Partners and Arancia	Warrenville, IL
Qteros	Clostridium phytofermentans termed "Q Microbe"	n-propanol, isopropanol, n-butanol, and mixtures thereof	Consolidated Bioprocessing	British Petroleu, Valero, Battery Ventures, Camros Capital, Long River Ventures, Soros Fund Management, and Venrock Associates	Marlborough, MA
Verenium	E. coli, Klebsiella sp.	Enzymes	Fermentation of biomass sugars to ethanol	British Petroleum, Value Prior to Pulping	Cambridge, MA
Zeachem	Acetogens	Acetic acid, ethyl acetate, propionic acid, propanol and propylene	Fermentation to acetic acid, esterification, followed by hydrogenation to ethanol	Globespan Capital Partners, PrairieGold Venture Partners, MDV-Mohr Davidow Ventures, Firelake Capital and Valero Energy Corporation	Lakewood, CO
Green Tech America	Saccharomyces		Fermentation of biomass sugars to ethanol		West Lafayette, IN
INEOS Bio	Proprietary organism		Syngas fermentation to ethanol	New Planet BioEnergy	Lisle, IL
Butanologens					
Cobalt Technologies	Clostridium		Fermentation of biomass sugars to butanol	Pinnacle Ventures, VantagePoint Venture Partners , The Malaysian Life Sciences Capital Fund , Life Sciences Partners, @Ventures , Burrill & Company , and Harris & Harris Group, Inc.	Mountain View, CA
Gevo	Saccharomyces		Fermentation of biomass sugars to butanol	Khosla Ventures, Virgin Fuels	Englewood, CO
DuPont and British Petroleum	Escherichia coli		Fermentation of biomass sugars to butanol		Europe

Biodiesel					
Texas A&M	Various	JP-8 fuel	Use of raceway systems in Pecos, Texas for biodiesel production	General Atomics	Pecos, TX
Texas A&M	Botryococcus braunii		Genetic mapping and improvements	University of Kentucky, University of Tokyo	College Station, TX
Texas A&M Department of Soil and Crop Sciences Oilseed Crop Development	Jatropha, Chinese tallow, Cotton				
University of Texas - Austin			Identifying the best strains of algae for producing oil from sites in Texas and from the university's algal culture collection, harvesting the algal strains, breaking the algal cells to extract oil, purifying the algal oil for jet fuel production and exploring uses and markets for waste by-products from the process.	Science Applications International Applications	
Synthetic Genomics	Chlorella, Cyclotella, Thalassiosira, others	Yield improvement of palm oil and Jatropha	Synthetic biology/genomics, environmental genomics	Exxon-Mobil, British Petroleum, Draper Fisher Juvetson, Meteor Group, Biotechonomy LLC and Plenus, S.A. de C.V., BP plc and ACGT Sdn Bhd.	La Jolla, CA
Phycal		Methane from anaerobic digestion for power	Genetic engineering to develop algae that capture less light		Honolulu, HI
Renewable Gasoline					
Sapphire Energy	Possibly cyanobacteria (Not publicly known)		Breeding and accelerated evolution of algae for renewable gasoline production	ARCH Venture Partners; along with The Wellcome Trust; Cascade Investment, LLC, Venrock, Bill Gates	San Diego, CA

Renewable Diesel					
Amyris	Saccharomyces	Artemisinin – Anti-malarial therapeutic	Renewable diesel. Utilize yeast isopropenoid pathways to engineer renewable fuels.	Khosla Ventures, Kleiner Perkins Caufield & Byers, TPG Biotech and Votorantim Novos Negocios,Temasek Holdings, GrupoCornelioBrennand , Naxos UK	Emeryville, CA
LS9	Escherichia coli	Chemicals	Renewable diesel. Using *E. coli* to convert fatty acid intermediates into petroleum replacement products via fermentation of renewable sugars.	Chevron, Procter & Gamble, Khosla Ventures, Flagship Ventures, Lightspeed Venture Partners, and Chevron Technology Ventures Investments	San Francisco, CA
Precursor Molecules					
Terrabon	Mixed consortium of organisms	Carboxylic acids	Fermentation of sugars obtained via lime pretreatment of biomass		Houston, TX
Plant and Crop Genetics					
Ceres	Sorghum, miscanthus and switchgrass		Improvement in yields and drought tolerance of dedicated energy crops. Less recalcitrant feedstocks.	Texas A&M (Texas Agrilife Research), Novozymes, CHOREN	Thousand Oaks, CA
Chromatin, Inc.	Sorghum		Mini-chromosome technology	ACGT, Dow AgroSciences, Bayer Crop Science, Syngenta	Chicago, IL
Mendel Biotechnology	Miscanthus giganteus, Sorghum		Plant "transcription factors" which are master regulators of gene networks. Increased yields of dedicated energy corps.	Bayer Crop Science, Monsanto, MMR Genetics, Richardson Seeds	Hayward, CA
Arborgen	Pine, Populus and Eucalyptus		Elite germplasm development for biofuels and bioproducts application	Scion, Range Fuels, Clemson university	Summervile, SC Have tree nurseries in Livingstons and Bullard, Texas.

Related Texas University Research					
Texas A&M Department of Soil and Crop Sciences	Corn & Sorghum Program		Corn, Sorghum germplasm, sorghum genetics, heat and drought resistance		College Station, TX
University of Texas - Austin Dept. Of Molecular Genetics and Microbiology, Professor Richard M. Brown	World renowned study of cellulose and its biosynthesis				Austin, TX
University of Texas - El Paso Department of Biological Sciences, Dr. Larry Jones			Fermentation of Saccharomyces and Zymomonas		El Paso, TX
Texas A&M Dept. Of Biology, Professor C.O. Patterson			Molecular Biology of Algae		College Station, TX
University of Texas - Permian Basin,Dr. J. Michael Robinson			Research on demonstrating long lived catalysts for the IDAHH fractionation of carbohydrates from lignin and thus to establish viable economics of alternative polyols platform	Chevron	Odessa, TX

Table 11.1
University Research

University	Department	Research Orientation	Technology	Principal Investigator	Investors/ Partners	Location
Texas Tech University System						
	Department of Plant & Soil Science	Oilseeds and Drought Tolerant Plants	Generate the feedstocks, production strategies, fuel processing, and developmental analyses necessary to allow over 20 million acres of Federal Lands in the Western U.S. to produce 1.6 billion gallons of renewable fuels annually.	Dr. Dick Auld		Lubbock, West Texas
The Texas A&M University System						
	Department of Soil and Crop Sciences	Corn & Sorghum Program	Corn, Sorghum Germplasm, Sorghum Genetics, Heat and Drought Resistance	Numerous		College Station
	Department of Biology	Basic Research on Algae and Algae Growth	Biology of Algae	Dr. C.O. Patterson		College Station
	Texas AgriLife Research	Brackish Water Algae Raceways	JP-8 fuel from algae triglycerides. Texas Ag Research Service - Algae typing, testing and process testing.	Bob Avant, Texas AgriLife Research	General Atomics	Pecos
	BioEnergy Alliance	Improvement of Secondary Energy Feedstocks and Processes	Identifying, assessing, cultivating, and optimizing production of second-generation energy feedstocks for cellulose and bio-oils with a focus on non-food crops; characterizing and optimizing the design of dedicated bioenergy crops through advances in genomic sciences and plant breeding; developing integrated logistics systems associated with harvest, transport, storage and coversion of bioenergy crops; and developing advanced biofuels processing technologies.	Dr. G. Kemble Bennett, Vice Chancellor and Dean of Texas A&M Engineering	Chevron	College Station

Table 11.1
University Research

The University of Texas System						
	UTEX - The Culture Collection of Algae	Algae Research and Catalogue	Maintenance of its diverse stock of living algae, in order to make these algal strains available to a user community worldwide at modest cost. Cultures in the Collection are used especially for research, but also for biotechnology development, teaching, water quality assessment, food for aquatic animals, biofuels, and a variety of other purposes.	Dr. David Nobles, Dr. Jerry Brand		Austin
	Department of molecular Genetics and Microbiology	Study of Cellulose Biosynthesis	Electron microscopy of cellulose synthesis	Professor Richard M. Brown		Austin
	Department of Biological Sciences	Kinetics of a mixed Saccharomyces spp. (yeast) culture in continuous flow through a chemostat. Improvement of ethanol yields via membrane stabilization studies. Immobilized cell experimentation. Fermentations involving the bacterium, Zymomonas spp., higher alcohol production for industrial uses.	Fermentation of Saccharomyces and Zymomonas	Dr. Larry Jones (Emeritus)		El Paso
	College of Arts and Sciences	Biomass Refining	Research on demonstrating long lived catalysts for the IDAHH fractionation of carbohydrates from lignin and thus to establish viable economics of alternative polyols platform.	Dr. J. Michael Robinson	Chevron	Odessa

Table 12 - Federal Funding Opportunities & Contacts

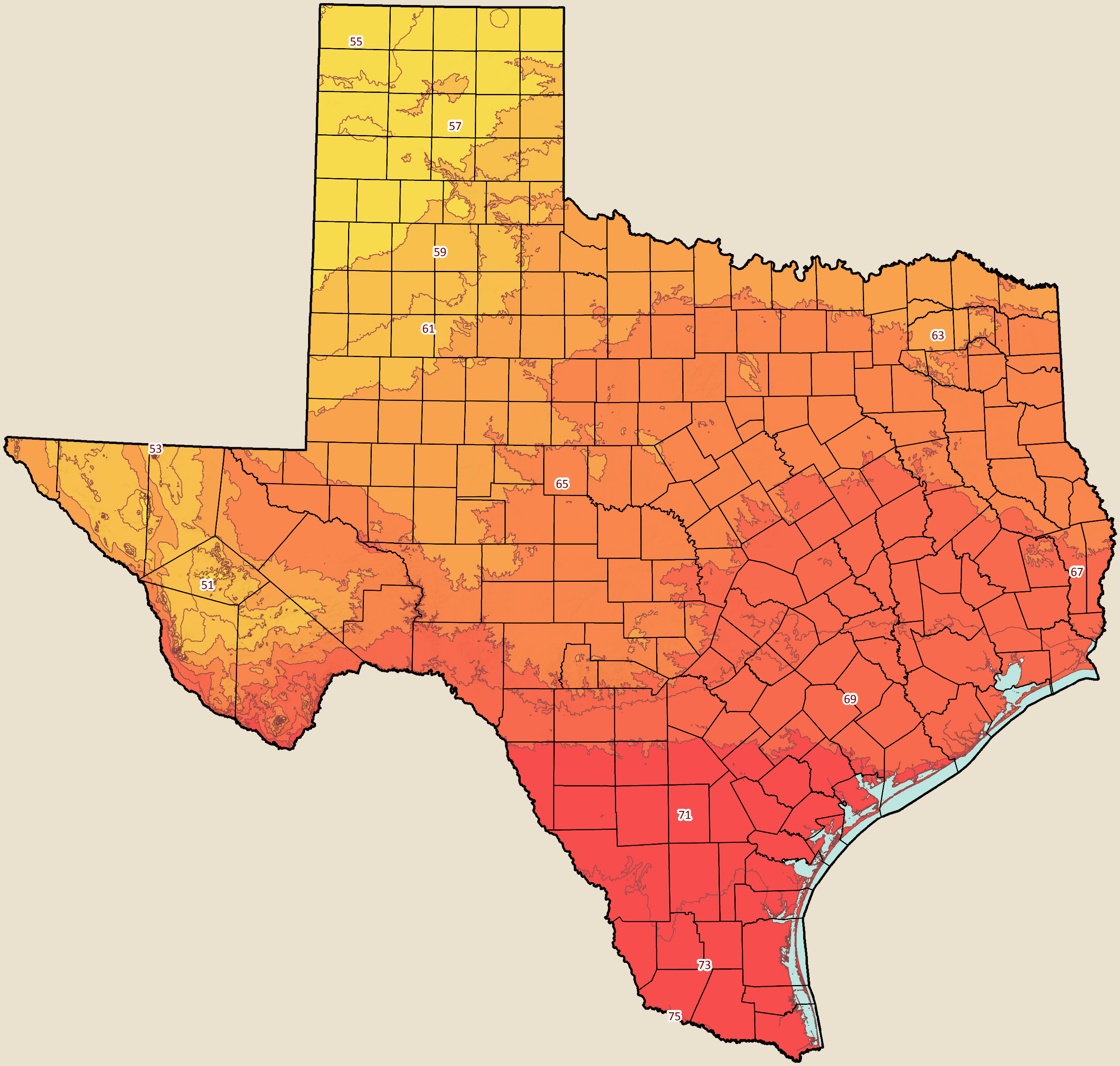
Agency/Program	**Key Personnel**	**R&D Areas**	**Texas Programs**
DOE	Dr. Steven Chu, Secretary		
Energy Efficiency and Renewable Energy	Dr. Kristina M. Johnson, Under Secretary		
Biomass Program	John Ferrell, Acting Program Manager john.ferrell@ee.doe.gov.	- Feedstocks/Sustainability - Processing & Conversion - Deployment - Integrated Biorefineries - Infrastructure - Analysis - Communications and Outreach - Strategic Planning	All
Golden Field Office	Rita Wells, Executive Director for Field Operations James Spaeth, Director Commercialization and Project Management 303-275-4771 Kevin Craig, Chief, Biomass Branch 303-275-4788	- Biomass - Geothermal - Hydrogen - Solar - Wind & Water	All
National Renewable Energy Laboratory (NREL)	Dan E. Arvizu, Director Mike Cleary, Director, National Bioenergy Center 303-384-6825 Mike.Cleary@nrel.gov	- Biomass characterization - Biochemical conversion - Thermochemical conversion - Chemical and catalyst science - Integrated biorefinery processes - Microalgal biofuels - Biomass process and sustainability analysis	All
Oak Ridge National Laboratory (ORNL)	Thom Mason, Director Martin Keller, Associate Laboratory Director 865-576-2900 masont@ornl.gov	- Biofeedstocks - Feedstock logistics - Biorefineries - Product delivery - End users - Sustainability	Crop biomass research, biomass processes
DOE Office of Science	William Brinkman, Director		
SBIR/STTR Program	Vince Dattoria, SBIR/STTR Program Manager vince.dattoria@science.doe.gov	- Energy production (Fossil, Nuclear, Renewable, and Fusion Energy) - Fundamental energy sciences	

USDA			
National Institute of Food and Agriculture	Roger Beachy, Director Ph. 202-720-4423	Fund bioenergy R&D and education in land grant universities. Funding source of Funding Opportunity Announcements (FOAs) as well as SBIR for USDA. - Agricultural systems - Biotechnology and genomics - Environment and natural resources - Technology and engineering - Plants	All
Biopreferred Program	Ph. 1-877-251-6522 BioPreferred@usda.gov	The program promotes and funds research to develop renewable, environmentally-friendly biobased products.	Biobased product R&D
Office of Energy Policy and New Uses (OEPNU)	Jim Duffield, Biodiesel jduffield@oce.usda.gov Hosein Shapouri, Ethanol hshapouri@oce.usda.gov	Develop and coordinate USDA energy policy, programs, and strategies.	Biofuels R&D
	Irene Xiarcos, Renewable Energy and Agriculture Integration ixiarchos@oce.usda.gov	Analyze the integration of renewable energy (wind, solar, geothermal) with agriculture.	All
Agricultural Research Services	Bob Fireovid, National Program 307: Bioenergy & Energy Alternatives	Develop new varieties and hybrids of bioenergy feedstocks with optimal traits.	Biomass feedstock R&D
National Science Foundation	Cora B. Marrett, Acting Director		
Biotechnology, Biochemical, and Biomass Engineering (BBBE) program	Theresa A. Good (703) 292-7029 tgood@nsf.gov	Supports fundamental engineering research that advances the understanding of cellular and biomolecular processes in support of the bioenergy industries	Biofuels and biopower R&D
Plant Genome Research Program (PGRP)	Anne W. Sylvester (703) 292-2190 asylvest@nsf.gov	Develop a basic knowledge of the structures and functions of plant genomes	Crop genomics R&D
Surpassing Evolution: Transformative Approaches to Enhance the Efficiency of Photosynthesis	Mark Brodl (703) 292-7879 mbrodl@nsf.gov Robert Burnap (703) 292-7582 rburnap@nsf.gov	Proposals to fund innovative and transformative research for the enhancement of photosynthetic efficiency.	Plant research
Developing Country Collaborations in Plant Genome Research (DCC-PGR)	Jane Silverthorne (703) 292-8420 jsilvert@nsf.gov	Developing Country Collaborations in Plant Genome Research	Crop genomics research, plant genetics

Environmental Protection Agency	Lisa P. Jackson, Administrator		
STAR Program Funds	http://www.epa.gov/ncer/rfa/	Fund research grants and graduate fellowships in numerous environmental science and engineering disciplines	Environmental colleges and departments - effects of fuels and biomass emissions on water and air
Office of Science and Technology Policy (OSTP)	John P. Holdren, Director Shere Abbott, Energy and Environment Division, Associate Director Ph. (202) 456-7116	For 2011, there are significant R&D budget increases for the DOE's Office of Science and the National Science Foundation	General biofuels and feedstock R&D
Department of Transportation (DOT)	Ray LaHood, Secretary		
University Transportation Centers Program	Peter H. Appel - Administrator, Research and Innovative Technology Administration Ph. 800-853-1351	Under the program participating universities conduct basic and applied research, education programs that include multidisciplinary course work and participation in research, and ongoing programs of technology transfer that make research results available to potential users.	Texas university colleges and departments interested in research on public transportation research utilizing biofuels.
Department of Defense			
Defense Advanced Research Project Agency (DARPA)	Regina Dugan, Director		
Strategic Technology Office: Energy and Self-Sufficient Operations	Donald Woodbury, Director 703-696-2362 donald.woodbury@darpa.mil	Biofuels and biofuels feedstocks	All
International Energy Agency			
		The IEA provides support for over 40 international co-operation and collaboration agreements in energy technology R&D, deployment and information dissemination. OECD Member countries, non-Member countries and international organizations may participate.	
Bioenergy	U.S. Member - Mr. Paul Grabowski Energy Efficiency and Renewable Energy Office of the Biomass Program, EE-2E 1000 Independence Ave., SW WASHINGTON, DC 20585-0121 paul.grabowski@ee.doe.gov	Biofuels and biofuels feedstocks	All
State Government			
American Recovery and Reinvestment Act - Texas	Susan Combs, Texas State Comptroller Austin field office - (512) 305-9800	Science & Research - Major research instrumentation program and facilities construction	All

International governments			
European Biofuels Technology Platform (EBTP)	Véronique Hervouet, Chair TOTAL SA 2 place de la Défense Cedex, Paris, France www.total.com	European Biofuels Technology Platform (EBTP) aims to contribute to the development of cost-competitive world-class biofuels value chains and the creation of a healthy biofuels industry, and to accelerate the sustainable deployment of biofuels in the European Union, through a process of guidance, prioritization and promotion of	All – must team with European counterparts
National Trade Associations			
National Biodiesel Board	605 Clark Ave PO Box 104898 Jefferson City, MO 65110-4898 Ph. (800) 841-5849	The NBB is the national trade association representing the biodiesel industry as the coordinating body for biodiesel research and development in the US.	Biodiesel crops and algae R&D
Renewable Fuels Association	425 Third Street, SW Suite 1150 Washington, DC 20024 (202) 289-3835	The Renewable Fuels Association (RFA) promotes policies, regulations and research and development initiatives that will lead to the increased production and use of fuel ethanol.	Starch crop research for biofuel production, biofuel vehicle testing

APPENDIX C: TEXAS ANNUAL AVERAGE TEMPERATURE AND PRECIPITATION MAPS



Legend

☐ Counties

Temperature Range (F)

- 🟨 49 - 53
- 🟨 54 - 57
- 🟧 58 - 61
- 🟧 62 - 63
- 🟧 64 - 65
- 🟥 66 - 69
- 🟥 70 - 75

N
W E
S

0 50 100 150 200
Miles

Source: NRCS Data Gateway. Accessed July, 2010.
Map Projection: NAD 1983 Texas Statewide Mapping System Lambert Conformal Conic.

TETRA TECH

Texas Average Annual Temperature

FILE	SCALE	
1.1_Avg_Annual_Temp.mxd	1:6,685,000	
FIGURE NUMBER	REV	DATE
1.1	3	8/31/10

TEXAS

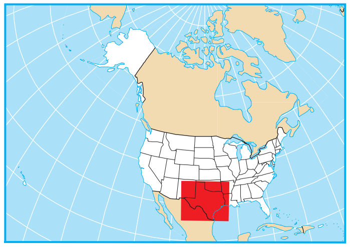
PRECIPITATION

Precipitation varies widely across the United States, from a low of 2.3 inches per year in California's Death Valley to a high of 460 inches on Hawaii's Mount Waialeale. Nevada ranks as the driest state, with an average annual precipitation of 9.5 inches, and Hawaii is the wettest, at 70.3 inches. The average annual precipitation for Texas is 27.78 inches.

Average Annual Precipitation (in inches)
1961-1990

- 🟦 180.1-200
- 🟪 140.1-180
- 🟪 120.1-140
- 🟪 100.1-120
- 🟩 80.1-100
- 🟩 70.1-80
- 🟩 60.1-70
- 🟩 50.1-60
- 🟩 40.1-50
- 🟩 35.1-40
- 🟩 30.1-35
- 🟨 25.1-30
- 🟨 20.1-25
- 🟧 15.1-20
- 🟧 10.1-15
- 🟧 5.1-10
- 🟥 5 and less

MILES
0 50 100 150 200
Albers equal area projection



pageprecip_tx3.pdf INTERIOR-GEOLOGICAL SURVEY, RESTON, VIRGINIA-2005