Partnerships: The Pathway to a Vibrant Bioeconomy for Alabama

Executive Summary

Alabama and its alliance of land grant institutions and other research partners are positioned to be national leaders in bioenergy and bioproducts education, research, extension and outreach. Each of the three land-grant universities in Alabama—Auburn University, Alabama A&M University, and Tuskegee University—has a rich past and an exciting future for conducting programs that are directed at utilizing our natural resources for energy and value-added products. This document outlines a comprehensive plan for education, research and development, extension and implementation activities conducted by an alliance composed of these universities with external partners that will lead to the creation of bioenergy and bioproducts that will help Alabama and the nation reach the energy goals outlined by the President and the 25x'25 initiative. The multidisciplinary programs at each of the three land-grant institutions are working in concert in the following major areas: Auburn University emphasizes utilization of biomass resources for conversion to liquid fuels, electrical power, heat, and other higher-value products; Alabama A&M University emphasizes oilseed crop production; and Tuskegee University emphasizes starch crop production. Moreover, two major federal government research units: the USDA ARS National Soil Dynamics Laboratory and the USDA Forest Service Forest Operations Research Unit of the Southern Research Station; and the Alabama Department of Agriculture and Industries and its Center for Alternative Fuels, also are integral research partners in the alliance in the areas of agricultural and forest production systems. This comprehensive plan outlines a vision, guiding principles, program activities, and necessary steps to create a bioeconomy in Alabama that will help meet and exceed the President's goals for 2017 as well as the goals set out in the 25x'25 initiative by producing as much as 2.5 billion gallons per year of liquid fuels, offsetting as much as 35% of the state's electrical power needs, reducing net greenhouse gas emissions, and creating thousands of jobs for Alabama citizens.

The Vision

The Alabama Agricultural Land Grant Alliance (hereinafter referred to as the Alliance), composed of Auburn University, Alabama A&M University, and Tuskegee University, and their research partners (USDA Forest Service, USDA ARS National Soil Dynamics Laboratory, and Alabama Department of Agriculture and Industries), endeavors to create bioenergy and bioproduct solutions that will contribute to the efforts underway to provide 25 percent of the country's energy from renewable resources by 2025. Alliance efforts are focused on the following goals:

- Provide major contributions to Alabama's and the nation's liquid fuel needs;
- Provide major contributions to Alabama's and the nation's needs for renewable power;
- Contribute significantly to reduction in net greenhouse gas production; and
- Make these contributions in a way that ensures sustainable uses of water and soil resources while revitalizing local communities and their economies.

Economic development based on biorefining is both viable and appropriate in Alabama. Technologies and business models are emerging that can help invigorate Alabama's established natural resource-based industries as well as create new bioproduct opportunities. By maintaining market value of existing agricultural and forest commodities and creating markets for biomass resources that are currently underutilized, new businesses and industries can be developed. Such economic growth has the potential to create vibrant, self-sustaining communities across Alabama while meeting our nation's need for energy and sustainable products. The Alliance endeavors to be a major force in education and discovery, serving as the catalyst for economic rebirth.

To develop the bioeconomy and reach the goals set out for Alabama and the nation, a suite of integrated sustainable farming and forest production systems will be implemented to provide the feedstocks for a successful biorefining industry. The result must include successfully integrated food, fiber, and forest production systems. These farming and forest production systems will be based on the following primary sectors:

- Woody biomass production from over 22 million acres of forestland,
- Dedicated energy crop production from up to 3 million acres of land,
- Oilseed crop production from up to 1 million acres of land, and
- Utilization of wastes and residues from agricultural, forest, commercial, and municipal sources.

__Woody Biomass Production:__ While other states may be developing entirely new bioeconomies, Alabama has a proven, successful industry that produces forest biomass. This forest products industry, which is essentially the world's largest handler of biomass today, contributes $10 billion to the state's economy annually with over 885 million dry tons of biomass standing in the state's forests. While this industry currently is based on pulp, paper, and solid wood products, efforts are needed now to help the industry transition to a more complete biorefining mode where biofuels, specialty chemicals, and other value-added products are manufactured in addition to the traditional pulp and paper and solid wood products. Conservative estimates for woody biomass that is currently not utilized indicate that approximately 14.6 million dry tons per year are available from logging residues and small-diameter trees. These 14.6 million tons per year have the potential to produce nearly 2.0 billion gallons of liquid fuels (through thermochemical conversion processes with yields of up to 130 gallons per ton.) Alternatively, this amount of woody biomass could allow 35% cofiring at the nine existing coal-fired power plants in Alabama. These are conservative estimates in that they are assuming no use of the wood volume that is currently used for pulp and paper or solid wood product manufacturing, therefore these estimates are achievable without placing undue pressures on existing fiber supply for those other manufacturing sectors.

__Dedicated Energy Crop Production:__ Commercial production of dedicated energy crops in Alabama has been underway for years through limited switchgrass operations in north central Alabama and industrial, short-rotation woody crops in south Alabama. Conservative projections indicate that over 2.6 million acres of dedicated energy crop production may be possible in the state. These crops could include cellulosic biofuel feedstocks such as switchgrass, miscanthus, high biomass sorghum, or short-rotation woody crops that could produce 15.6 to 26 million tons to per year (based on a yields ranging from 6 to 10 tons per acre per year.) The biomass from these energy crops will have the potential to provide as much as 2.0 to 3.4 billion gallons per year of liquid fuels using thermochemical conversion processes. Other crops that could be candidates for short-term sugar or starch feedstocks include sweet sorghum or industrial sweet potato. In recent sweet potato trials in Alabama, ethanol yields of up to 1000 gallons per acre per year were achieved. If 100,000 acres of sweet potato were produced in appropriately integrated farming systems, this could yield 100,000 million gallons of ethanol per year. Dedicated energy crops and oilseed crops will be important components in integrated farming systems that utilize multiple crops in rotations and minimize soil borne pests and weeds while improving soil quality and fertility—at the same time maintaining production of traditional food and fiber crops within farming systems.

__Oilseed Crop Production:__ Alabama farmers have demonstrated the ability to grow significant acreages of oilseed crops such as soybeans, peanuts, and sunflowers. With a renewed demand for soybeans and new interest in rapeseed, Alabama growers have the potential to increase production to over 1 million acres, which could support a regional oilseed processing sector that in turn could provide feedstocks for the existing biodiesel production industry. Conservative estimates point to a potential production of at least 40 million gallons per year of biodiesel within the state using locally grown crops.

__Wastes and Residues:__ Many forms of agricultural and forest products wastes and residues are available in Alabama for use as feedstocks in a bioeconomy. These feedstocks, which include poultry litter, urban wood wastes, spent pulping liquors, pulp mill sludge, and recycled cooking oils have significant potential for regional use as energy products. For example, over 2 million tons of poultry litter are produced annually. This litter can be used as an energy source on the farm or at other distributed power generation sites. Poultry litter could provide about 5% of the power currently generated at Alabama's coal-fired electrical power plants or it could provide a similar amount of power at distributed generation sites around the state. With the implementation of gasification systems in the pulp and paper industry, spent pulping liquors and other mill wastes and residues may be recovered more efficiently to provide additional electrical power or other specialty chemicals. Research at Auburn University has developed biochemical processes to convert the cellulose-rich sludge from Alabama's paper mills into ethanol at very high efficiencies. Estimates for this sludge-to-ethanol process indicate that approximately 25 million gallons per year of ethanol could be produced from Alabama's pulp mills thereby relieving the problem of placing this material in landfills. An estimated 1 million tons of urban wood waste generated in Alabama could produce 130 million gallons of liquid fuel annually. Used cooking oil is another locally-available feedstock that has the potential to be used by municipalities for biodiesel production. By using oil recycled from homeowners, a municipality can produce their own biodiesel and offset as much as 50% of their fleet fuel use while realizing significant cost savings in their wastewater treatment systems.

__Impact on Alabama and the Nation:__ The vision for an Alabama bioeconomy goes far beyond impacting the agricultural and forest products sectors. In recent years, the state has seen monumental shifts in its manufacturing economy through the loss of much of its traditional textile industry and then the development of automotive, steel, and aircraft manufacturing industries (manufacturers include Honda, Hyundai, Daimler-Chrysler, Toyota, Kia, International Engines, Thyssen-Krupp stainless steels, and Airbus-Northrup Grumman.) These operations provide significant opportunities for collaborative development of new, more efficient engines and vehicle systems designed specifically for biofuels and for new lightweight, high-strength biobased composite parts created from Alabama's locally grown resources. The potential of biobased composites has the promise of replacing the once vibrant textile industry with new biobased product sector.

__Meeting the Goals for 2017 and 2025:__ Achieving the energy vision outlined here will not be possible overnight. However, the most rapid advances in biorefining can be made by focusing efforts on those sectors where a biomass delivery infrastructure and farming system infrastructure are in place and functioning today. By concentrating on the existing forest products industry infrastructure and a readily-mobilized agronomic crop acreage for oilseed crops, and by utilizing conservative energy conversion rates, Alabama can develop the systems by 2017 to deliver over 15 million tons of woody biomass and produce 1 million acres of oilseed crops. The conversion of woody biomass to liquid fuels will rely heavily on transformations in the existing pulp and paper industry to produce liquid fuels along with their traditional products. Using conservative conversion rates of 85 gallons of fuel per ton of biomass and 40 gallons of biodiesel per acre, this biomass and oilseed production can result in over 700 million gallons of liquid fuels annually, which is equal to 22% of the current fuel usage in the state. Therefore, it is possible for the state to meet the President's goal of 20% alternative fuel use by 2017.

During the years following 2017, there will be ample time to further develop an agricultural energy crop industry and to improve the conversion rates for biomass to liquid fuels to take full advantage of the potentials outlined previously. By the year 2025, we envision an expanded bioeconomy in Alabama founded on sustainable, integrated food-fiber-fuel farming systems that will result in the following outcomes:

- Produce at least 2.5 billion gallons of liquid fuel from primarily lignocellulosic feedstocks to offset 75% of Alabama's annual petroleum-based fuel consumption;
- Produce at least 15 million tons of biomass to offset 35% of the fossil fuel used annually in the state's current coal-fired power plants providing clean, carbon-neutral energy for Alabama through conversion at large power generation complexes and smaller, distributed generation sites;
- Expand revenue streams and bolster the existing 10 major pulp and paper manufacturing complexes by converting them to true biorefineries;
- Create at least 10 additional new large biorefineries specializing in liquid fuel production from dedicated lignocellulosic energy crops;
- Create at least 5 smaller biorefineries specializing in liquid fuel production from sources such as municipal solid waste, urban wood waste, regionally-appropriate energy crops, etc.;
- Create close alliances between the bioeconomy and the state's other manufacturing sectors, with special emphasis on linking biofuels and biobased products with Alabama's successful automotive industry; and
- Create 5,000 new jobs in the biorefineries and the associated industries.

In achieving these milestones, Alabama will exceed the goals of the 25x'25 program for energy use within the state and thereby contribute to the ability of the nation to meet its overall energy security goals.

The Core Challenges for Developing a Bioeconomy and Reaching the Nation's Goals

The realization of the potential of biorefining and meeting the nation's goals for 2017 and 2025 depends on: 1) the application of sustainable practices for the production of biomass feedstocks; 2) development and implementation of cost-effective systems to produce, harvest, process, and transport biomass feedstocks; 3) advancement of certain core technologies dealing with the separation, purification, and conversion of the basic biomass components to a range of products; and 4) public acceptance and development of appropriate legislative policies that foster a bioeconomy.

Sustainability and development of integrated farming systems are keys to developing a successful biorefining industry. Long term sustainable practices for maintaining soil and water resources will be one of the major determining factors in the ability of the industry to survive. These practices will include adoption of expanded conservation tillage techniques and use of crops that require lower amounts of water and fertilizer while preserving wildlife habitat. Biotechnology combined with traditional genetic improvement methods hold many of the keys to developing varieties of energy crops that use water and nutrients more efficiently while increasing biomass yields. When historic advances in corn yields are used as a model, there is great potential to increase energy crop yields far beyond those currently seen in practice. Careful integration of these new cropping techniques into traditional agricultural and forest production systems is also of utmost importance to insure continued production of sufficient food and fiber crops without disruptions in local communities and social structures. While research needs are great, extension and outreach programs will be critical to long-term adoption of these integrated food-fiber-fuel farming systems.

While systems are in place today to harvest and deliver agricultural and forestry feedstocks to their target processing or manufacturing centers, these systems are not necessarily optimized for cost and productivity in a biorefining economy. Many questions exist about the optimal systems for harvesting, packaging, and transporting agricultural energy crops like switchgrass, miscanthus, or high-biomass sorghum, which are not currently grown on a commercial scale in any state. For woody biomass, current harvesting and transportation systems developed for pulpwood or sawn lumber products are not optimal for feedstock materials such as logging residues or small diameter woody material. It is well documented that current log transportation systems operate in conditions where only 40% of the miles driven are loaded. New systems are needed to densify biomass and subsequently improve the utilization and productivity of our biomass transportation systems. Answering questions about necessary feedstock processing steps will depend largely on desired transportation distances, which are dictated by the scale of the biorefining operations. Considerable research and extension efforts are needed to develop, demonstrate, and implement optimal systems to harvest, handle, process, and transport biomass feedstocks, at the lowest cost and in the most desirable forms to biorefineries.

The chemical, biological, and thermochemical pathways from the biomass constituents to commercial chemicals, polymers, and fuels are well established, but further research, development, and demonstration are needed to improve process efficiency and economics in order for these technologies become viable commercial options. The technologies include chemical and biological processes to convert biomass to sugars and then to products, thermochemical conversion of biobased feedstocks to syngas or pyrolysis oils and then to fuels, and direct biomass fractionation technologies to separate biomass into pure chemical components. Other technologies include direct gasification of biomass to use in heat and power generation systems.

Public acceptance of a bioeconomy has already encountered unanticipated consequences in the debate of food versus fuel, carbon sequestration, and greenhouse gas benefits. While much of the media debate is based on incomplete data, this highlights the need for research and subsequent educational efforts focused at a broad group of producers, landowners, consumers, and policy makers. The foundation of a successful bioeconomy must include the development of integrated farming systems where food, fiber, and fuel are produced sustainably and where society clearly understands the benefits.

Guiding Principles

Research, development, education, extension, and implementation activities within the Alliance partners' programs operate under the following four primary guiding principles:

Research and Development: Concerted research and development efforts are focused on finding energy and value-added product technologies that are cost-competitive with traditional petroleum-based products. Developing new technologies that are cost effective will encourage the growth of new industries able to compete without the need for subsidies or programs that place existing industries at an economic disadvantage.

Regionally Appropriate Feedstocks and Optimal Technologies: Each region of the country has unique climate, soil, and cultural conditions that lend themselves to production of certain biomass feedstocks. The Alliance advocates a balanced portfolio of feedstocks that are best suited to each region. Correspondingly, there is an optimal set of feedstock conversion or utilization methods best suited to these feedstocks.

Systems Approaches: Emphasis on systems approaches to problem solving is a hallmark of the Alliance programs. By combining expertise in production of agricultural and forest biomass with engineering expertise on harvesting, processing, and transportation; engineering expertise on conversion of biomass to fuels, chemicals, power, and heat; engineering expertise on performance of fuels in engine systems; with expertise on economics, policy, and social sciences, we can address bioeconomy questions from a systems perspective thereby developing optimal solutions. The use of systems approaches will be integrated throughout biorefining education programs.

The Partnership Concept: Partnerships developed with industry and government agencies have the potential to speed development and implementation of new feedstock production systems and energy and bioproduct technologies. Members of the Alliance endeavor to develop multiple partnerships and linkages with other major research universities and with Alabama's forest products, agricultural, and energy industries. Additional partnerships with local, state, and federal agencies (such as the USDA ARS National Soil Dynamics Laboratory, the USDA Forest Service, and the Alabama Department of Agriculture and Industries) as well as biotechnology and biomass-to-fuels/energy companies are critical components in the program to ensure seamless pathways from fundamental research to demonstration, deployment and commercialization of new technologies. Similar relationships with farmers, landowners, and citizens are equally critical to insure acceptance and long-term success of the bioeconomy.

Achieving the Vision

The Alliance is focusing efforts on three major areas of need to help achieve the vision outlined previously. These areas are:

- *State-of-the-Art Educational Programs Producing Graduates Able to Advance a New Bioeconomy*
- *Cooperative R&D and Extension Programs Leading to Demonstration and Commercialization Projects*
- *Highly Coordinated Infrastructure of R&D and Extension Facilities*

Educational Programs for the New Bioeconomy: Producing skilled professionals is critical for the development and operation of the new bioeconomy. The Alliance is already addressing these challenges by initiating efforts at the undergraduate and graduate levels. While numerous courses are currently offered in traditional areas related to biorefining (agriculture, forestry, engineering), new courses specifically focused on bioenergy and bioprocessing have been initiated recently. These courses will serve as the initial offerings in minors or certificate programs allowing students to specialize in biorefining. At this time, existing degree programs such as agronomy and soils, forestry and wildlife sciences, biosystems engineering, or chemical engineering appear sufficient to train students in the fundamental science and engineering topics integral to the biorefining sectors. The best approach for undergraduate students is to offer interdisciplinary minors or certificate programs in bioenergy cropping systems or bioenergy and bioproduct production where students from each major can choose to develop an additional specialization in biorefining, based on a foundation in a traditional subject matter discipline. At the graduate level, similar subject matter specializations can be offered for M.S. and Ph.D. programs in programs like chemical engineering or biosystems engineering. The foundation for these courses has already been developed through collaboration among chemical engineering, biosystems engineering, and biology where pilot curriculum programs have been conducted in biological engineering and biorefining. All of these programs can be offered collaboratively among the three land grant institutions using distance learning methods or even traditional classroom teaching (e.g. students from Tuskegee University already benefit from a jointly offered Tuskegee-Auburn graduate course in food and bioprocess engineering.)

R&D and Extension Programs Leading to Demonstration and Commercialization Projects: Programs developed by members of the Alliance are designed to conduct fundamental and applied research connected with extension and outreach efforts that will encourage the successful development of the new bioeconomy in Alabama. These programs operate within the four guiding principles outlined earlier and they address four major issues: 1) agricultural and forest production systems; 2) the biomass feedstock supply chain; 3) thermochemical and biochemical conversion systems; and 4) public policy issues concerning the bioeconomy. In each issue area, demonstration and commercialization projects are either underway or planned to lead the state into its transformation to a successful biorefining industry through the ***"Energy Partners"*** program initiated by Auburn University. This program began with the goal of providing immediate bioenergy and bioproduct solutions to problems faced today by individual farmers, landowners, industries, or municipalities. As the program proceeds, it will facilitate commercialization projects that are based on technologies being developed by Alliance partners.

Agricultural and Forest Production Systems: The foundation of a bioeconomy in Alabama is a portfolio of sustainable practices and systems to produce biomass feedstocks on Alabama's farms and forests. This segment of the Alliance's programs will focus on identifying regionally-appropriate biomass feedstocks for Alabama and the best practices for their production. Agricultural and silvicultural scientists at each of the three land grant universities and the USDA research partners will develop an Alabama portfolio of forest biomass types (including new short rotation woody crops, agroforestry systems, underutilized small diameter material in current forest production systems, and logging residues) agricultural crops (such as switchgrass, miscanthus, high biomass sorghum, sweet sorghum, sugar cane, sweet potatoes, microalgae, etc.), and agricultural and municipal wastes and residues (such as poultry litter, waste vegetable oils or animal fats, or municipal solid wastes.) This portfolio of feedstocks will be based on soil, climate, and local production capabilities and will be produced in forms that can be easily transferred to producers through the Alabama Cooperative Extension System (which is a collaborative between all three land grant institutions), the eXtension network, the Alabama Department of Agriculture and Industries, and the Alabama Forestry Commission. Along with feedstock type recommendations, research and extension programs must be conducted to educate producers on the practices necessary for sustainable production of these feedstocks. This includes developing knowledge on maintaining appropriate levels of soil nutrients for long term site productivity, methods for increasing biomass removal while reducing soil compaction and soil erosion, and water requirements for profitable crop production. Extension programs and educational resources will be devoted, through the use of targeted extension teams to educate and assist producers in implementing biomass feedstock production enterprises. At least 18 teams of extension professionals are already organized and working in subject matter areas closely aligned with the needs of the bioeconomy (such as renewable energy, rapid response agronomic team, irrigation and water management, geospatial technologies, and workforce development.) These teams are able to mobilize rapidly to provide educational programs in a wide variety of subjects to producers of feedstocks from agricultural and forest systems.

Auburn University's primary focus is on production of lignocellulosic biomass feedstocks (woody biomass and other dedicated energy crops like switchgrass, miscanthus, etc.) Since forests occupy two-thirds of the Alabama landscape, the Alliance activities are focused first on taking these existing forest stands and making sure that intensive biomass removals can be accomplished with minimal adverse long-term impacts. Researchers at Auburn and the USDA Forest Service have examined the sustainability of intensive forest production systems through study of nutrient cycling, reductions in nonpoint source pollution from intensive forest operations, and implementation of precision forestry techniques to insure long term site productivity in biomass production systems. In contrast to the existing forest industry, an agricultural biomass industry does not exist in Alabama and therefore needs additional R&D and extension to initiate it. Collaboration between Auburn University energy crop researchers and the USDA ARS Soil Dynamics Laboratory is building on long-running energy crop field research and creating large-scale energy cropping system research and demonstration sites where the latest techniques in conservation tillage and precision agriculture are being utilized in applied research programs on crops like switchgrass, miscanthus, and high biomass sorghum. These sites contain research on genetic improvements and fertility requirements. As these applied integrated farming system demonstration sites are developed at strategic locations in Alabama, such as the E.V. Smith Natural Resources Discovery Complex, they will be used in extension programs educating regional farmers on sustainable food, fiber, and fuel production practices. Research at Tuskegee University is studying the potential for the production of industrial sweet potato as a potential feedstock for ethanol. Other sugar crops such as sweet sorghum and sugar cane are also potential candidates for immediate implementation of ethanol production and are being studied by Auburn University. Since acreages under row crop production are frequently fallow during the winter, study of bioenergy crop species including winter canola and rapeseed is being conducted by both Alabama A&M University and Auburn where a collaborative research and demonstration project is underway at the Tennessee Valley Research and Extension Center. Further research collaboration between Auburn University and the Alabama Department Agriculture and Industries is examining the production of microalgae as a potential source of oil for subsequent biodiesel production. Significant goals for this work will be demonstration sites for the major dedicated energy crops at various locations in Alabama and subsequent adoption in the state of integrated farming systems that include dedicated energy crops.

<u>Biomass Feedstock Supply Chain:</u> Ultimate profitability of biorefining enterprises will depend in large part on the delivered costs and forms of biomass feedstocks. While the production costs of the feedstock are very important cost components, the costs of harvesting, processing, packaging, and transporting the feedstock are major ingredients that will limit the amount of feedstock available for biorefining unless major advances are made in the supply chain.

If a biofuel conversion plant were operational today, woody biomass could be delivered immediately using existing forest harvesting and transportation systems. However, current systems that harvest and transport forest biomass are configured for larger trees used in the manufacture of pulp and paper and solid wood products. To encourage the procurement of currently underutilized small diameter trees and logging residue, and thereby avoid using current feedstocks that supply the pulp and sawtimber sectors, new cost-effective machines and systems are needed to harvest, process, package, and transport smaller diameter trees and logging residues. Current R&D efforts at Auburn University are examining alternative machine systems that consist of smaller-scale feller bunchers, skidders, and chippers that may be more suited to harvesting small diameter stems on smaller tract sizes. Additional R&D efforts are studying deployment of bundling and transport systems for logging residue and material harvested from forest health improvement harvests and harvesting and collection techniques that maximize energy content of the delivered biomass. These efforts are accomplished through collaboration between Auburn University and the USDA Forest Service Southern Research Station.

Major questions remain unanswered about similar systems to harvest, process, transport, and store agricultural energy crop feedstocks. As in forest production systems, current biomass harvesting and handling systems have been optimized to provide forage to livestock production systems—not for the biorefining industry. Newer, more productive and more robust machine systems must be developed to harvest and densify energy crops with high lignin contents. Additional research is needed to determine the optimal methods to process the feedstocks into the most appropriate forms for biorefineries. Biomass feedstocks have low bulk densities and therefore require some level of densification to allow them to be transported efficiently. Research is needed to develop lowest cost systems for biomass densification while maintaining the desirable properties needed for subsequent biorefining. Many agricultural equipment manufacturers are positioning themselves to provide new lines of biomass harvesting, processing, and transportation equipment for a biorefining industry, and significant opportunities exist to develop partnerships between universities, government agencies, and the equipment manufacturing industry for the development of new machines and machine systems. Activities in this area are fostered through the close collaboration of Auburn University and the USDA ARS National Soil Dynamics Laboratory also located in Auburn. Currently, researchers are studying alternative harvesting and baling machines, new types of yield monitors for precision biomass yield mapping, and optimal storage techniques – especially as they influence downstream processing, fractionation, and pretreatment of biomass for biochemical or thermochemical conversion. Researchers at Tuskegee and Auburn University are both examining harvesting and storage practices for industrial sweet potato. Finally, researchers at Auburn University are working to identify optimal systems for algae flocculation, harvest, and processing to extract constituents desirable for production of liquid fuels, electrical power, nutraceuticals, etc. Major milestones for commercialization of these systems will be marketing of new harvesting systems specifically optimized for agricultural biomass production, initial implementation of starch crops like sweet potato, and demonstration of pilot scale microalgae harvesting and processing systems.

<u>Thermochemical and Biochemical Conversion Systems:</u> Primary R&D on conversion systems is conducted in the Alliance at Auburn University and is focused on both thermochemical and biochemical processes that convert biofeedstocks to a range of products that include liquid fuels, high value chemicals, electrical power, and heat. Research begins by focusing on separation of the biomass into its basic chemical constituents by using biomass fractionation to produce pure streams of cellulose, hemicelluloses, and lignin. Fractionation is a powerful technology platform that will allow the industry to convert a wide range of biomass feedstocks to a relatively uniform set of fundamental chemical forms that can be further processed into a wide range of specialty products. Research on biomass fractionation holds great promise for improving efficiencies of biochemical conversion processes and yielding product streams, such as lignin, that are most suited to gasification or production of higher value products. Auburn University is partnering with Purevision Technologies, Inc. to utilize their patented technology to study fractionation of softwoods and other regionally appropriate feedstocks. As this technology is developed at larger scales, a desired milestone will be its deployment in a pulp mill where hemicelluloses will be extracted and converted to ethanol.

Concerning advanced energy resources and systems, the program has two main focal points. The first concentrates on conversion of biomass carbohydrates (hemicellulose and cellulose) to component sugars by either thermochemical (steam/acid) or biological (enzymatic) pretreatment techniques. Following fractionation of biomass, research is studying downstream pretreatment and simultaneous saccharification and cofermentation (SSCF) processes that convert the cellulose and hemicelluloses to mixed alcohols and other products. In addition to traditional research on dedicated energy crops and woody biomass, one of the new avenues of biochemical research at Auburn University is the utilization of pulp mill sludges and municipal solid wastes for the production of ethanol. Although there are challenges to overcome in removing ash from the pulp mill sludge substrate and in conducting SSCF, the initial research has shown that it is rich in a form of cellulose ideal for the production of ethanol. Initial feasibility studies are complete and designs are underway to help construct a pilot-scale pulp-mill-sludge-to-ethanol demonstration facility in collaboration with a forest products industry partner. Other research is underway on the conversion of municipal solid waste to ethanol in partnership with Masada Resources.

The second and most emphasized area focuses on thermochemical conversion of biomass feedstocks through gasification or pyrolysis to produce synthesis gas or bio-oil that can be used for heat and power generation systems, or catalytically converted to liquid fuels or further to hydrogen. Since many of Alabama's regionally-appropriate feedstocks are woody biomass or dedicated lignocellulosic energy crops, thermochemical conversion approaches appear to the most feasible systems to emphasize since gasification produces a synthesis gas that allows the production of multiple products, Auburn University has chosen to heavily emphasize R&D on gasification for production of electrical power, liquid fuels, and high value chemicals. Ongoing R&D and extension programs are currently studying gasification of forest, agricultural, and urban wastes to produce electrical power and heat. In these systems where the biomass residue is of low value and low bulk density, Auburn University, Alabama Power, and Community Power Corporation are examining small-scale atmospheric pressure, air-blown gasification systems that may be field deployed rather than using densification techniques and transporting the biomass long distances. Field deployment of small-scale gasification and power generation systems is a key goal of the Alliance's program. Major laboratory research on pressurized, oxygen-blown, fluidized bed gasification is also underway at Auburn University. This research, with partners of the Gas Technology Institute, the Electric Power Research Institute, and the Southern Company, is studying feedstock preprocessing, pressurized feeding, gasification processes, hot-gas cleanup techniques, and gas-to-liquids processes, such as Fischer-Tropsch techniques, to produce clean syngas for power production or a variety of liquid fuels and chemicals. As the research progresses, major commercialization milestones include the implementation of a large-scale biomass gasification plant for heat or power production; implementation of a pulp mill biomass gasification unit to produce liquid fuels; implementation of a pulp mill booster gasification system for spent pulping liquors; and final conversion of a pulp mill to an ultimate biorefinery. Additional thermochemical R&D efforts underway within the Alliance and at Auburn University are examining the use of fast pyrolysis techniques to produce bio-oils and the use of supercritical water for rapid depolymerization of biomass to form a biocrude product.

To compliment the basic research efforts in thermochemical and biochemical conversion, considerable extension and outreach programs are underway in the area of producing biodiesel from locally available feedstocks. These programs are being coordinated by the Alabama Cooperative Extension System and the Alabama Department of Agriculture and Industries and are part of the ***"Energy Partners"*** program. Biodiesel systems are being deployed at farms and in several municipalities across Alabama. For on-farm biodiesel production, Alabama A&M University, Alabama Cooperative Extension System, and Alabama Department of Agriculture and Industries are working in concert to implement oilseed crops and processing systems and biodiesel production units. In the case of the municipalities, extension personnel at the state and county levels are assisting the cities in establishing residential and commercial recycling programs for used cooking oils and then implementing biodiesel production systems that power city fleets. To date, 10 cities in Alabama are in various stages of implementation of these types of biodiesel production programs that not only provide a cost effective diesel fuel solution for the city, but perhaps most importantly solve significant maintenance problems for city sewer and waste water treatment systems.

The following table lists ***"Energy Partner"*** demonstration projects (discussed in the preceding text) that have already been identified as candidates to accelerate the state's transition to an enhanced bioeconomy and ultimate achievement of the goals for 2017 and 2025.

Implementation	*Energy Partners* Projects Conducted Through the Alliance	Status
2007	Small-scale Biodiesel Production for Farms and Municipalities	Underway
2008	Integrated Energy Cropping Systems Demonstrations at E.V. Smith	Underway
2008	Small-scale Biomass Gasification For Distributed Power Generation for Farms, Businesses, and Municipalities	Underway
2009	Algae Harvesting and Energy Production from Commercial Aquaculture Systems	Feasibility studies complete
2010	Gasification, Combined-Heat Power Generation Using Agricultural Residues	Feasibility studies underway
2010	Municipal Solid Waste (MSW)/ Pulp Mill Sludge to Ethanol Pilot Plant	Feasibility studies complete
2011	Large-scale Biomass Gasification for Process Heating in Manufacturing Plants	Searching for industry partner
2012	Pulp Mill Sludge to Ethanol Commercial Plant	Industry partners identified
2014	Pulp Mill Biomass Gasification to Liquid Fuels Demonstration	Searching for industry partner
2014	Pulp Mill Hemicellulose Extraction and Conversion to Ethanol Demonstration	Searching for industry partner
2015	Pulp Mill Booster Black Liquor Gasification Demonstration	Searching for industry partner
2017	Conversion of Pulp Mill to Ultimate Biorefinery	Searching for industry partner

Additional projects will be identified as the initiative proceeds. The capital requirement for the small scale projects range from $20,000 to $250,000 while the larger scale commercial projects range from under $10 million to over $50 million. It is envisioned that members of the Alliance and their partners will help to underwrite or find government and industry partners willing to underwrite one or two of these projects per year, providing 25-50% of the required investment in each case. For those commercialization projects not yet ready to proceed, the Alliance will assist them through cooperative R&D to the point justifying capital investment by industry partners.

Public Policy Issues Concerning the Bioeconomy: Public awareness of biorefining for production of biofuels and renewable power is currently at a very high level (with both positive and negative connotations.) However, many questions remain unanswered about the appropriate suite of public policies and legislation needed to foster a newly developing industry without negatively impacting Alabama's existing industries, communities, and its environment and natural resource base. These questions must be answered through the concerted efforts of multidisciplinary teams including disciplines including but not limited to the biophysical sciences, engineering, economics, political science, and sociology. Questions to be addressed include: 1) how can the emerging bioeconomy be developed in ways that will generate employment opportunities and income for landowners, including limited resource landowners, in such a way that rural economies and small towns are revitalized? 2) what investments in physical and entrepreneurial infrastructure exist in Alabama and what additional investments are needed to promote a successful biorefining industry? 3) what are the aggregate effects on our existing natural resource base (including water, soil, air) of a sustainable biomass production system? and 4) does Alabama have the human capital necessary to develop a successful biorefining industry? Fundamental research on bioeconomy policy issues is underway at Auburn in areas that include aggregate economic impacts of energy policy at federal and state levels (conducted in partnership with Texas A&M), impacts of bioenergy and bioproduct manufacturing sectors on local economies, and impacts of the bioeconomy on the stability and economic health of local communities.

Additional questions must be answered about the depth of public acceptance of the bioeconomy and public adoption of biofuels and biobased products. For example, even though scientists and engineers have estimates of the woody biomass currently available in Alabama along with estimates of the potential amounts of switchgrass that could be produced on Alabama farmland, research is needed to gain greater insights into how much biomass Alabama farmers and forest landowners are willing to sell to the biorefining industry, and at what price. Previous research conducted at Auburn University has investigated the willingness of farmers to adopt switchgrass production systems, however, this research needs to be repeated given the changes in social and economic conditions. In addition, research is needed to gauge what level of biomass removal and what level of environmental impacts will be accepted by society and then use this information in economic and production models to determine how to establish a profitable and sustainable biorefining industry in Alabama. Members of the Alliance are actively involved in both R&D and extension and outreach concerning public policy issues. Representatives from each of the Alliance institutions are all members on the Alabama Permanent Joint Legislative Committee on Energy and in this capacity play active roles in developing new legislative proposals related to energy research, education, and extension. Alliance members are also active in policy making activities at the federal levels.

Coordinated Infrastructure of R&D and Extension Facilities: R&D and extension facilities for production of forest biomass and dedicated energy crops exist in all three of the primary partners in the Alliance. The Alabama Agricultural Experiment Station hosts 14 active research centers occupying over 8,000 acres of land strategically distributed around the state where considerable energy cropping system studies are already underway. The largest research unit, the E.V. Smith Natural Resources Discovery Complex, located on interstate 85 midway between Auburn and Montgomery, already has long-running switchgrass experimental plots, and these plots are being augmented by new research and demonstration fields of energy crops such as high-biomass sorghum, sweet sorghum, sunflower, rapeseed, and sweet potato. Additional energy cropping systems research is underway at the Tennessee Valley Research and Education Center in north Alabama, where collaboration between researchers at Alabama A&M and Auburn is examining rotations of cotton, soybean, and rapeseed with the assistance of a comprehensive surface and subsurface irrigation infrastructure. An additional 9,000 acres of forest lands are maintained by Auburn University for research and demonstration of forest biomass production systems and best management practices. The 5,000 acre Solon Dixon Forestry Education Center in southern Alabama is a one-of-a-kind facility where students of all ages and from many universities come to study management of forests and wildlife. A feature unique to Alabama is the Caterpillar ForestPro Training Center located on Alabama Agricultural Experiment Station forestlands near Auburn. This facility is the only location in the world where Caterpillar tests and demonstrates its forest products equipment line. Most importantly, this facility allows Auburn faculty and students and USDA Forest Service research engineers to work alongside Caterpillar engineers in testing new machine concepts for harvesting and handling forest biomass.

A major emphasis of the initial stages of the R&D activities is the creation of a Bioenergy and Bioproducts research area on the Auburn campus. Our vision is to create a space that encourages collaboration among scientists and engineers from a variety of disciplines and other research partners in the Alliance. Cross-disciplinary collaboration is the key to the successful application of systems approaches to problem solving and technology implementation. The first phase of this research area is located in Auburn's existing forest products laboratory. New individual laboratory spaces are being created that are dedicated to biomass fractionation and thermochemical conversion of biomass to syngas and liquid fuels. The fractionation laboratory will house a one-of-a-kind prototype device that produces pure streams of cellulose, hemicelluloses, and lignin from biomass feedstocks. The gasification laboratory will contain a recirculating fluidized bed gasifier, gas cleanup unit, and multiple Fischer-Tropsch reactors to produce liquid fuels. By collaborating with the adjacent USDA Forest Service research laboratory, feedstock processing and analysis capabilities will provide a variety of forms and types of biomass feedstocks for study in the fractionation and gasification laboratories. Future plans call for additional laboratory spaces to house pilot-scale biochemical conversion (pretreatment, hydrolysis, and fermentation), transesterification, and fuel testing and analysis. To compliment the laboratory emphasis on thermochemical conversion, a mobile biomass gasification unit, designed in partnership with Community Power Corporation, is currently being demonstrated throughout the state to power an electrical generation unit for onsite power generation and space heating needs. This unit is being used in R&D programs as well as in education and demonstration programs for agriculture, forest products enterprises, industry, and municipalities. Existing laboratories for oil seed processing and transesterification will be moved to the new laboratory once space is available and will work in partnership with a mobile transesterification unit, or "Biodiesel Classroom on Wheels" operated by Alabama A&M University and the Alabama Department of Agriculture and Industries. This mobile unit serves as a field classroom for teaching fundamentals of biodiesel production.

Additional pilot-scale biofuel production facilities are planned for the E.V. Smith Natural Resources Discovery Complex, which is ideally suited to demonstrate the pilot-scale production of liquid fuels from biomass that can be grown on site. Plans for the site include a visitors center and learning campus where the biomass and biofuel producers and the general public can learn about the latest discoveries in bioenergy and bioproducts, along with issues in management of our soil and water resources.

The following table outlines the specific research, extension, and implementation activities that will occur within collaborating groups in the Alliance (and individual centers within the institutions.)

Partners within the Alabama Land Grant Alliance	Program Activities					
	Feedstock production	Feedstock supply chain	Feedstock pretreatment	Conversion technologies	Product testing	Policy issues
AU Center for Bioenergy and Bioproducts	x	x	x	x	x	x
Alabama Center for Paper and Bioresource Engineering		x	x	x	x	x
AU College of Agriculture, Alabama Agricultural Experiment Station (AAES)	x	x	x	x	x	x
AU School of Forestry and Wildlife Sciences (and AAES)	x	x	x	x		x
AU College of Science and Mathematics	x	x	x	x		x
AU Ginn College of Engineering	x	x	x	x	x	x
Alabama Cooperative Extension System	x	x	x	x		x
Alabama A&M University	x	x				x
Tuskegee University	x	x	x	x		x
USDA ARS National Soil Dynamics Laboratory	x	x	x			
USDA Forest Service Southern Research Station Forest Operations Unit	x	x	x			x
Alabama Department of Agriculture and Industries – Ctr. for Alt. Fuels	x	x	x	x	x	x
Alabama Forestry Commission	x	x				x

Summary

Throughout their storied histories, beginning over 150 years ago, the three land-grant institutions in Alabama (Auburn University, Alabama A&M University, and Tuskegee University) and their dedicated faculty and students have provided leadership for the natural resource sectors of Alabama's economy. During these 15 decades, leaders like George Washington Carver have laid the groundwork for harnessing the benefits of our natural resources to create a diverse portfolio of products based on our biological resources. Today's researchers and educators maintain these rich traditions in the further development and delivery of scientifically sound and economically viable solutions for the production, management, and utilization of Alabama's resources. Through the bioenergy and bioproducts programs outlined in this document, the Alliance will serve as a catalyst for the production and use of new value-added products and energy sources in Alabama and throughout the nation. These products will include annual production of 2.5 billion gallons of liquid fuels, 35% of the state's electrical power needs, thousands of new jobs in the biorefining sector, and significant reductions in greenhouse gas emissions. The end result will be a network of communities across the state that are strengthened by a new bioeconomy based on innovative yet sustainable uses of our natural resources.