Action Plan: National Program 213: Bioenergy

The ARS Bioenergy program develops technologies to enable sustainable commercial production of biofuels by the agricultural sector in ways that enhance our natural resources without disrupting existing food, feed, and fiber markets. Research will optimize both the production of plant feedstocks and the biorefining of agricultural materials to bioenergy and value-added coproducts. This research will strengthen rural economies, provide increased supplies of renewable transportation fuel, enhance energy security, and improve the U.S. balance of trade.

Goals: ARS has adequate research capabilities to pursue three major Research Goals associated with its Bioenergy Mission:

- Enable new varieties and hybrids of bioenergy feedstocks with optimal traits
- Enable new optimal practices and systems that maximize the sustainable yield of high-quality bioenergy feedstocks
- Enable new, commercially preferred biorefining technologies

The growth and long-term viability of bioenergy production in the Nation is impeded by a number of technical and commercial barriers. ARS addresses only technical barriers and does so by leveraging its strengths and unique capabilities to pursue technical barriers that can be overcome by ARS resources and provide substantial and unique contributions towards the Nation's bioenergy goals. A list of unique ARS competencies that contribute to the ARS Bioenergy Mission is provided in Appendix A. Appendix B lists the technical barriers impeding the bioenergy industry and indicates which barriers will be addressed by ARS research.

In addition to tackling specific technical barriers and leveraging ARS core competencies, ARS bioenergy research is consistent with relevant non-technical considerations associated with public policy, general resource constraints, and overall practices/trends within the bioenergy industry. Appendix C provides a comprehensive list of these relevant non-technical considerations. Plans for transferring the technologies that arise from ARS bioenergy research are summarized in the Technology Transfer Plan (see Appendix D).

Relationship of this National Program to the ARS Strategic Plan: Outputs of National Program 213 (NP 213) research support the Actionable Strategies associated with the performance measures shown below from the ARS Strategic Plan for 2006-2011, Objective 2.1: "Expand domestic market opportunities"—specifically, **Performance Measure 2.1.1**: "Create new scientific knowledge and innovative technologies that represent scientific/technological advancements or breakthroughs applicable to bioenergy." The target for Performance Measure 2.1.1 is to develop technological breakthroughs or scientific advancements that make significant contributions toward reducing the cost and increasing profitability, improving the efficiency, increasing the yield, and increasing the sustainability of producing or converting biobased feedstocks into biofuels.

In addition to the ARS Strategic Plan, the ARS Bioenergy Research Strategy supports the National Action Plan of the United States Biomass Research and Development Board, and the Energy Strategic Plan of USDA Research, Education and Economics mission area.

NP 213 Research Components

The ARS Bioenergy Action Plan is composed of three distinct research components, each of which focuses on one of the three Goals. These components were developed based on input from ARS stakeholders.

Component 1: *Feedstock Development*
Component 2: *Feedstock Production*
Component 3: *Biorefining*

Though each research component is associated with relatively independent technical barriers and considerations, there are numerous interdependencies between the goals and components that require substantial coordination and sharing of technical information in order to maximize national impact. ARS possesses proven, unique capabilities in managing and coordinating complex, large-scale, multi-disciplinary and multi-objective agricultural research programs. The ARS Action Plan for integrating bioenergy research into a single, coordinated program that maximizes its potential impact is described in the Action Plan for Program Coordination (Appendix E).

Component 1: Feedstock Development

Development of new germplasm, parental stocks, and cultivars with value-added traits to enhance biomass yields, conversion efficiencies, and biorefinery co-product value are critical needs for the developing bioenergy industry. ARS will play a major role in feedstock development with fundamental research on molecular, biochemical, and genetic control of key plant traits. Objectives will include genetic and genomic research to enhance the value of bioenergy crops, identify molecular markers and functional gene sequences to facilitate selection of desired traits in breeding programs, develop innovative and efficient breeding strategies and evaluation tools, and practical breeding and germplasm development to support the bioenergy and agriculture industries. ARS scientists functioning within this action plan will coordinate with existing projects in several other national programs, including NP 301 Plant Genetic Resources, Genomics, and Genetic Improvement; NP 302 Plant Biological and Molecular Processes; NP 303 Plant Diseases; NP 304 Crop Protection and Quarantine; NP 306 Quality and Utilization of Agricultural Products; and NP 215 Rangeland, Pasture, and Forage Systems. Projects within this component will be strengthened by collaborative and coordinated research supported by other governmental agencies, various non-governmental organizations, universities, private industry, and international partners.

Problem Statement 1A: Breeding and Evaluation of New Germplasm

Existing knowledge of germplasm resources is inadequate to meet the needs of a rapidly growing bioenergy industry. Biomass yield and quality factors, including recalcitrance of cellulosic biomass, oil-seed content and composition, plant factors that reduce conversion efficiency, and characteristics that increase the value of biorefinery co-products are major impediments to start-up and long-term efficient production of alternative fuels. Target traits and genes must be identified to allow genetic improvement of farm-gate value of bioenergy feedstocks and their co-products. Information is lacking to identify regionally optimal species and germplasm for use in support of large-scale feedstock conversion to bioenergy. Many species of potential bioenergy crops do not currently have sufficient pest resistance mechanisms and stress tolerances to be functional long-term bioenergy crops in the face of drought and potential global climate change. Species and cultivars must be matched with climatic, edaphic, cultural, and practical limitations that vary on a regional basis. Species and cultivars ready for deployment and those in need of genetic enhancement must be identified.

Research Needs

Plant species and germplasm resources need to be evaluated on a regional basis for their potential use and associated environmental risks in development as bioenergy crops . Critical traits for feedstock improvement need to be identified and high-throughput phenotyping methods advanced. Improved cultivars and elite germplasm of bioenergy crops are needed for feedstock production.

Anticipated Products

- Identification of plant traits that enhance feedstock yield, conversion efficiency, and co-product value and incorporation of these traits into elite germplasm
- More rapid, efficient, and repeatable methods for measuring key traits that define feedstock quality

- Risk analyses of plant species and traits to assess environmental impacts and sustainability
- Improved breeding methods and selection strategies for use in development of bioenergy crops
- Cultivar evaluation data that can be used to identify optimal adaptation zones of species and cultivars on a regional basis
- Improved cultivars and parental stocks with enhanced feedstock yield and value-added traits to improve conversion and biorefinery co-products

Potential Benefits

The varieties and germplasm developed will enable the production of new energy crop commodities from agricultural materials. The research will make the U.S. economy more sustainable by providing renewable Raw materials for biobased fuels and coproducts.

Problem Statement 1B: Biological and Molecular Basis of Plant Traits

Lack of biological and genetic information limits optimization of existing and new bioenergy crops. Breeding programs are handicapped by lack of fundamental knowledge about the underlying genes that control important plant traits that limit either production or utilization of crops as bioenergy feedstocks. Identification of biological mechanisms controlling cellulosic recalcitrance, modification of seed composition, overcoming susceptibilities to biotic and abiotic stress factors, and enhancing sustainable biomass production are crucial to the success of many germplasm enhancement programs. Application of interdisciplinary research approaches are now allowing plant breeders and geneticists to exploit vast databases of genetic and genomic information in crop and model plants, yet these approaches have not specifically addressed the biological restrictions of many bioenergy crops and the complex production and bioconversion systems in which they will be utilized. Using these approaches along with complimentary efforts in molecular biology, genomics, plant physiology, plant pathology, and entomology will be required.

Research Needs

Knowledge of the biological and molecular processes that govern efficient utilization of plant materials for bioenergy is necessary. Genetic, genomic, and bioinformatic tools are needed to exploit new information so the development of bioenergy crops can be accelerated.

Anticipated Products

- High-density linkage and association maps and DNA marker sets for potential bioenergy and model species
- Enhanced knowledge of syntenic relationships among plant species and ability to utilize gene sequence data across species for germplasm enhancement
- Genomic and gene sequence information for several bioenergy crops and rapid-cycle model plants
- Addition of new functional gene sequence data to public data bases
- Identification and validation of candidate genes for improvement of targeted biofuel traits

- Molecular understanding of complex plant traits including cell-wall synthesis and structure, growth, stand establishment, persistence, biomass yield, and conversion potential
- Determination of genetic inheritance mechanisms in complex polyploid perennials
- Development of genetically modified, mutant, T-DNA tagged, and recombinant populations for testing hypotheses related to genetic and biological control of plant traits

Potential Benefits
A better understanding of the plant biology, genetic, and molecular mechanisms governing energy value will accelerate the development of adapted germplasm and new energy crop varieties. Valuable gene discovery, genomic characterization, and evaluation data will facilitate genetic selection and improvement.

Component 1 Resources
The problem statements identified under this component are being addressed at the following ARS locations:

- Albany, CA
- Lincoln, NE
- St. Paul, MN
- Tifton, GA

Component 2: Feedstock Production

Agricultural producers, government agencies, energy companies, and policy makers around the country need to know with certainty what kinds of bioenergy feedstocks can be produced, how much feedstock can be dependably harvested, and what will be the likely impacts of the bioenergy economy on whole-farm economic return and natural resources quality. ARS will develop new sustainable production strategies and decision tools to produce abundant amounts of new generation feedstocks for the emerging biorefinery industries, while maintaining the integrity of U.S. food, feed, and fiber production. These production strategies will be designed to protect the natural resources base to ensure long-term, sustainable production needs are met.

USDA-ARS research within Component 2 of the NP-307 Action Plan will be coordinated among existing projects in several other national programs including: NP-202 Soil Resource Management; NP-204 Global Change; NP-206 Manure and Byproduct Utilization; NP-211 Water Availability and Watershed Management; NP-215 Rangeland, Pasture, and Forage Systems; NP-216 Agricultural System Competitiveness and Sustainability; and NP-305 Crop Production.

Problem Statement 2A: Accurate information at different levels of scale to help plan for future bioenergy production needs in ways that maintain the integrity of U.S. agriculture

Research Needs

Assessment tools that can dependably quantify the amounts of feedstocks that could be harvested in different U.S. regions, and provide strategies to balance the production of food, feed, fiber, and fuel crops.

Anticipated Products

- Whole-farm management decision tools that estimate the optimal site-specific strategies to economically incorporate sustainable bioenergy production into existing farm production systems
- An analysis framework that integrates field and whole-farm scale economic and biophysical impacts information to increase the sensitivity of USDA-ERS national crop price estimates and help optimize whole-farm production strategies
- An easy-to-use whole-farm planning tool that can be used to estimate the optimal ways to incorporate bioenergy feedstock production into existing food, feed, and fiber production systems to enhance system-wide biological and economic benefits
- Models that predict changes in soil organic matter in response to biofuel feedstock production, with an emphasis on the impacts of biomass removal
- Estimated projections of the effects of changing climate and available resources on biomass yields, and the certainty of production for various U.S. feedstock production systems.
- An assessment of net greenhouse gas generation by different feedstock production systems based on life cycle accounting
- Informative maps showing feedstock production potential for different U.S. regions, with indicators of the impacts of harvest on natural resources quality
- Estimates of biomass feedstock production impacts on natural resources to support web-based information delivered by USDA-NRCS for use in outreach programs

Potential Benefits
Dependable decision-making tools will help producers and biorefiners make sound management decisions about the relative opportunities and risks associated with bioenergy production. This information will help producers decide when and where to produce feedstocks. Biorefiners are able to plan where to site their facilities and estimate the dependability of feedstock supply for conversion. Creation of regionally-specific biomass production systems that compliment food, feed, and fiber markets, and that enhance the natural resources base. The information provided by these tools will help ensure that feedstock removal does not lead to a reduction in carbon sequestration, soil organic matter, or an increase in soil loss.

Problem Statement 2B: Greater amounts of biomass feedstocks are needed to achieve U.S. goals for replacing transportation fuels with renewable sources. This increase will require greater production from each acre of land used, and new kinds of production systems for the next generations of feedstocks that compliment food, feed, and fiber production.

Research Needs
- Management practices are needed for existing agricultural production systems to increase the amounts of bioenergy feedstocks that can be produced and the efficiency of their production
- Production systems need to be developed for perennial cellulosic feedstock crops for the next generation of bioenergy conversion technologies
- Assessments are needed demonstrating the economics and energy efficiency of existing and new harvest, handling, pre-treatment, storage, and delivery practices and systems for next-generation bioenergy feedstocks

Anticipated Products
- Science-based management recommendations for incorporating winter cover crops into summer row crop production systems to enhance soil organic carbon content and allow removal of greater amounts of crop residues
- Optimal crop rotations that incorporate bioenergy feedstock production into existing food, feed, and fiber production systems to enhance system-wide biological and economic benefits
- Recommendations for using feedstock crops or alternative production systems to increase overall production efficiencies, decrease costs, or increase the value of agricultural production
- Management guidelines for the sustainable removal of crop residues for energy production with no subsequent impacts on carbon sequestration and soil health in irrigated high-value specialty crop production systems
- Improved establishment and management tools and technologies for herbaceous energy crops to increase establishment success, reduce costs, and decrease the time period to reach full production potential
- Management guidelines to optimize the quality of different herbaceous energy crops to increase conversion efficiency
- Guidelines for harvesting biomass from areas enrolled in USDA Farm Bill Conservation Title programs, such as the Conservation Reserve Program and riparian buffers, will retain conservation benefits

- Technical and economic guidelines and decision-making tools for determining optimal harvest, handling, pre-treatment, storage, and delivery systems

Potential Benefits

- Farmers will be able to harvest abundant amounts of crop residues with an understanding of the economic and biological feasibility of incorporating biomass feedstock production into their current agricultural production systems. They will be able to determine what changes or modifications to their existing systems will allow increased production, without harming the environment or lowering future economic return
- Farmers and biorefineries will be able to grow, harvest, and store feedstocks that optimize producer income and feedstock production efficiencies. New technologies will help producers more reliably establish new bioenergy crops such as switchgrass, and manage dedicated energy crop on marginal lands. Policy makers will be provided with guidelines for assessing the environmental benefits new generation bioenergy feedstock production systems

Problem Statement 2C: Strategies are needed to use conversion co-products from agricultural-based energy production on farms to reduce the need for purchased inputs for crop production systems.

Research Need

An understanding of the biological activities of bioenergy conversion co-products is needed to develop management guidelines for their safe use to reduce the need for purchased soil amendments and pesticides.

Anticipated Products

- Documentation of the concentrations of chemical constituents in ash produced by thermochemical gasification reactors from herbaceous biomass crops, and management guidelines for use as a replacement for purchased soil amendments
- Known effects of ligneous co-products from cellulosic ethanol production on soil carbon levels and the stability of soil aggregates
- An understanding of the biological activity of *Brassica* seed meals and dried distillers' grains on weed populations and disease progression in high-value crop production systems
- Known impacts of bio-char from pyrolysis as a soil amendment on soil carbon levels and management guidelines for on-farm use

Potential Benefits

Bioenergy conversion by-products have the potential to increase soil carbon levels, soil stability, and suppress weed, insect, and disease pests. Description of the biological activities of these by-products in crop production systems and documentation of their fate in the ecosystem will help provide recommendations to design guidelines for their use. Demonstration of beneficial uses of bioenergy by-products as soil amendments and pest control agents will reduce the need for purchased soil amendments and pesticides.

Component 2 Resources

The problem statements identified under this Component are being addressed at the following ARS locations:

- Ames, IA
- Auburn, AL
- Brookings, SD
- Corvallis, OR
- Florence, SC
- Ft. Collins, CO
- Lincoln, NE
- Mandan, ND
- Morris, MN
- Orono, ME
- Pendleton, OR
- Prosser, WA
- St. Paul, MN
- West Lafayette, IN

Component 3: Biorefining

The Action Plan for Biorefining is divided into four separate Subcomponents…

3a. Biocatalytic Conversion
3b. Thermochemical Conversion
3c. Biodiesel
3d. Process Economics and Life Cycle Analyses

These four Subcomponents have independent research objectives, involve different ARS researchers, and have different stakeholders.

ARS research under the Biorefining Component will be coordinated with other Agency research in:

- Feedstock Development Component of the NP 213 Bioenergy Action Plan
- Feedstock Production Component of the NP 213 Bioenergy Action Plan
- Quality and Utilization of Agricultural Products National Program (NP 306)
- Manure and Byproduct Utilization National Program (NP 206)
- Food Animal Production National Program (NP 101).

Subcomponent 3a: Biocatalytic Conversion

Problem Statement 3a1: Cost-effective conversion of lignocellulosic feedstocks to ethanol or butanol

Lignocellulosic biomass is an abundant, non-food, non-feed feedstock for the production of fuel-grade ethanol or butanol. However, significant technical challenges must be overcome to achieve cost-competitive conversion of these feedstocks. The strong, complex, fibrous, cell-wall material that constitutes lignocellulosic feedstocks is difficult to deconstruct and depolymerize into fermentable sugars. Significant pretreatment is required to open the lignocellulosic structure for enzymatic hydrolysis (deconstruction). In addition, saccharification (depolymerization) requires a number of enzymes, many of which are product-inhibited. Further, pretreatment and saccharification processes often result in relatively dilute sugar solutions containing chemical byproducts that inhibit the subsequent fermentation. The five-carbon sugars constituting most of the hemicellulose fraction are fermented relatively slowly and are not converted at all by typical ethanol-producing yeast. In addition, optimal operating conditions in the pretreatment and hydrolysis processes depend on the nature and condition of the cellulosic feedstock.

Research Needs

- Enable commercially-viable pretreatment and preprocessing technologies, particularly ones that can be deployed on-farm
- Enable commercially-viable enzymatic systems for saccharification
- Enable commercially-viable biocatalysts for converting cellulosic-derived sugars into ethanol or butanol
- Enable commercially-viable biorefining technologies that can handle heterogeneous mixtures of biomass feedstocks
- Develop cost-effective and rapid analytical methods to assess desired feedstock characteristics of lignocellulosic feedstocks

- Thoroughly understand the key feedstock characteristics affecting ethanol (or butanol) production costs

Anticipated Products
- Commercially-preferred processes for the partial or full conversion (and to the extent possible – on-farm conversion) of heterogeneous, lignocellulosic feedstocks to fermentable sugars
- Commercially-preferred biocatalysts for the production (and to the extent possible – on-farm production) of ethanol or butanol from cellulosic sugars
- Analytical methods that producers, consumers and intermediaries routinely use to assess the quality of lignocellulosic feedstocks for biorefining
- Decision tools that crop breeders routinely utilize to develop superior varieties of lignocellulosic-based biorefinery feedstocks

Potential Benefits
- Increased revenue to farmers and rural communities from the conversion of lignocellulosic biomass to bioenergy & co-products or value-added intermediates
- Significant amounts of bioenergy are produced from renewable, energy-efficient, sustainable, and domestic feedstocks with minimal impacts on traditional agricultural markets for food or feed

Problem Statement 3a2: Biological production of hydrogen and methane from lignocellulosic feedstocks
Hydrogen – a zero-emission fuel for high-efficiency engines (e.g., fuel cells) – can be produced directly from carbohydrates by certain anaerobic bacteria. However, fermentative production of hydrogen suffers from low yields, low production rates, and product (hydrogen) inhibition. Similarly, biological fuel cells (microbial or enzymatic) for producing electricity from carbohydrates also suffer from low voltages and current.

Research Needs
- Develop microbial processes to produce hydrogen in high yields and with high productivities from carbohydrates
- Develop pure or mixed cultures of microorganisms that produce hydrogen from lignocellulosic feedstocks
- Develop biological fuel cells to produce electricity at commercially-relevant voltages and currents

Anticipated Products
- Commercially-viable processes for the biological production of hydrogen and/or electricity from lignocellulosic biomass

Potential Benefit
- Cost-effective production of hydrogen – a zero-emission fuel for high-efficiency engines (fuel cells) – and/or electricity from renewable, non-food, non-feed agricultural materials will strongly enable our transition to sustainable high-quality-of-life societies

Problem Statement 3a3: New and improved processes for biocatalytic conversion of starches and sugars to ethanol or butanol

Energy efficiencies associated with first-generation biorefineries need to be increased and their costs need to be reduced. For instance, distillation processes currently used for the recovery and purification of fuel ethanol require significant amounts of energy. In addition, biocatalytic biorefineries are susceptible to contamination from microorganisms that lower product yields, decrease productivity, and lower the value of biorefinery co-products.

Besides corn a variety of other starch-based and sugar-based feedstocks could be converted into bioethanol (or biobutanol). Examples include cereal grains such as wheat & barley and food processing byproducts/wastes. In addition, some grains can be winter cropped (e.g., barley), thereby allowing farmers to increase the per-acre production of feedstocks for bioethanol production. However, commercially-viable processes for biocatalytic conversion of these alternative starch- and sugar-based feedstocks do not exist.

Research Needs

- Enable commercially-preferred methods and processes that decrease the cost or increase the energy efficiencies of starch- and sugar-based biorefineries
- Enable commercially-preferred methods and processes for controlling microbial contamination in fuel ethanol plants
- Enable commercially-preferred processes for converting alternative starch- and sugar-based feedstocks to bioethanol and biobutanol

Anticipated Products

- Commercially-viable and energy-efficient technologies for the recovery and/or purification of ethanol and/or butanol
- Highly efficient processes and unit operations that are retrofitted into existing corn-to-ethanol plants
- User-preferred methods for minimizing microbial contamination in ethanolic biorefineries
- Commercial processes for converting region-specific starch- and sugar-based feedstocks (e.g., sorghum, wheat, barley, food processing byproducts, sugar beets, sugar cane) into fuels and chemicals

Potential Benefits

- High energy efficiency of starch- and sugar-based biorefineries
- Low cost biorefining of starch or sugar to bioethanol or biobutanol

Problem Statement 3a4: Biorefinery co-products

Co-products associated with existing biofuels (distillers' grains and soybean meal) are important raw materials for the animal feed industry. Further, the market value of distillers' grains has a significant impact on the economics of fuel ethanol facilities. However, distillers' grains, as currently produced, have performance limitations (such as low flowability and propensity to cake) that depress their market value. In addition, fiber content and amino acid profiles in current distillers' grains products limit their utility in animal feeds.

The existing market for the lignin byproduct from biocatalytic cellulosic biorefineries is limited to combustion for heat and/or power. Higher-value uses for the lignin, hemicellulose and/or fermentation-derived byproducts are needed to make biocatalytic biorefineries commercially viable.

Research Needs

- New or modified processes and/or handling methods that cost-effectively overcome the existing shortfalls of distillers' grains and increase their value as animal feed ingredients
- Enable new, commercially-viable, value-added uses for distillers' grains
- Develop new technologies that enable new, commercially-viable, value-added co-products for biocatalytic biorefining

Anticipated Products

- Commercially-preferred new or modified processing/handling methods for distillers' grains that significantly increase their use in animal feeds
- New, commercially-viable technologies for increasing the value of existing co-products from biocatalytic biorefineries
- New, commercially-viable technologies for producing value-added co-products from biocatalytic biorefineries

Potential Benefits (outcomes)

- Increased market value and utilization of distillers' grains and its components
- Co-products from commercial lignocellulosic biorefineries

Sub-Component 3a Resources

The problem statements identified under this sub-component are being addressed at the following ARS locations:

- Albany, CA
- Brookings, SD
- Madison, WI
- Peoria, IL
- Wyndmoor, PA

Subcomponent 3b: Thermochemical Conversion

Problem Statement 3b1: Managing biomass feedstocks for thermochemical processing
In theory, thermochemical processes can convert a variety of agricultural feedstocks. But the physico-chemical and thermodynamic characteristics of a particular feedstock significantly impact both its processing by thermochemical approaches and the quality of the end-products. Basic understanding of how some feedstocks and specific feedstock characteristics affect the performance of thermochemical processes is lacking. In addition, rapid analytical methods to quantify feedstock characteristics that critically impact the performance and control of thermochemical processes are lacking. Commercially-viable methods for handling, preprocessing and blending agricultural feedstocks are also lacking.

Research Needs

- To understand and quantify the effect of agricultural feedstocks on the performance of thermochemical processes and the characteristics of end-products Feedstocks of particular importance include:
    - combined plant-derived lignocellulosics and animal waste feeds
    - bio-gas and sludge from anaerobic digesters
    - sugar-based biorefinery wastes (DDGs, lignin, starchy byproducts, syrup, etc)
    - bio-oils of various origins (plant-derived lignocellulosics and/or animal wastes)
    - bio-chars of various origins (plant-derived lignocellulosics and/or animal wastes)
    - gas stream from pyrolysis-based conversion processes
    - preprocessed (e.g., chopped, dried, densified, torrefacted, charred) feedstocks
- To understand and quantify the effect of the following feedstock characteristics on the performance of thermochemical processes and the characteristics of process end-products and co-products:
    - mineral composition
    - genetic variability
    - maturation, cultivation practice, harvest timing, storage
    - particle size and uniformity
    - animal waste or sludge composition
- To develop rapid (possibly spectroscopic-based) analytical methods that will assess critical feedstock quality characteristics impacting the performance and control of thermochemical processes
- To develop cost-effective methods for handling, storage, preprocessing and blending agricultural feedstocks that optimize the performance of thermochemical processes.

Anticipated Products

- Databases for feedstock characteristics vs. thermochemical processing performance adopted by conversion industry, feedstock producers, plant breeders, and livestock nutritionists
- Industry-adopted analytical methods for assessing feedstock quality

- Commercially-viable schemes for handling, storing, preprocessing and blending agricultural feedstocks that enable thermochemical conversion processes

Potential Benefits

- Commercial thermochemical conversion facilities can produce on-spec products at minimal cost while utilizing most, if not all, of available feedstocks
- Feedstock producers can provide materials most desired by thermochemical conversion facilities

Problem Statement 3b2: On-farm production of heat and/or power

As energy costs increase, agricultural producers are burdened with higher costs for their heat and electricity requirements. By generating their own heat and/or power from farm-produced biomass feedstocks, farmers could minimize their energy costs, minimize the volatility in their energy costs, and sell excess power to generate additional income.
However, commercially-viable processes for on-farm heat or power production do not currently exist. In gasification and pyrolysis, the production of off-spec product during startup, shutdown, etc. is a barrier to on-farm deployment of these technologies.

Research Need

- Enable robust, commercially-viable gasification systems for on-farm generation of heat and power

Anticipated Product

- Technologies for on-farm conversion of agricultural materials to heat and/or power

Potential Benefit

- Agricultural producers are assured heat and power of predictable (and low) cost for their operations

Problem Statement 3b3: Commercially viable thermochemical processes for producing liquid fuels from agricultural feedstocks

Thermochemical processes hold much promise for the cost-effective production of liquid fuels, at-or-near the farm, from abundant agricultural feedstocks. However, significant technical and market barriers currently preclude commercial utility of these processes. For instance, the production of off-spec product during startup, shutdown, etc. is a barrier to on-farm deployment of these technologies.

For pyrolysis-based processes, a major problem is that the bio-oil product has high levels of organic acids and is therefore unstable and corrosive. In addition, the bio-oil end-product has very limited markets.

For gasification-based units, a major problem is that biomass-derived syngas must be cleaned-up or upgraded so that it is suitable for Fischer-Tropsch reforming to liquid fuels. Although capital and operating costs associated with converting the intermediate syngas to liquid fuels is too high, particularly for small-scale units, research to tackle this particular issue is better suited to DOE.

Research that enables the commercial deployment of thermochemical processing at-or-near the farm; and/or the thermochemical conversion of animal manures &/or by-products from post-harvest processing for food/feed/fiber production, at-or-near the feedstock source is especially needed and is appropriate for ARS.

Research Needs

- For pyrolysis-based processes:
  - enable commercially-viable methods for stabilizing bio-oil
  - develop robust systems that generate minimal off-spec product
  - utilize inexpensive and preferably renewable co-reactants (e.g., water) to produce marketable products

- For gasification-based processes:
  - enable commercially-viable methods for syngas purification/upgrading
  - develop robust systems that generate minimal off-spec product

Anticipated Products

- Technologies for at-or-near farm conversion of agricultural feedstocks to fuels and co-products

Potential Benefits

- Farmers and rural communities maximize their capture of the economic returns available from biofuel production
- Agricultural producers are assured liquid fuels of predictable (and low) cost for their operations

Problem Statement 3b4: Biorefinery co-products

The profitability of thermochemical-based conversion processes depends, in no small part, on the production of value-added co-products. As commercial deployment of these processes becomes more common (the supply of individual co-products increases), economic returns from co-product sales may become more problematic. To the extent possible, co-reactants used to produce co-products should be renewable. It is especially important that by-products from thermochemical processing do not become wastes , which incur internalized or externalized disposal costs.

Some co-products are expected to have on-farm utility as plant nutrients (gasification ash) or soil amendments (pyrolysis char). In addition, pyrolysis char (“agri-char”) could provide farmers with an additional revenue stream from carbon sequestration. Such on-farm utility helps ensure the sustainability of bioenergy production and makes thermochemical processing an especially attractive alternative for deployment at-or-near the farm.

In spite of these needs, technological know-how to enable commercially-viable co-products from thermochemical processing does not currently exist.

Research Need

- New technologies that enable new, commercially-viable, value-added co-products for thermochemical-based biorefining

Anticipated Products

- Technologies for the commercial production of value-added co-products from the thermochemical conversion of agricultural materials
- Thermochemical co-products that are utilized on-farm

Potential Benefits

- Enhance commercial viability of thermochemical-based biorefineries
- Products and co-products that maximize the sustainability of bioenergy production

Sub-Component 3b Resources

The problem statements identified under this sub-component are being addressed at the following ARS locations:

- Corvallis, OR
- Florence, SC
- Wyndmoor, PA

Subcomponent 3c: Biodiesel

Problem Statement 3c1: Increasing feedstock (fatty acid) availability
Increasing production of biofuels has resulted in significantly higher market prices for the major feedstock in biodiesel production – soybean oil. To ensure the continued availability of affordable lipids for both food and fuel production, biodiesel must be produced from a wider variety of feedstocks, especially from those not used in food production.

Research Needs
- Increase the oil content or composition in crops, such as soybeans, which are already being used to produce biodiesel. Conversion research is needed to enable the commercial production of biodiesel fuels from these new varieties.
- Non-conventional crops, such as camelina, are being considered for biodiesel production. Conversion research is needed to enable the commercial production of biodiesel from these oils.
- Many non-plant sources of lipids (for example, food-processing wastes) could be used to produce biodiesel fuels. Research is needed to enable commercial production of biodiesel from these materials.

Anticipated Products
- Commercial production of biodiesel fuels from new varieties of conventional feedstocks
- Commercial production of biodiesel fuels from non-conventional, agriculture- and food-based sources

Potential Benefits
- Availability of affordable lipids for both biodiesel and food production

Problem Statement 3c2: Biodiesel production processes
As new alternative fuels are introduced, a period of uncertainty exists as to which fuels are most viable. Under these circumstances, the future viability of the biodiesel industry depends, in part, on minimizing the costs (including externalities) associated with biodiesel production. Emphasis is especially needed on conversion technologies that can be deployed at or near the farm.

Research Needs
- Conversion research is needed that will enable:
    - lower capital and/or operating costs
    - increased product yields
    - increased energy efficiency
    - increased use of renewable materials
    - increased process robustness to variations in feedstock quality, composition or type
    - increased recycling of catalyst and other process materials, and
    - lower emissions and wastes

  associated with commercial biodiesel production.

Anticipated Products
- Lower-cost commercially-preferred biodiesel production processes

- Reduced externalities from commercial biodiesel production facilities

Potential Benefit

- Long-term competitiveness of biodiesel industry

Problem Statement 3c3: Improving the inherent performance of fatty acid esters as fuels

Although biodiesel possesses distinct advantages, market acceptance of biodiesel fuel is hampered by some performance limitations (relative to petrodiesel) that are directly attributable to the chemical structure of biodiesel's major components. These limitations include:

- higher cloud point (cold flow)
- susceptibility to oxidative and hydrolytic degradation
- higher NO_x emissions under some circumstances

Research Needs

- Identify the underlying causes for performance limitations and enable corrective measures that are commercially viable and compatible with rapidly evolving emissions control technologies. Possible corrective measures include:
    - fuel additives
    - new or modified fractionation technologies
    - new or modified biodiesel production or purification technologies
    - modifying fatty ester profiles
    - blending of biodiesel produced from alternative feedstocks

ARS research in this area must be closely coordinated with related efforts funded by DOE and EPA.

Anticipated Product

- High-performance commercially-preferred biodiesel fuels for all environments and combustion applications

Potential Benefits

- Blending levels acceptable to engine manufacturers for biodiesel in diesel fuels are significantly increased
- The market potential for biodiesel fuels is significantly expanded

Problem Statement 3c4: Biodiesel fuel quality assurance

Some contaminants originating from the raw materials used for biodiesel production or from the production processes themselves create significant fuel performance problems. Although the nature of problem-causing contaminants may be known, industry standards for acceptable levels may be inappropriate, too loose, or not available. In addition, accurate, reliable, simple and rapid analytical methods that suppliers, producers, distributors and users alike can use to determine the level of these contaminants may not exist.

Research Needs

- Identify problem-causing contaminants and to determine effective quality assurance standards for these contaminants that will be adopted by industry
- Enable technologies for neutralizing or removing problem-causing contaminants

- Develop analytical methods preferred by industry to measure the levels of problem-causing contaminants

ARS research in this area must be closely coordinated with related efforts funded by NIST

Anticipated Products

- Industry-preferred quality assurance standards and methods to enable effective quality-control in biodiesel manufacturing and commerce
- Effective, commercially-viable process technologies to mitigate the undesirable effects of contaminants

Potential Benefits

- Predictable and reliable performance of biodiesel fuels
- Substantially decreased incidences of post-manufacturing remediation of commercial biodiesel products

Problem Statement 3c5: Biodiesel co-products

The profitability of biodiesel production depends, in no small part, on maximizing the value of glycerol co-product. This issue becomes more pressing as increasing biodiesel production creates an excess supply of (and depressed market prices for) glycerol byproduct.

Research Needs

- Enable biorefining technologies that increase the profitability of glycerol co-product. Examples include increasing glycerol product purity or decreasing glycerol purification costs
- Develop new technologies that enable new, commercially-viable, value-added co-products of biodiesel production

Anticipated Products

- Effective, commercially-viable process technologies that increase the value and/or decrease the production costs of glycerol co-product
- New, commercially-viable, value-added co-products from biodiesel biorefineries

Potential Benefits

- Minimize earnings volatility for biodiesel manufacturers
- Long-term viability of the biodiesel industry

Sub-Component 3c Resources

The problem statements identified under this sub-component are being addressed at the following ARS locations:

- Peoria, IL
- Wyndmoor, PA

Subcomponent 3d: Process Economics and Life Cycle Analyses

Problem Statement 3d1: Estimating process costs and externalized costs
To determine the commercial viability and potential economic impact of new technologies for biorefining requires accurate estimates of the costs associated with these facilities. Biorefining research should enable technologies that will generate significant economic impact; and comprehensive, accurate process cost estimates can identify what research will generate the most impact. However, models for estimating process costs associated with new technologies do not exist.

In addition, externalities (such as impacts on the environment and natural resources) can significantly contribute to the overall societal cost associated biorefining and must be considered. However, complete life cycle analyses that estimate all the costs, including externalities, are not available.

Research Needs
- Industrially-realistic process cost models for existing and proposed biorefining processes
- Process and life-cycle costs associated with technologies that could be enabled by biorefining research at ARS
- Realistic, "field to wheel" life cycle assessments (LCA) that accurately estimate total (internalized and externalized) costs associated with biorefinery products

Anticipated Products
- Publicly-preferred computer simulations and models that accurately predict biorefinery economics
- Publicly-preferred Life Cycle Analyses that estimate the overall economic, environmental, and social impact of producing biofuels and coproducts

Potential Benefits
- The economic returns from bioenergy research will be maximized.
- ARS research in bioenergy will maximize its economic impact
- Policy decisions on biorefining will be based on accurate estimates of total life cycle costs (e.g., environmental, economic, and social)

Sub-Component 3d Resources
The problem statements identified under this sub-component are being addressed at the following ARS locations:
- Wyndmoor, PA

Appendix A: Unique ARS Competencies Relevant to Bioenergy Research

ARS possesses numerous core competencies that provide taxpayers with substantial value and proven resources in agricultural research. Some of these unique capabilities can enable rapid progress in bioenergy technology development; the relevant capabilities include:

1. Plant genetics, genomics and biotechnology research for crop improvement: ARS is a world leader for research in plant molecular and biological processes, informatics and genetic improvement. ARS is also a leader in biotechnology risk assessment and mitigation research.
2. Plant genetic resources: ARS has plant germplasm collections of significant relevance to energy crops. For instance, ARS manages the National Plant Germplasm System in partnership with land-grant universities and agricultural experiment stations. This repository, which has seeds of nearly 10,000 species, will be an invaluable source of genes that could benefit energy crops. In particular, ARS manages USDA germplasm collections for oilseeds, grains, small grains, and grasses.
3. Microbial genetic resources: ARS has unique collections of microbial genes important to bioenergy. Examples include rhizobium bacteria (for nitrogen fixation), fungi (for degradation of lignocellulosic feedstocks), anaerobic bacteria (for butanol and biohydrogen) and yeast (for bioethanol). The ARS Culture Collection (Peoria, IL) is the largest of its kind in the world, with over 85,000 accessions of bacteria, yeast and fungi and includes the ARS Patent Culture Collection.
4. Developing germplasm and production systems for perennial grasses: ARS is the worldwide leader in research for forage grasses, including the development of new varieties, new production management systems, and quality assessment. For instance, eight out of ten scientists working on non-turf grasses are at ARS.
5. Developing germplasm and production systems for forage legumes: ARS has about 25% of the Nation's capacity for breeding forage legumes and the greatest capacity outside of commercial enterprises.
6. Developing germplasm and production systems for sugar cane: ARS is the U.S. leader for breeding sugar cane.
7. Developing oilseed germplasm: ARS is a leading breeder of oil seed varieties with optimal traits for biodiesel production.
8. Ability to field test new crop varieties and/or production practices simultaneously in any agricultural region in the Nation: ARS has about 100 locations scattered throughout the Nation.
9. Development of optimal and sustainable production systems for any agricultural region of the country: ARS is uniquely capable of identifying the best combination of dedicated energy crops, dual-purpose crops, dual-cropping, inter-cropping and/or cover-cropping systems for a particular producer. The optimal mix depends on a variety of factors including soil conditions, water availability, climate zone as well as the agricultural and processing systems that already exist in the nearby area. Through its network of research facilities, ARS can leverage its agency-wide knowledge and capabilities and serve the unique needs of a particular agro-ecosystem. In addition, ARS is a leader in the application of proper risk analysis methodologies to the control of invasive species.
10. Developing integrated systems for soil, water and waste management: ARS has long-standing, successful research programs for the development of integrated on-farm

systems designed to manage soil & water resources, recycle wastes and mitigate emissions.

11. Long-term, innovative, high-risk, high-impact research in utilization (biorefining): For over 50 years, ARS has been a world leader in the development of technologies for the "utilization" of agricultural products. ARS research has created out-of-the-box, cutting-edge, disruptive technologies that have changed markets and opened substantial opportunities for agricultural producers and converters.
12. Developing chemical and/or biochemical processes for making value-added products and co-products: ARS has unique R&D capabilities for developing innovative, integrated processes to fractionate, refine and convert agricultural materials into multiple, value-added products. Providing industry with technologies for converting a particular feedstock into multiple products helps minimize business risk. In the best case, all of the raw materials to a biorefinery would be converted into value-added products and the biorefinery would produce no waste streams (close-system biorefining).
13. Research capacity for rapid assistance to utilization (biorefining) industries: As the Nation transitions to a biobased economy, new business opportunities for biobased products (including fuels and co-products) require technology development resources, such as ARS's capabilities for utilization research. Because it has the capabilities and capacity to respond to industry's needs quickly, the Nation is better able to take advantage of market windows-of-opportunity for biobased products and hasten the Nation's transition toward a sustainable bioeconomy that is less dependent on foreign resources.
14. In-house pilot plant facilities: Each of the four ARS Regional Research Centers (Albany, CA; New Orleans, LA; Peoria, IL; Wyndmoor, PA) has pilot plant facilities for scaling-up biorefining technologies and skilled engineers to perform scale-up research. ARS also has three cotton ginning laboratories (Las Cruces, NM; Lubbock, TX; Stoneville, MS) where scale-up work for on-farm preprocessing could be done.
15. Strong relationships with stakeholders in agriculture: ARS has strong, long-standing relationships, including substantial goodwill, trust and cooperation, with traditional stakeholders in agriculture such as farmers, livestock producers, commodity groups, agricultural processors and the land grant universities.
16. Strong interdisciplinary and nationwide infrastructure: ARS performs research covering the entire continuum of technologies (from molecular biology, through agronomic practices, agricultural engineering, and quality assurance, to biorefining and product-prototype development) to solve problems in agriculture. The unique multi-disciplinary and national perspective ensures that ARS brings a "big-picture" approach and focuses on the highest-priority research. The network of ARS laboratories also provides the Nation with the research infrastructure necessary for identifying and developing optimal biomass feedstock varieties and production systems covering a broad range of geographic and climactic conditions. In particular, numerous accomplishments from the four Regional Research Centers provide examples of how ARS, by bringing together a great diversity of disciplines, many of which are not associated with traditional agricultural research, can create innovative and high-impact technologies in a timely manner. This gene-to-bioproduct capability, unencumbered by innovation barriers such as intellectual property rights restrictions which in the private sector impede and/or block the exchange of critical technical information between collaborators, means that ARS is uniquely capable of delivering to the Nation within a minimal timeframe, the multidisciplinary solutions needed to enable substantial growth in biobased industries and bioeconomies.

17. Strong relationships with the land-grant university and agricultural extension systems: Most ARS laboratories are co-located at land-grant universities, and many ARS scientists are adjunct professors. As a consequence, ARS has strong relationships with the entire land-grant university and agricultural extension systems. ARS research involves significant collaboration with university researchers and is substantially coordinated with related efforts at the Nation's academic institutions.
18. Proven ability to manage and coordinate multi-disciplinary technical development programs in agriculture: ARS has the critical mass of resources in all relevant technical fields to identify and pursue successful, systems-wide solutions that tackle the most critical technical barriers hindering growth of sustainable bioeconomies [see #13 above]. In addition, ARS has the requisite management savvy and infrastructure to coordinate and integrate its technical capabilities (including external partnerships) to ensure that its research efforts generate the greatest economic impact in the shortest possible timeframes.

By developing a strategy that leverages its relatively strong and unique capabilities, ARS provides unique and substantial contributions toward realizing its bioenergy Vision, Mission and Expected Outcomes.

Appendix B: **Technical Barriers**

A number of technical barriers hamper achievement of ARS bioenergy research Goals. Most of the technical barriers relevant to bioenergy are delineated below.

ARS possesses adequate (and in many cases – unique) capabilities to tackle technical barriers highlighted in green. To the extent possible, ARS leads Federal research efforts to overcome these particular barriers.

ARS possesses adequate (but not unique) capabilities to tackle technical barriers highlighted in yellow. Consequently, ARS research addresses these barriers, but only in partnership with stakeholders and customers associated with the entire value-added chain that collectively possess the resources to deploy the resulting technologies.

ARS does not possess adequate or unique resources to overcome technical barriers highlighted in orange. However, ARS coordinates its research with other domestic and international research institutions leading efforts to address these barriers.

I. Feedstock Development

- Inadequate information on feedstock traits that affect conversion efficiencies of biocatalytic- or thermochemical-based biorefineries
- Germplasm collections of current and potential energy crops have not been characterized for bioenergy traits
- Lack of large scale screening tools for phenotypic characterization of traits desirable in biorefinery feedstocks: Effective breeding programs require such screening tools.
- Lack of molecular breeding tools for potential energy crops: Such tools would greatly accelerate the effective use of untapped genetic diversity, particularly from novel and unadapted germplasm, to develop new and superior varieties.
- Constrained ability to breed optimal varieties for biorefining if genetic diversity in current commercial crops is limited
- Low photo-efficiency (yield of usable energy from sunlight) of photosynthesis relative to photovoltaic devices: Bioenergy is just one option for capturing solar energy and must compete with other technologies such as photovoltaics
- Identity of all genes involved in plant cell wall synthesis and structure are not yet known and there are extensive gaps in the our knowledge base about how these genes (and the metabolic pathways they influence) function
- Limited genomic and biotechnological methods to modify plant cell wall content in energy crops and crop residues to optimize saccharification and co-product development
- Lack of high-throughput cell wall assays to identify plant genetic resources, mutants, and breeding lines that advance new technologies
- Cultural and disciplinary barriers within the scientific community between those performing basic research in plant genetics and metabolic processes and plant breeders who need to apply this knowledge: ARS overcomes these barriers through cross-location research teams.

II. Feedstock Production

- Lack of validated, complete production systems for herbaceous energy crops: Long-term production systems for energy crops must be fully tested and validated in order to attract the significant investment capital needed to build biorefineries.
- Insufficient water availability in some geographical areas for cultivating energy crops: Some existing bioenergy crops such as corn have significant water requirements for economic yields. To the extent possible, plant breeding or innovative agronomic practices should be developed to increase yields and extend the potential acreage of energy crops that would otherwise be limited by water availability. Use of "grey" (wastewater or brackish) water in crop irrigation is another powerful solution to limited water availability.
- Soil types in some geographical areas are unsuitable for cultivating energy crops
- High energy requirements for cultivating some energy crops: Current agricultural practices and ethanol production processes use considerable quantities of fossil fuels. However, given AEI's goal of reducing U.S. dependency on non-renewable fuels, it is imperative that the U.S. reduce future use of fossil fuels in the production of bioenergy. It is critical that the Nation transition to feedstocks, production practices and biorefining processes that produce much more energy than they use. Feedstocks that require minimal energy input for production (e.g., soil tillage) are preferred.
- Substantial input requirements (e.g., fertilizer, biocides) for cultivating some energy crops: In order to maximize the economic viability of bioenergy, the Nation needs feedstocks and agronomic systems that minimize the levels of fertilizer and biocide inputs. Examples include leguminous energy crops such as soybean. In addition to improving production economics, minimizing inputs also:
  - ➢ minimizes the amount of non-renewable minerals, natural gas, etc. required for the production of such inputs
  - ➢ preserves soil and water quality
- Insufficient knowledge base to recommend optimal production practices so that natural resources (e.g., water and soil) can support sustained production of biorefinery feedstocks
- Lack of effective harvesting and handling (including transporting and storing) technologies for low bulk-density biobased feedstocks: Cost-effective storage systems for dedicated, cellulosic energy crops are needed to handle the seasonal variation in production. Systems for economically harvesting, transporting and storing crop residues do not exist.
- Lack of economic tools to assess commercial feasibility of producing biorefinery feedstocks
- Inability to model new agricultural and processing systems sufficiently to explore potential scenarios, conduct economic analyses of these systems, and develop decision-making tools for farmers, processors, and investors

III. Biorefining

- Relatively high resistance of plant cell walls to chemical and enzymatic hydrolysis imposes high conversion costs: Cell wall structure evolved over hundreds of millions of years to provide plants with mechanical strength and protect from infection and infestation. Cell wall recalcitrance is the most critical barrier to cellulosic ethanol and would benefit greatly from new, disruptive technologies.

- Dilute aqueous systems require high energy inputs for separation/recovery: Biocatalytic conversion processes involve dilute reaction solutions and so require the recovery and recycle of large volumes of solvent (water). The energy inputs associated with existing technologies for product recovery (i.e., distillation) are quite high and substantially reduce the energy efficiency of these processes.
- Cellulosic conversion technologies do not handle feeds of variable composition efficiently: In most agricultural regions, the source of ligno-cellulosic feedstocks will be mix of various woody and herbaceous materials. In order to be commercially viable, biorefineries must be effective at converting feeds of changing composition.
- Seasonal variability in feedstock volume and composition: Because of the high capital costs associated with ligno-cellulosic biorefineries, these facilities need to be operated year-around to minimize the cost of biorefining. However, the seasonal nature of harvesting crops does not easily provide for continuous feedstock supply. Biomass storage can alleviate the disparity between feedstock availability and consumption, but storage increases costs and will likely lead to composition changes that require operational changes at the biorefinery.
- Energy and process efficiencies of first-generation (starch-based) biorefining need improvement: Although grain-based ethanol is commercially successful, the energy efficiency of corn-based biorefineries is relatively low. And bacterial contamination of yeast fermentors is a problem in ethanol production. In addition, if a greater variety of grains could be converted into ethanol, overall agricultural productivity would increase.
- Lack of cost-effective biological production of hydrogen from lignocellulosic feedstocks: As a fuel, hydrogen offers unique environmental benefits as its combustion product is water. Although the feasibility of producing hydrogen from lignocellulosic materials via biological conversion has been demonstrated, the costs are much too high for commercial deployment.
- Lack of cost-effective, close-to the farm processes to fractionate or pretreat biomass materials prior to biorefining: Although economies-of-scale associated with biorefining processes favor large facilities, the high cost of transporting and storing low-density, highly-seasonal ligno-cellulosic biomass limits the size, too. Partial processing of biomass into value-added, higher-energy-density intermediates could reduce overall costs and provide producers with opportunities to capture more value.
- Lack of cost-effective, close-to the farm, thermochemical processes for biorefining of agricultural feedstocks to biopower or marketable, higher-energy-density (Kcal/kg) intermediates: Technologies for thermochemically converting cellulosic biomass, animal manures and other agricultural wastes into pyrolysis oil or syngas at-or-near the farm appear feasible. But these technologies require significant research to develop working prototypes that demonstrate realistic commercial potential.
- Lack of cost-effective thermochemical processes for small-scale production of liquid fuels: Processes for refining pyrolysis oils or reforming syngas are associated with strong economies-of-scale. Although research at the Pacific Northwest National Lab resulted in new technology that might enable production of liquid fuels from syngas, the technology is far from commercial viability.

- Lack of suitable catalysts for thermochemical conversion of feedstocks: Chemical catalysis could significantly improve and are frequently necessary for effective gasification gas-to-liquids-conversion or pyrolysis of agricultural feedstocks.
- Lack of commercially-viable quality-assurance methods for raw materials, intermediate products and/or products
- Lack of accurate techno-economic models for biorefineries: Non-biased, science-based cost and life-cycle analyses of biorefining processes are essential both to accurately predict the commercial viability of proposed technologies and to identify highly productive research. Also lacking are micro-economic models that consider the total costs (including externalities) associated with biorefining.
- Lack of public pilot plants for scaling-up biorefining technologies
- Quality, consistency and flowability issues limit market utility of co-products associated with first-generation biorefineries (i.e., distillers grains)
- Lack of commercially-viable, value-added co-products from biocatalytic conversion of ligno-cellulosics: The commercial viability of cellulosic biorefineries would be improved if they could produce value-added co-products from the lignin or hemicellulose fractions.
- Lack of commercially-viable, value-added co-products from thermochemical conversion of ligno-cellulosics: Byproducts such as char or ash could provide value to the converter and to farmers whose soils would benefit from added nutrients and/or amendments.
- Biodiesel production is limited by the lack of viable processes for converting feedstocks other than soybean oil: Technologies that enable the commercial conversion of alternative feedstocks are needed.
- Biodiesel is a relatively expensive fuel: More efficient and lower-cost processes for producing biodiesel are needed.
- Most biodiesel manufacturers lack sufficient technical resources to trouble shoot technology-based operational or product quality issues
- Biodiesel sometimes exhibits performance problems relative to petroleum-based diesel fuel: Cold-flow and oxidative stability are two properties for which biodiesel fuels can create problems and that limit biodiesel's utility as a fuel.
- Lack of commercially-viable quality-assurance methods for biodiesel production and distribution: Low-level contaminants in biodiesel fuels can create performance issues. Consequently, methods to ensure that biodiesel production processes produce high-quality fuels are needed.
- Lack of commercially-viable, value-added uses for the glycerol co-product from biodiesel production

Appendix C: Non-technical Considerations Guiding Bioenergy Research

In addition to leveraging its special competencies and capabilities for overcoming technical barriers, ARS bioenergy research is consistent with the following considerations.

- Public policy
  1. Focus on research priorities that are unlikely to receive adequate attention by the private sector or by other agencies in a timely fashion
     ARS focuses on pre-competitive, longer-term, high-risk research that is unlikely to be done within time frames that meet market opportunities by either the commercial sector or non-profit research institutions. ARS does not do research already underway in laboratories elsewhere unless ARS has unique capabilities applicable to such research.
  2. Focus on research priorities that hold the greatest potential for broad, sustainable economic impact
     As a Federal agency, ARS is a good steward of the public investment in its operations and assigns the highest priority to research yielding the most return from this investment. For instance, consistent with this consideration, ARS research assigns high priority to technologies associated with cellulosic ethanol because fuel ethanol is already a well-developed market and so market barriers to the deployment of these technologies are relatively low.
  3. Food/feed vs. fuel
     ARS emphasizes technologies that would likely minimize disruptions in existing markets for food, feed and fiber. For instance, consistent with this consideration, ARS research in bioenergy assigns high priority to the development, production and biorefining of ligno-cellulosic crop residues and low-input, herbaceous perennials produced on marginal lands.
  4. Focus on technologies that are most likely to strengthen rural economies
     ARS emphasizes bioenergy technologies that help farmers and rural America minimize economic risk and maximize economic returns. For instance, ARS emphasizes technologies that provide rural enterprises with:
     - multiple options for marketing their products
     - opportunities to add value to their products (at-or-close-to-the-farm)
     - products that can be used on farm to minimize dependency on foreign-sourced and/or non-renewable resources
     - the ability to be more energy self-sufficient, thereby minimizing volatility and maximizing local control over energy costs in rural enterprises and communities
  5. Maximize flexibility of biorefineries to utilize diverse feedstocks
     In order to realize widespread deployment of biorefineries throughout the Nation, conversion technologies should be able to utilize a wide range of biobased feedstocks. Such processes would give farmers the flexibility to plant energy crops that make the most economic sense. In addition, the ability to utilize a wide range of biobased feedstocks would better allow converters to utilize a combination of feedstocks available either on a continuous basis (e.g., municipal solid waste) or only in certain seasons (e.g., crop residues).
  6. Enable sustainability

ARS bioenergy research emphasizes technologies that will enable environmentally, economically and socially sustainable processes and systems.

7. Enhance/preserve natural resources
   For crop-based feedstocks, production and harvesting practices will be identified that ensure the long-term productivity of soil and water resources. Agronomic systems that reclaim and/or rehabilitate unproductive lands will also be identified. This is a critical need as the current practice for many crop residues such as corn stover is to retain them on the field. Similarly, many areas targeted for dedicated energy crops are on marginal soils such as CRP land. The REAP project (Renewable Energy Assessment Project) is one example of ARS investigations on the impact of bioenergy production on natural resources. In addition, thermochemical technologies can destroy pathogens or bioactive compounds in manures and produce chars that could ensure long-term sequestration of carbon or may increase soil fertility.
8. Manage risk of invasive species
   ARS bioenergy research is consistent with Federal and State regulations concerning invasive species. Executive Order 13112 is especially relevant to this issue. Although ARS is not precluded from working with species listed as "invasive," we are required to apply proper risk analysis methodologies to determine the potential benefits and harm both regarding such research and the potential applications of such work.
9. Plant biotechnology risk management
   Energy crop research at ARS follows USDA/EPA/FDA regulations for genetically engineered plants. For instance, ARS is developing male-sterile varieties of switchgrass to minimize potential gene flow in the field.

- General resource constraints
  1. In-house resource capacity constraints
     Although ARS is a productive and effective research institution, ARS is constrained by the limits of its existing capabilities. ARS strategy must realistically consider the resource capacity constraints that limit the number and type of barriers it can tackle effectively. Specific ARS resources will be directed to bioenergy research only if that decision is expected to generate more overall impact than if those same resources were allocated to other, high-priority issues or opportunities in agriculture. Assessment of in-house resource constraints must consider the relative strengths and weaknesses of ARS capabilities versus those of other research institutions that could do the same work.
  2. Leverage ARS Capabilities
     ARS focuses on research that utilizes existing and, in particular, the unique capabilities ARS possesses. In addition, ARS assigns the bulk of its resources on those technical barriers that will generate the greatest impact if they are overcome.
  3. Partner and collaborate to access additional resources inside and outside ARS
     In order both to minimize the timeline to develop and deploy new, enabling technologies and to provide the best return for taxpayers' investment, ARS research will take advantage of every opportunity to leverage research capabilities either inside or outside ARS. The Nation cannot afford duplicative efforts, and the duplication of existing resources should be avoided whenever possible.

- Relevant industrial practices and trends

1. Existing infrastructure for grain collection/storage/transportation may not accommodate grain varieties optimized for bioenergy production
Elevators, hopper cars, trailers and quality control practices used in distributing grain in the U.S. serve primarily the food and feed markets. Some varieties of grain optimized for the production of bioenergy and co-products may also have suboptimal or even unacceptable properties for existing grain users in the food industry. In such circumstances, the risk that such bioenergy-optimized varieties could contaminate traditional food-optimized grains may inhibit the adoption of these biorefining varieties in the marketplace. Although procedures might be implemented to segregate bioenergy-varieties from food-varieties, grain elevator operators may refuse to handle biorefining varieties if segregation cannot be guaranteed and contamination events could create problems in food applications.
2. Industry prefers products that have existing markets or new products with low commercial barriers
Because ARS develops technologies that will be deployed by industry, the primary targets for ARS research in bioenergy are fuels and co-products that already have existing markets that can accommodate substantial growth. Further, ARS research for enabling new products should have strong support from stakeholders that can overcome the market barriers associated with these new products.
3. Many biodiesel converters lack access to technical support
Many biodiesel biorefiners are relatively small-scale operations that do not have in-house expertise to solve their technical problems. For these operators, access to highly competent technical expertise can make the difference between being profitable or shutting down operations. ARS has extremely experienced and knowledgeable scientists/engineers who provide such technical support not otherwise available.
4. Identifying stakeholders that are willing and able to utilize ARS-developed technology
With the exception of the biodiesel industry (see above), technology management as practiced by companies in the chemical, material and fuels industries is quite different from technology management practices in traditional agricultural and food sectors. In the chemical/materials/fuels industry, intellectual property rights (IPR) are highly valued assets that confer strong competitive advantages to owners. In general, companies in this industry are reluctant to work with public research institutions because of their strong business preference for control of IPR. This reluctance is compounded by much of the industry’s unfamiliarity and generally weak relationships with USDA and ARS. As a consequence, biorefiners’ definition of “precompetitive” research leans more in the direction of basic, fundamental science than is typical for many programs in ARS. In addition, significant market barriers to the deployment of new technology in the biorefining industry (such as equipment development costs, product development costs, and high economies-of-scale/capital intensity associated with cellulosic biorefineries) mean that ARS must have partners that possess adequate business resources to overcome these market barriers. Companies with such resources are often, but not always, large multinational corporations for which IPR ownership is especially valuable. The conditions required to deploy ARS-developed biorefining technologies require that ARS research pay special attention to identifying strong commercial partners that collectively possess the resources and the desire to deploy ARS-developed biorefining technologies.

Appendix D: Technology Transfer Action Plan

This section of the Action Plan presents component-specific action plans for transferring the technologies resulting from ARS bioenergy research.

Component 1: **Feedstock Development**

Strategies for effective technology transfer are guided with input from the National Program Staff, the Office of Technology Transfer (OTT), line management, and in cases where protection of new germplasm is desired, the ARS Plant Variety Intellectual Property Committee (PVIP). Improved germplasm lines that do not meet the criteria of a new distinct variety or cultivar are publicly released as breeding materials. New varieties (with or without PVP-protection) may also be publicly released unless seeking a Plant Variety Protection Certificate (PVP) or a Plant Patent will enhance technology transfer. This decision is made by the PVIP. This committee also recommends to OTT if obtaining a PVP is recommended only for seed certification purposes or if protection and either non-exclusive or exclusive licensing is in the best interests of technology transfer. Regardless of the mechanism used to transfer new plant materials, ARS policy is that all new plant materials will be made widely available to the research community for research and breeding purposes. Considerations in selecting the most appropriate technology transfer approach include:

- optimum transfer and use of the research results, needs of stakeholders and customers
- accepted standards for releasing cultivars of specific crops;
- priorities and polices of joint owners (if any), depth and strength of “market pull” for the particular crop;
- need to segregate the crop during production and processing;
- any requirements for regulatory approval;
- need for special marketing a delivery systems; and
- need to create an incentive for growers and industry to develop a new crop.

Component 2: **Feedstock Production**

ARS research in feedstock production must have customer support from producer groups (e.g., farmers or ranchers) and/or relevant government agencies. Further, ARS potential intellectual property and know-how for feedstock production is managed in ways that maximize ARS impact and ARS’ ability to track this impact. New cultural practices for farming systems are generally transferred through publication, including publication on websites, traditional extension practices, ARS’ new Natural Resources Alert System, and other approaches that transfer results to growers with as little transaction cost as possible. For models and software-based decision systems, the most effective means of technology transfer is chosen on a case-by–case basis. There may be opportunities in this area for significant partnerships with academic institutions and others who may take on the responsibility for distribution and maintenance and quality control of computer-based information.

Component 3: **Biorefining**

Due to both

1. relatively large investments in biorefining research at other USG agencies (especially DOE), universities and private sector companies and
2. trends and practices in biorefining industries (see point #3 of "Relevant industry practices and trends" in Appendix C of the Bioenergy Strategy document),

ARS must coordinate its biorefining research through partnerships with both the private sector and other Federal agencies. In order to be effective, technology transfer must consider involvement of customers and stakeholders from the entire value-added chain, thereby accessing all the resources needed to overcome the major technical and business barriers hindering deployment of ARS technologies. ARS partners have much to gain from tapping into ARS expertise in feedstock development and sustainable agricultural production systems, the backbone to any conversion business strategy.

Early feedback from potential cooperators and stakeholders regarding specific biorefining research helps to gauge the potential impact of the research and to pinpoint worthwhile targets for further research. OTT (ARS Office of Technology Transfer) can offer significant value towards achieving ARS goals in biorefining research by helping researchers forge complementary, win-win partnerships early on in the research process.

Through Cooperative Research and Development Agreements (CRADAs), patents, and licensing agreements, ARS creates incentives for the private sector to invest in the development and commercialization of ARS research. These tools help to ensure that ARS-developed technologies are broadly disseminated and generate the greatest possible benefits for U.S customers and stakeholders in the new bio-economy.

Each PPO (project plan outline) must describe the technology transfer plan for the project. At a minimum, this description must identify…

1. likely research outputs/technologies to be transferred
2. potential markets for the technologies that the research will enable
3. collaborators or partners required to do the research
4. planned mechanisms for transferring the results/technologies
5. projected customers/users of the results/technology

In addition, Lead Scientists involved in biorefining researchers must obtain, through their Technology Transfer Coordinator and as early as possible in the research process, feedback from cooperators or partners on the estimated value of technologies expected to result from the research.

Appendix E: Action Plan for Program Coordination

To coordinate bioenergy research across the three components and throughout the Agency, ARS uses a leadership framework wherein separate **Leadership Teams** (associated with four relatively independent, feedstock-to-bioenergy, value-added chains) are responsible for cross-component coordination. Each cross-component Leadership Team allocates ARS resources between the three components so as to generate the greatest impact in the shortest time. These cross-component Teams take full advantage of ARS' unique capacity to perform highly integrated research from world-class research capabilities at ARS in all aspects of bioenergy production. In addition to affecting cross-component collaboration between ARS laboratories, the Leadership Teams also ensure that ARS bioenergy research is closely aligned with companion efforts in other Federal agencies and in the private sector.

ARS may change the number and focus the Leadership Teams in response to changes in ARS priorities for bioenergy research. The initial cross-component Leadership Teams are as follows:

- Lipids to fuels
- Starches & sugars to ethanol and butanol
- Cellulosics to ethanol and butanol
- Thermochemical processing of cellulosics and animal wastes

The Leadership Team framework is represented in Table 1; the four initial Teams make up the rows in the table and the three Components are the table columns. Table 2 identifies the National Program Staff (NPS) members on each Leadership Team.

The ARS Bioenergy Leadership Team accomplishes coordination of the cross-component teams as a single, integrated program. The Bioenergy Leadership Team allocates ARS resources between the cross-component efforts in a manner consistent with the relevant non-technical considerations. This Leadership Team also ensures that the overall priorities for ARS bioenergy research program are properly aligned with USDA bioenergy objectives and are complimentary to priorities of other Federal agencies. Overall coordination ensures that ARS takes full advantage of new opportunities, reacts quickly to technological or market changes, and maximizes the overall impact of its bioenergy research. Initial membership of the ARS Bioenergy Leadership Team consists of the following:

- Lead NPL, Feedstock Development
- Lead NPL, Feedstock Production
- Lead NPL, Forages (NP215)
- Lead NPL, Biorefining

Table 1
Leadership Team Framework for ARS Bioenergy Research

	Feedstock Development	Feedstock Production	Biorefining
Lipids to Fuels			
Starches & Sugars to EtOH/BuOH			
Cellulosics to EtOH/BuOH			
Thermochemical Processing			

Table 2
NPS Members on Leadership Teams

- *Lipids to Fuels:*
    - Oilseed NPL
    - Lead NPL, Feedstock Development
    - Lead NPL, Feedstock Production
    - Lead NPL, Biorefining

- *Starches & Sugars to EtOH/BuOH:*
    - Sugar Cane NPL
    - Water Quality NPL
    - Animal Production NPL
    - Lead NPL, Feedstock Development
    - Lead NPL, Feedstock Production
    - Lead NPL, Biorefining

- *Cellulosics to EtOH/BuOH:*
    - Forges NPL
    - Soil & Air NPL
    - Water Quality NPL
    - Lead NPL, Feedstock Development
    - Lead NPL, Feedstock Production
    - Lead NPL, Biorefining

- *Thermochemical Processing:*
    - Forges NPL
    - Soil & Air NPL
    - Manure and Waste Utilization NPL
    - Water Quality NPL
    - Lead NPL, Feedstock Development
    - Lead NPL, Feedstock Production
    - Lead NPL, Biorefining