



Biorefining National Program

5-Year Action Plan

2014-2019



How This Action Plan Was Developed

The goal of the Agricultural Research Service (ARS) Biorefining National Program (NP 213) is to conduct research that enables new, commercially-viable technologies for the conversion of agricultural materials into fuels, value-added co-products, and biobased products. To achieve this goal, this Action Plan was designed to meet the following criteria:

1. Maximize the long-term economic impact of ARS biorefining research
2. Emphasize ARS' unique capabilities and avoid overlap with research at other institutions
3. Maximize returns to agricultural stakeholders from ARS investment of public funds

By developing commercially viable technologies for the production of biobased industrial products, ARS biorefining research increases the demand for agricultural products and therefore benefits both agricultural producers and rural communities.

According to the U.S. Department of Energy's (DOE's) Energy Information Administration (EIA), U.S. demand for gasoline is forecasted to drop over the next 10 years; this drop will reduce demand for blendstock ethanol, which is roughly 10 percent of the gasoline demand (Figure 1). The 10 percent "blend wall" is a result of government regulations and limitations imposed by the Nation's gasoline distribution infrastructure, and although demand for E85 and E15 will rise, those volumes are relatively low. As a consequence, industry production capacity is expected to exceed demand for fuel ethanol sometime in the 2013-2014 time frame.

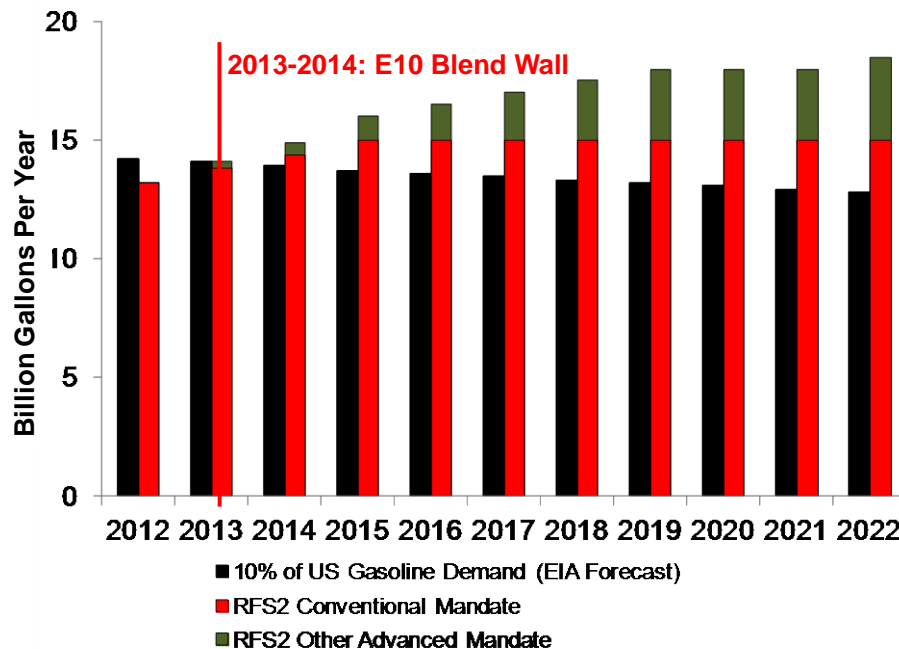


Figure 1. Forecasted demand for ethanol blendstock vs. RFS2 targets

Chart courtesy of Dr. Byron G. Johnson, Phillips 66

Consistent with the first criterion, ARS will target research that could help biorefiners diversify their product mix and therefore offset the anticipated drop in ethanol demand. In the recent past, biorefiners have endured narrow margins and lower profitability. Some grain-ethanol and biodiesel producers have had to shut down operations for lack of sufficient revenue to cover variable costs. Reduced corn production resulting from drought conditions in 2011 and 2012 drove up prices for feedstock grain, and higher prices for fuel ethanol are not possible given stable petroleum prices. Similarly, the availability of low-cost methane from shale gas has significantly reduced margins for biogas producers. Existing biorefiners would greatly benefit from expanding their options for processible feedstocks beyond just corn and soybean oil, to other readily available, lower-cost materials, such as lignocellulosics. Although biodiesel is not limited by infrastructure-imposed blending restrictions, current U.S. production volumes for biodiesel, about 1 billion gallons/year, is less than half the existing capacity. Again, high prices for feedstock material (soybean oil in this case) and stable petroleum prices are squeezing margins for biodiesel producers.

The second criterion relates to ARS' uniquely broad capacities in all aspects of biofuels research (feedstock development, sustainable feedstock production systems and biorefining), and to ARS' unique relationship with the Nation's existing biofuels industry (corn ethanol and biodiesel). Because of both ARS' broad in-house research capacities, including world-class collections of plant germplasm and microorganisms, and its lack of internal barriers to the exchange of ideas (intellectual property), ARS can quickly and efficiently deliver benefits to industry and agriculture.

To ensure that ARS research leverages its unique competencies, ARS does not plan to conduct research in fields dominated by other institutions. For example, ARS will not target biorefining research in algal-based biofuels, an area of focus in DOE, Department of Defense (DoD), and private enterprise, or in microbial fuel cells, a field heavily supported by DoD. Other excluded areas include large-scale gasification-based technologies, which DOE and private companies have earnestly pursued, and very capital-intensive green-field Generation II or Generation III biorefineries, another former focus of DOE.

In support of the third criterion, ARS has unique and substantial resources to foster and nurture collaborative research with industry partners; and ARS manages its intellectual property to maximize the economic returns to the **public** from its research, and to benefit the U.S. economy, as quickly as possible.

An important resource available to biorefining researchers at ARS is the USDA Regional Biomass Research Centers that focus in-house USDA research capabilities to expand regional bioenergy production systems. Each Center coordinates ARS resources associated with a number of ARS National Programs and recruits the best public and/or private research and technical partners to conduct research that will enable complete regionally-appropriate field-to-biofuels systems. ARS biorefining research that involves collaboration with USDA Regional Biomass Research Centers is of high priority.

In applying the criteria to the development of this Action Plan, ARS concluded that further research to increase ethanol production capacities would have little impact on the Nation's renewable energy goals at

this time. In contrast, ARS biorefining research to enable the production of advanced biofuels compatible with the Nation's existing fuel-distribution infrastructure is of high priority.

ARS conducts biorefining research to enable technologies that improve profitability, reduce risks, increase the value of co-products and biobased products, and expand the options available to existing biorefiners for generating revenue. Collaborations with existing biorefiners are critical to ensure that ARS conducts research that benefits industry. And given its limited resources for biorefining research, ARS must focus its biorefining research on a relatively limited number of promising biorefining technologies. ARS has been a long-time leader in research on biochemical conversion of agricultural materials into biobased products. ARS also leads Federal government research to benefit biodiesel producers, which make up the bulk of lipid-based biorefiners. Furthermore, ARS has significant research experience and capabilities in pyrolysis, a technology that can produce advanced biofuels compatible with the Nation's existing fuel-distribution infrastructure and could be deployed at or near the farm.

Consequently, this Action Plan has three Components, each of which focuses ARS strengths:

- Biochemical conversion
- Biodiesel
- Pyrolysis

Component 1. Biochemical Conversion

Under Component 1, ARS will conduct research of potential benefit to biorefiners that utilize biochemical conversion technologies.

Processes for the biochemical conversion of agricultural materials typically involve the following process steps:

- Feedstock fractionation;
- Production of fermentable sugars;
- Biocatalytic and/or chemical conversion; and
- recovery and purification of advanced biofuels, biobased chemicals, and/or co-products.

Major advantages of biochemical conversion, which involves the use of enzymatic and/or microbial biocatalysts, are its relative simplicity and its relative environmental friendliness.

Biochemical conversion is the basis for most all existing bioethanol production, which utilizes either sugarcane (Brazil) or corn (United States) feedstocks. Processes that use sugar-based feedstocks, such as sugar cane or sweet sorghum, are relatively simple – the sugar juice is extracted from the plant and fermented directly. Processes that use grains, such as corn, require the enzymatic hydrolysis of the starch into simple sugars before microbial conversion and typically involve pre-hydrolysis fractionation of the grain to produce marketable co-products.

Biological conversion of cellulosic biomass is a three-step process: (1) pretreatment; (2) enzymatic saccharification of plant fiber (cellulose and/or hemicelluloses) into simple sugars; and (3) biocatalytic and/or chemical conversion of the sugars to desired products. Pretreatment separates cellulose, and possibly hemicellulose, from the lignin, making both polysaccharides accessible to hydrolysis enzymes.

Three Problem Statements are associated with Component 1:

1. [Technologies for producing advanced biofuels or other marketable products.](#)
2. [Technologies that reduce risks and increase profitability in existing industrial biorefineries.](#)
3. [Accurately estimate the economic value of biochemical conversion technologies.](#)

Problem Statement 1. Technologies for producing advanced biofuels or other marketable biobased products.

This Problem Statement focuses on research that can enable biorefineries for biocatalytically converting sugar/starch-based feedstocks (such as non-corn grains, sweet sorghum, sugar cane, or sugar beets) or plant-derived fiber (such as grain fiber, stover, straw, or bagasse) into gasoline- or diesel-compatible substitutes for fossil-based fuels or other marketable products. These feedstocks may include food-processing wastes or agricultural residues, as well as energy crops.

The current biofuels industry is dominated by corn ethanol. But current limits on both the amount of ethanol that can be practically blended with gasoline and the amounts that can be economically produced from corn are significant barriers to further growth in the Nation's biofuels industry. The forecasted decrease in demand for gasoline, coupled with the overbuilding of grain ethanol production capacity, has muted the need for research to increase production of fuel ethanol.

In contrast, there is a strong need for marketable biofuels that can directly replace fossil-derived liquid transportation fuels. Such advanced biofuels, as well as other products and/or co-products from the biorefineries that produce them, will help maintain the economic viability of existing biorefineries and enable growth of the biorefining industry. Examples of high-value products and co-products include chemicals (>C2 alcohols, ketones, aldehydes, carboxylic acids, and aromatics), proteins and peptides, sugar alcohols (xylitol, sorbitol and mannitol), biopolymers (dextran, alternan, pullulan, schizophyllan, polygallic acid, functional hemicellulose and cellulose derivatives), and livestock feeds. Technical challenges to commercialization of these products include:

- Identification and demonstration of viable routes to new products
- Low efficiency of existing pretreatment and hydrolysis (enzyme) technologies
- Limited number of microorganisms that fully utilize all sugars/proteins for the fermentative conversion of agricultural materials to advanced biofuels and chemicals

Biorefineries that process a variety of feedstocks enjoy a significant competitive advantage. However, most biocatalytic-based biorefineries are relatively inflexible regarding feedstock choice. Consequently, research to help make biocatalytic-based biorefining processes more feedstock-flexible could generate significant impact.

Further, to increase the likelihood that industry will adopt technologies enabled by ARS research addressing Problem Statement 1, close coordination is required between ARS researchers and product/co-product users. ARS research to develop products or co-products for animal feed applications will also likely require collaboration with ARS animal nutrition laboratories and may also benefit from collaboration with ARS feedstock development researchers.

ARS research addressing Problem Statement 1 will not focus on biogas (i.e., methane). The technology for biogas production is relatively mature, and technologies for producing biogas would most likely be used overseas, where the biogas industry is much more prevalent.

Research Needs

- New commercially viable technologies for fractionating agricultural materials and/or food-process wastes into products for direct sale or for further processing into marketable products. Examples include
 - Sugars and syrups
 - Lipids and lipid components
 - Hemicellulose
 - Proteins
 - Gums and pectins
 - Lignin
- New commercially viable processes for depolymerizing cellulose and hemicellulose to fermentable sugars
- New commercially viable biocatalytic-based processes for the production of advanced biofuels and/or biobased chemicals
- Commercially viable hybrid (biocatalytic and/or chemical) processes to convert sugars, oligosaccharides, non-food proteins, and/or lignin to advanced fuels and/or biobased chemicals

Anticipated Product

- Biocatalytic, chemical or hybrid (biocatalytic and chemical) technologies that are used by industry for the production of advanced biofuels, biobased products, and/or co-products

Potential Benefits (Outcomes)

- Expanded markets for biofuels and biobased products
- Increased demand for agricultural products

Problem Statement 2. Technologies that reduce risks and increase profitability in existing industrial biorefineries.

First generation biorefineries are subject to large swings in profitability due to volatility in feedstock cost and selling price of product biofuel. Although modern biorefineries are very efficient, improvements in operational robustness and efficiencies could have significant impact on economic viability. In addition, retooling ethanol facilities to produce advanced biofuels and other marketable co-products, or to increase the value of existing products from grain feedstocks will decrease business risk and increase long-term profitability of these biorefineries.

Efforts addressing Problem Statement 2 must involve collaborations with industrial biorefiners or receive external funding support as early as possible in the research.

Research Needs

- Commercially viable technologies for increasing process efficiencies or reduce the incidence of operating disruptions in existing biorefineries
- Commercially viable technologies that enhance the feedstock-flexibility of existing biorefineries
- Commercially viable technologies for the production of biofuels and other marketable products from food processing wastes
- Commercially viable technologies that increase the number of marketable products produced in existing biorefineries
- Commercially viable technologies for converting ethanol into advanced biofuels or biobased chemicals
- Commercially viable technologies that enhance the value of existing byproduct streams

Anticipated Products

- New ARS-enabled technologies that are used by existing biorefiners to reduce their business risks and increase profitability
- New ARS-enabled technologies that are used by industrial buyers of co-products from existing biorefiners

Potential Benefits (Outcomes)

- An economically healthy biorefining industry
- Stable demand for agricultural products to supply feedstocks for the ethanol production industry

Problem Statement 3. Accurately estimate the economic value of biochemical conversion technologies.

The viability and sustainability of a commercial process is a function of its economic competitiveness. In turn, the potential impact of a new biorefining technology is a function of its anticipated effect on the production economics for a commercial biorefinery. By knowing the major cost components for a process technology, ARS researchers can focus their efforts so as to yield the most impact. Therefore, technoeconomic analyses will be conducted to accurately estimate the expected economic impact of ARS biorefining research.

Research Need

- Accurate estimates of the effect of new technologies on capital and operational costs in commercial biochemical conversion facilities

Anticipated Products

- Capital and operating cost models for new biocatalytic- and hybrid-based biorefining technologies
- Research that maximizes the impact of public funding is identified for biochemical conversion technologies

Potential Benefits (Outcomes)

- Increased commercial deployment of new biorefining technologies.

Component Resources

Research under Component 1 is conducted by the following ARS scientists:

Location	Researchers
Wyndmoor	Johnston, McAloon, Moreau, Nghiem, Yadav, Hicks
Peoria	Cotta, Bischoff, Dien, Saha, Slininger
Albany	Holtman, Lee, Orts, Offeman, Wagschal, Wong, Wood
New Orleans	Eggleston

Component 2. Biodiesel

Biodiesel fuel has captured a 1 billion gallon/year market for blending in the diesel fuel pool in the United States. Chemically, biodiesel consists of esters of fatty acids, from vegetable oils and animal fats, with simple alcohols, principally methanol, via relatively simple reactions (esterification and transesterification). Although about half of the biodiesel produced in the United States is derived from soybean oil, biodiesel is also produced from other common oils and fats available in the market today. Because virtually all of these feedstocks for biodiesel production are byproducts of vegetable- and animal-protein production, biodiesel has an extremely positive life cycle carbon reduction compared with that of fossil fuels. In addition, most biodiesel production is conducted in moderately-sized facilities in rural communities.

Now that biodiesel has been approved by the U.S. Environmental Protection Agency as an advanced biofuel under the Renewable Fuels Standard (RFS2), its market is anticipated to grow to 4 billion gallons, more than 10 percent of the on-road diesel pool, by 2022. In the face of this growing demand, new biodiesel feedstock will need to be developed, and more demanding expectations for diesel engine performance (e.g., higher engine temperatures/pressures, greater fuel economy, and lower emissions) will require higher-quality fuels.

Three Problem Statements are associated with Component 2:

1. [Improve biodiesel's engine performance.](#)
2. [Technologies that reduce risks and increase profitability in existing industrial biorefineries for converting lipids.](#)
3. [Accurately estimate the economic value of technologies for converting lipids.](#)

Problem Statement 1. Improve biodiesel's engine performance.

The formation in biodiesel of filter-blocking solids at temperatures below 40° C can restrict flow of fuel to an engine. As a result, many northern States relax or rescind biodiesel-use mandates during winter months. In addition, biodiesel's negative effect on a fuel's cold-flow performance limits general adoption of biodiesel to blend levels of 5–10 percent in petroleum diesel (B5–B10).

Solids associated with this poor cold-flow performance may be (1) contaminants originating in the feedstock, (2) persistent intermediates of biodiesel production, (3) crystallized fatty acid methyl esters, or (4) some combination of these factors. Current technologies for improving biodiesel's cold-flow performance are either ineffective or prohibitively expensive.

Research Needs:

- Commercially viable processes to modify fatty acid alkyl ester structures in biodiesel to improve its low temperature operability

- New commercially viable technologies to significantly lower the crystallization temperature of biodiesel by reducing the levels of contaminants (e.g., sterol glucoside) and/or persistent intermediates (e.g., saturated monoglycerides)

Anticipated Product

- Technologies deployed by industry to significantly improve cold-flow performance of biodiesel fuels

Potential Benefits (Outcomes)

- An economically healthy biodiesel production industry
- Stable demand for agricultural products to supply feedstocks for biodiesel production

Problem Statement 2. Technologies that reduce risks and increase profitability in existing industrial biorefineries for converting lipids.

Biodiesel producers are subject to large swings in profitability due to volatility in feedstock cost and selling price of biodiesel. Although modern biodiesel production facilities are very efficient, improvements in operational robustness and efficiencies could have a significant effect on economic viability. Improvements in such areas as feedstock preparation and catalyst choice could simplify process technologies, reduce waste streams, and improve economics.

Furthermore, the oxidative and hydrolytic stability of biodiesel is also relatively poor relative with petroleum-based diesel fuel. The current biodiesel specifications are set for a 6-month storage life, which is too short to support the market growth now targeted.

In addition, retooling biodiesel facilities to produce other marketable co-products from lipid feedstocks will decrease business risk and increase long-term profitability of these biorefineries. For example, hybrid molecules produced by combining components from pyrolysis oil with fatty acids/esters may be marketable chemicals. Glycerol is an existing co-product from biodiesel production (10 wt. percent) whose traditional markets have been overwhelmed even by the current biodiesel industry; the current glycerol supply glut will only be exacerbated as biodiesel production increases.

Efforts addressing Problem Statement 2 must involve collaborations with industrial biorefiners or receive external funding support as early as possible in the research.

Research Needs

- Commercially-viable technologies for expanding the feedstock-flexibility of existing biodiesel production facilities
- Commercially-viable technologies for increasing the number of marketable products produced in existing biodiesel facilities
- Commercially-viable technologies to enhance the value of existing byproduct streams

Anticipated Products

- Technologies that are used by industrial biodiesel producers to reduce risks and increase profitability
- Commercially-viable technologies for manufacturing new products or co-products at biodiesel facilities

Potential Benefits (Outcomes)

- An economically healthy biodiesel industry on-track for providing 4 billion gallons of biodiesel by 2022
- Stable demand for agricultural products to supply feedstocks for biodiesel production

Problem Statement 3. Accurately estimate the economic value of technologies for converting lipids.

The viability and sustainability of a commercial process is a function of its economic competitiveness. In turn, the potential impact of a new biorefining technology is a function of its anticipated effect on the production economics for a commercial biorefinery. By knowing the major cost components for a process technology, ARS researchers can focus their efforts to yield the most impact. Therefore, techno-economic analyses will be conducted to accurately estimate the expected economic impact of ARS biorefining research.

Research Need

- Accurate estimates of the effect of new technologies on capital and operational costs in commercial facilities for the conversion of lipid-based feedstocks

Anticipated Products

- Capital and operating cost models for biorefineries that convert lipids
- Research that maximizes the impact of public funding is identified for lipid-conversion technologies

Potential Benefits (Outcomes)

- Increased commercial deployment of new biorefining technologies

Component Resources

Research under Component 2 is conducted by the following ARS scientists:

Location

Wyndmoor

Researchers

Haas, McAloon, Ngo, Wyatt, Zerkowski

Component 3. Pyrolysis (Thermolysis)

Thermolysis or thermochemical conversion of biomass comprises 1) pyrolysis, heating in the absence of oxygen; 2) gasification, heating under partial oxygen conditions; and 3) combustion, heating under excess oxygen. The advantages of thermochemical-based biorefining include the ability to process a wide range of feedstocks (e.g., agricultural residues, crop residues, energy crops, manure, and even agricultural plastics) and a relatively high throughput rate for a biorefining process. Pyrolysis offers a unique potential to directly produce hydrocarbon fuel intermediates (i.e., refinery fuel blendstocks) that can potentially enter existing petroleum refinery flow streams without creating a whole new refinery system. In fact, the only commercial biorefineries that produce drop-in hydrocarbon fuels are pyrolysis-based (KiOR and Diamond Green Diesel). Among the thermochemical conversion routes, pyrolysis is the only one that has the full potential to provide small footprint technologies that can accommodate at- or near-farm production of liquid fuel intermediates and chemicals from biomass. Distributed, village-scale pyrolysis has been suggested by industry groups, finance communities, and some philanthropists as a viable tool for strengthening rural economies. Near- or on-farm pyrolysis has the potential to play a major role in helping the United States meet renewable fuel standard (RSF2) goals. Research is needed at both fundamental and applied levels to establish pyrolysis as a viable process for the conversion of biomass to hydrocarbon fuels and chemicals at farm scale.

Two Problem Statements are associated with Component 3:

1. [Pyrolysis processes to produce marketable bio-oils.](#)
2. [Accurately estimate the economic value of pyrolysis-based conversion technologies.](#)

Problem Statement 1. Pyrolysis processes to produce marketable bio-oils.

While fast pyrolysis is a highly efficient method of liquefying and densifying biomass into more easily transportable bio-oil, there are well-documented problems such as corrosiveness and instability, associated with bio-oil produced via thermal-only processing. These problems are associated with high levels of oxygenated components. Research is needed to economically produce bio-oil with reduced oxygen content so that it can be a marketable intermediate for renewable drop-in fuels in transportation, stationary engines, and boilers.

Research is also needed to improve pyrolysis-based conversion technologies to enable the commercial at- or near-farm production of stable (low oxygen) bio-oil for subsequent generation of heat, power, and marketable liquid fuels.

Catalysts may be used in either the initial solid and liquid phase (in situ) reactions or subsequent vapor phase (ex situ) reactions of pyrolysis to lower levels of oxygenated compounds in the product bio-oil. Current technical barriers to catalytic pyrolysis include loss of carbon due to coke formation, catalyst fouling/deactivation, and lack of requisite robustness for near- or on-farm applications.

Although catalysts can reduce the oxygen content of the liquid product, cost penalties are associated with their use, such as cost of the catalyst, catalyst fouling and deactivation, and process complexity associated

with catalyst recycling and regeneration. Noncatalytic pyrolysis processes that produce low-oxygen bio-oil and that are less expensive and less complex than a catalytic process, will be more suitable for near- or on-farm deployment.

In addition, research is needed to identify components in bio-oils that hinder upgrading and negatively affect the quality of upgraded products. Cost-effective processes for removing or neutralizing the negative effects of these components must be developed.

Furthermore, the physicochemical and thermodynamic characteristics, including those affected by handling, harvest logistics and storage, of a particular feedstock significantly affects conversion efficiency and product quality. For example, certain minerals in feedstocks can catalyze pyrolysis reactions and thereby affect product distributions and overall yield. In turn, harvest and storage times of feedstocks can affect feedstock compositions. Basic understanding of how feedstock characteristics affect the performance of pyrolysis-based processes is lacking. In addition, rapid analytical methods to quantify feedstock characteristics which significantly impact end-product quality and process performance are lacking.

A variety of options can be used for harvesting, storing, and preprocessing (drying, size-reduction, etc.) biomass feedstocks before near- or on-farm pyrolytic conversion. In turn, the choice of feedstock and handling/preprocessing options will affect both the efficiency of pyrolysis processing and the quality of the resulting bio-oil and co-products. Studies indicate that certain co-reactants, such as agricultural plastics, can enhance pyrolysis performance. Research is needed to identify feedstocks, blends of feedstocks, and feedstock handling practices that improve bio-oil quality, don't poison catalysts, and enable high product yield.

Lastly, because of the relatively low value of fuel products and the high volatility in fuel prices, biorefineries that produce high-value coproducts such as chemicals will be more economically resilient and profitable. In contrast, a biorefinery or proposed biorefinery that produces only biofuel is less likely to attract investment capital. Research is needed to develop marketable co-products from pyrolysis-based biorefining. Potential co-products include chemical precursors (e.g. levoglucosan, pyrolytic lignin), chemical end-products, and biochar-based products. Industrial collaborators are needed to identify marketable co-products.

Research Needs

- Commercially viable process systems, feedstock or co-reactants, feedstock collection/storage practices, feedstock preprocessing methodologies (e.g., chopping, drying, densifying, torrefying, charring), or catalysts that enable the commercial production of marketable, partially-deoxygenated bio-oils
- Commercially viable process systems, feedstock or co-reactants, feedstock collection/storage practices, feedstock preprocessing methodologies (e.g., chopping, drying, densifying, torrefying, charring), or catalysts that enable the commercial production of marketable co-products

- Commercially viable process systems, feedstock or co-reactants, feedstock collection/storage practices, feedstock preprocessing methodologies (e.g., chopped, dried, densified, torrefied, charred), or catalysts that enable commercially viable near- or on-farm conversion systems

Anticipated Products

- Pyrolysis-based technologies that are used by industrial biorefineries for producing marketable advanced biofuels and/or fuel intermediates
- Identification of desirable feedstock traits and feedstock handling/preprocessing/blending practices that are adopted by biorefiners, feedstock producers or plant breeders to enhance pyrolysis processing performance

Potential Benefits (Outcomes)

- Expanded markets for biomass-derived, pyrolysis-based biofuels and biobased products
- Attractive economic returns for farmers and rural communities from near- or on-farm bio-oil production
- Increased demand for biomass-based agricultural products

Problem Statement 2. *Accurately estimate the economic value of pyrolysis-based conversion technologies.*

The viability and sustainability of a commercial process is a function of its economic competitiveness. In turn, the potential impact of a new biorefining technology is a function of its anticipated effect on the production economics for a commercial biorefinery. By knowing the major cost components for a process technology, ARS researchers can focus their efforts so as to yield the most impact. Therefore, technoeconomic analyses will be conducted to accurately estimate the expected economic impact of ARS biorefining research.

Research Need

- Accurate estimates of the effect of new technologies on capital and operational costs in commercial pyrolysis-based conversion facilities

Anticipated Products

- Capital and operating cost models for new pyrolysis-based conversion technologies
- Research that maximizes the impact of public funding is identified for pyrolysis-based conversion technologies

Potential Benefits (Outcomes)

- Increased commercial deployment of pyrolysis-based biorefineries.

Component Resources

Research under Component 3 is conducted by the following ARS scientists:

Location	Researchers
Wyndmoor	Boateng, Elkasabi, Goldberg, McAloon, Mullen
Peoria	Compton, Jackson