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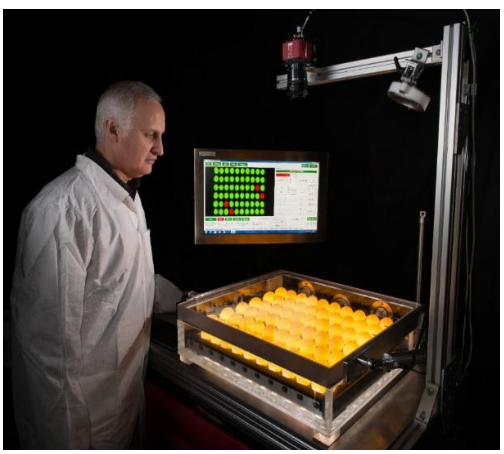
Programs

September 2018

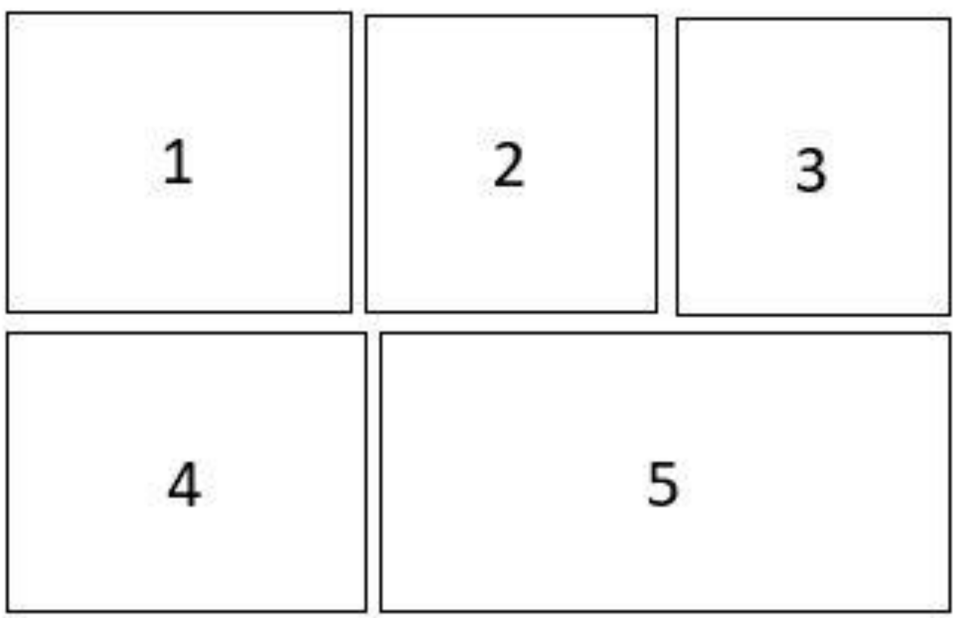
National Program 213
BIOREFINING
&
National Program 306
QUALITY AND UTILIZATION OF AGRICULTURAL PRODUCTS

ACCOMPLISHMENT REPORTS
2013-2017



Captions for cover photos:

1. The first automated egg grading system developed by ARS at the request of the USDA Agricultural Marketing Service uses LED light and computerized software.
2. ARS researchers demonstrated that Napier grass grown in Georgia for ethanol conversion is twice as productive per acre as corn harvested from the Midwest.
3. ARS worked with the Cooper Tire Company on research that led to the development of a guayule rubber passenger car tire, providing the first U.S. source of domestic rubber.
4. ARS led extensive work on sampling dust emissions from cotton gins; regulators used their findings to establish data-based limits on particulate emissions, which benefited cotton ginners in multiple states.
5. ARS developed an infrared-blanching and hot-air drying system for fruit and vegetables that reduced energy use 75 percent; a patent for the system was exclusively licensed to Treasure8. (Left to right): Dave Spivack (Treasure8), Kaylin Punotai (ARS intern), Hamed El-Mashad (UC-Davis), ARS Research Leader Tara McHugh, Yi Shen (UC-Davis), ARS Research Engineer Zhongli Pan; Asher Wenig (Treasure8), Ruihong Zhang (UC-Davis), and Chandrasekar Venkitasamy (UC-Davis).



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ARS Accomplishment Reports 2013-2017

The mission of the USDA Agricultural Research Service (ARS) is to conduct research to develop and transfer solutions to agricultural problems of high national priority and provide information access and dissemination to ensure high-quality, safe food, and other agricultural products; assess the nutritional needs of Americans; sustain a competitive agricultural economy; enhance the natural resource base and the environment; provide economic opportunities for rural citizens, communities, and society as a whole; and provide the infrastructure necessary to create and maintain a diversified workplace.

All ARS research projects are assigned to at least one of sixteen ARS National Programs managed by National Program Leaders and other ARS senior staff. This oversight ensures all work conducted by ARS scientists is relevant, significant, and has high scientific merit. The research under two of these National Programs, Biorefining (NP 213) and Quality and Utilization of Agricultural Products (NP 306), focuses on the needs and issues of agricultural producers and processers who produce food, fibers, bioenergy, and other biobased products from harvested agricultural products. Goals for these two National Programs include enhancing product quality, improving product processing, developing new value-added products, and reducing the environmental impacts of postharvest agricultural production. Meeting these goals supports agricultural producers and others in rural communities by increasing market demand for their goods and increasing the value of their production.

NP 213 and NP 306 research projects are closely related by their focus on links between agricultural production, consumer demand, and the enhancement of rural economies. Many ARS scientists and engineers collaborate on research across the two programs. These connections prompted the ARS Office of National Programs in 2017 to merge NP 213 and NP 306 into a single new National Program called Product, Quality, and New Uses (NP 306). This National Program will begin its initial 5-year research cycle in 2019.

Because of this pending merger, it is appropriate to present the Accomplishment Reports for NP 213 and NP 306 in the single document that follows. These reports highlight the accomplishments of research projects from both programs over the past 5 years—accomplishments that demonstrate the vital role ARS science holds in addressing challenges to U.S. agricultural production and developing tools and techniques that support agricultural producers and industry stakeholders.

The National Program 213 Action Plan 2013-2017
NP 213: Components and Problem Statements

COMPONENT 1 – Biochemical Conversion

PROBLEM STATEMENT 1: *Technologies for producing advanced biofuels or other marketable biobased products.*

PROBLEM STATEMENT 2: *Technologies that reduce risks and increase profitability in existing industrial biorefineries.*

PROBLEM STATEMENT 3: *Accurately estimate the economic value of biochemical conversion technologies.*

COMPONENT 2 – Biodiesel

PROBLEM STATEMENT 1: *Improve biodiesel's engine performance.*

PROBLEM STATEMENT 2: *Technologies that reduce risks and increase profitability in existing industrial biorefineries for converting lipids.*

PROBLEM STATEMENT 3: *Accurately estimate the economic value of technologies for converting lipids.*

COMPONENT 3 – Pyrolysis (Thermolysis)

PROBLEM STATEMENT 1: *Pyrolysis processes to produce marketable bio-oils.*

PROBLEM STATEMENT 2: *Accurately estimate the economic value of pyrolysis-based conversion technologies.*

The National Program 306 Action Plan 2013-2017
NP 306: Components and Problem Statements

COMPONENT 1 – Food

PROBLEM STATEMENT 1.A: *Define, measure, and preserve/enhance/reduce attributes that impact quality and marketability.*

PROBLEM STATEMENT 1.B: *New bioactive ingredients and functional foods*

PROBLEM STATEMENT 1.C: *New and improved food processing and packaging technologies.*

COMPONENT 2 – Nonfood

PROBLEM STATEMENT 2.A: *In collaboration with industrial partners, develop new post-harvest technologies: (i) to increase or protect the market demand for [or to increase the value of] existing U.S.-produced nonfood biobased products derived from agricultural products and byproducts, and (ii) to enhance product quality, improve process efficiencies, and reduce processing risks for existing U.S. producers of nonfood biobased products derived from agricultural products and byproducts.*

PROBLEM STATEMENT 2.B: *Enable technologies for (i) expanding market applications for existing biobased products, or (ii) producing new marketable nonfood biobased products derived from agricultural products and byproducts, and ensure that these technologies will generate economic impact by estimating their potential economic value.*

PROBLEM STATEMENT 2.C: *Collaborate with breeders and production researchers in the development of both new cultivars/hybrids and new production practices/systems that optimize the quality and production traits of crop-derived products and byproducts for conversion into nonfood biobased products.*

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National Program 213
Biorefining

NP 213 Accomplishment Report 2013-2017

BACKGROUND AND GENERAL INFORMATION

The U.S. biorefining industry has the potential to supply a significant portion of the national demand for fuels, chemicals, and other high-value U.S. consumable products, such as proteins, sugar alcohols, biopolymers, cosmetics, pharmaceuticals, health foods, and livestock feeds. The production of these bioproducts is not meant to completely replace their petroleum-based counterparts, but rather to supplement their use with a renewable resource base—plants and animal byproducts—to meet demand and to take advantage of low-value crops or byproducts of agricultural production that could increase farmers' profits. As an example, U.S. petroleum refineries are mainly set up to produce gasoline. When fluctuating demand for diesel begins to reduce supply, the price of diesel inches up. Biodiesel is normally blended with fossil-fuel diesel in various ratios to extend diesel supplies. Refining biodiesel from used vegetable oils or the non-food switchgrass plant helps close that gap and ensures an adequate supply to maintain the strength of the U.S. economy.

The goal of the USDA 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 and value-added products. To achieve this goal, the NP 213 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; and
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 agricultural producers and rural communities.

Biorefiners have narrow margins and lower profitability, mainly due to variability in feedstock costs and fuel market prices, particularly for conventional corn ethanol and soybean biodiesel. A sustainable and growing biorefining industry is dependent on having:

- Cost-effective and efficient processes for converting biomass to biofuels and biobased chemical and products;
- Readily available, diverse, low-cost supplies of feedstocks; and
- Production and cost analysis tools.

During the time period covered by this report, NP 213 research scientists focused on providing biorefining solutions in three main areas.

1. Developing new technologies for producing advanced biofuels, with an emphasis on quality biodiesel and marketable bio-oils. This report highlights a myriad of accomplishments in this area that range from a new method to produce drop-in fuels, such as butanol, to biobased additives for biodiesel, or a simple process to reduce bio-oil oxygen to improve production efficiencies. These technologies can lead to increased profitability and often lower production costs for biorefiners, which in turn increases demand for biomass agricultural products.

2. Reducing risk and increasing profitability of existing biorefineries with feedstock flexibility, expanded coproduct value and production, and improved process reliability. As documented in this report, ARS is uniquely positioned to advance biorefining efficiencies, because it holds the world's largest collection of microorganisms useful in biofeedstock conversion processes. ARS scientists have developed new, improved yeasts for ethanol and biodiesel production from biomass, investigated alternative nonfood feedstocks that are competitive with conventional feedstocks, and produced an antimicrobial bio-oil. This research provides support to the economic health of the biorefining industry and stabilizes demand for feedstocks, which provides better economic returns for farmers and rural communities.

3. Providing tools for accurately estimating the impact of technologies on biorefinery production and costs. Developing economic feasibility models to assess whether these technologies are more competitive with petroleum-based processes is a new direction for ARS in this Action Plan. As shown in this report, NP 213 scientists have developed cost prediction and production models to:
    - Optimize yeast growth and ethanol production from xylose in common bioreactor designs;
    - Improve biobased branched-chain fatty acid production, and
    - Estimate costs of pyrolysis conversion of several different agricultural wastes into bio-oil.

    This research assists industries in assessing the financial impact of adopting new biorefining technologies prior to use, and promotes their commercial deployment.

PLANNING AND COORDINATION FOR THE NP 213 5-YEAR CYCLE

Frequent customer and stakeholder interactions with ARS scientists are key to successful ARS research programs. Similarly, stakeholder participation and input are central to assessing performance and setting priorities of National Programs. In 2013, NP 213 researchers and National Program Leaders held a workshop with stakeholders from agriculture, industry, universities, and other governmental agencies to identify issues and create goals to guide NP 213 research over the current 5-year program cycle. With the input from customers, stakeholders, and other scientists, important research needs were identified and summarized in the Problem Statements under three research Components. These were brought together in the resulting NP 213 Action Plan to guide the current research projects that began their 5-year research cycle in 2014.

The Action Plan was used by the National Program Leaders as the basis for assigning objectives to each of the research projects under which individual ARS scientists conduct research. With guidance from the National Program Leaders, the research leaders and individual scientists developed objectives for each project. Project lead scientists then developed highly detailed 5-year project plans—similar to those presented in peer-reviewed papers—based on the assigned objectives. These plans were reviewed for relevancy and scientific quality by an external peer panel coordinated by the ARS Office of Scientific Quality Review. The review panel suggestions for greater clarity and focus on research approaches and methods of some project plans were addressed by the lead scientists and subsequently approved by the panel.

To expand on the increased demand for agricultural products that benefit both agricultural producers and rural communities, National Program Leaders decided to merge the Biorefining National Program (NP 213) with the Quality and Utilization of Agricultural Products National Program (NP 306) into a new National Program: Product Quality and New Uses (NP 306) beginning with the upcoming 5-year research cycle. The new 5-year research cycle will begin with a customer/stakeholder workshop in late 2018. This will be followed by the writing of a new Action Plan for the combined National Program and the establishment of new research objectives that will be completed in early 2019.

STRUCTURE OF NATIONAL PROGRAM 213

At the start of this Action Plan in 2014, NP 213 had nine projects. There are currently seven research projects associated with NP 213 at four locations: Albany, California; Peoria, Illinois; New Orleans, Louisiana; and Wyndmoor, Pennsylvania (listed in Appendix 1 by project number). The research of each project is assigned to one or more of three components under the current NP 213 Action Plan specifically targeting research on a priority area of biorefining. The following are the three components of this National Program:

COMPONENT 1: Biochemical Conversion

The research in this Component focuses on the processes of biochemical conversion, targeting new technologies used by the existing biorefining industry to advance beyond simple conversion of sugar cane or corn to ethanol. ARS research under this component seeks to develop and refine technologies that enable biorefiners to produce advanced biofuels that can directly replace fossil fuel-derived liquid transportation fuels, generate marketable high-value coproducts, and allow greater flexibility in feedstocks utilized. Process efficiency and business risk are also addressed.

COMPONENT 2: Biodiesel

Efforts under this Component are intended to address the needs of the established U.S. biodiesel industry. ARS research is directed towards improving biodiesel engine performance at cold temperatures that currently limit general adoption of biodiesel to 5-10 percent blend levels in petroleum diesel. Current biodiesel refineries need expanded options for feedstocks, new and more valuable coproducts, and production and cost decision tools to remain economically viable. Research on these issues targets reduced business risk and increased profitability, while attempting to expand demand for agricultural products.

COMPONENT 3: Pyrolysis (Thermolysis)

The scientists working on research in this Component focus on improving farm-level pyrolysis-based conversion technologies. The research attempts to find solutions to producing bio-oil more economically with reduced components that hinder quality and upgrading. The goal is to produce valuable coproducts and expand availability of viable biomass feedstocks. This research also aims to increase near- or on-farm bio-oil production and aid rural economies.

RELATIONSHIP OF NP 213 TO OTHER NATIONAL PROGRAMS

The research projects assigned to NP 213 focus on biorefining, while feedstock development and production research is conducted in other National Programs. Thus, NP 213 scientists collaborate on feedstocks with scientists assigned to other National Programs with research contributing to both NP 213 and to the goals of other National Programs. The relationship of the NP 213 components to other National Programs is illustrated in Figure 1:

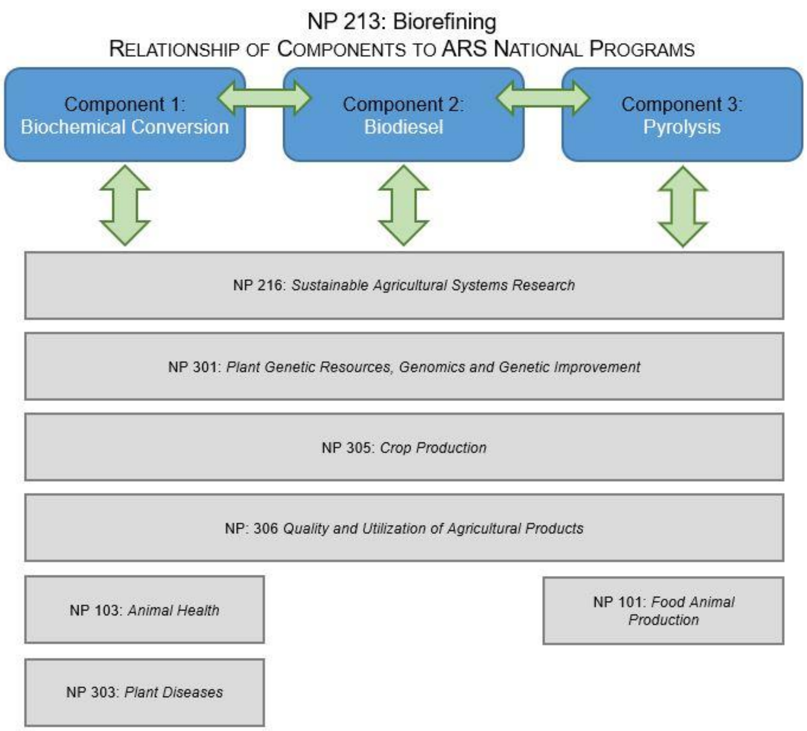


FIGURE 1: Association among other ARS National Programs both contributing to and receiving assistance from the three components of National Program 213 (Biorefining).

<u>NP 301 (Plant Genetic Resources, Genomics and Genetic Improvement); NP 303 (Plant Diseases)</u>**:** Scientists in these National Programs contribute to NP 213 by breeding improved germplasm and superior crop varieties; developing and applying new genetic and bioinformatic tools; and safeguarding and utilizing plant genetic resources and databases to enhance feedstock production and quality for fuel and industrial products.

<u>NP 216 (Sustainable Agricultural Systems Research); NP 305 (Crop Production):</u> NP 213 scientists collaborate with scientists from these National Programs in improving production

systems for traditional and new crops that represent oilseed, starch, sugar, and cellulosic feedstocks. These enterprises result in new technologies that optimize biorefining feedstock production, quality, efficiency, and profitability.

In addition, NP 216 includes the ARS Regional Biomass Research Centers (www.ars.usda.gov/natural-resources-and-sustainable-agricultural-systems/biorefining/docs/regional-biomass-research-centers/), which were established in 2010 to develop the best feedstocks and sustainable feedstock production systems for specific agro-eco regions where advanced biofuels will likely be produced. Each Regional Biomass Research Center fosters collaborative research within the complete bioenergy supply chain to accelerate the creation of commercial supply chains for the production of advanced biofuels.

NP 101 (Food Animal Production); NP 103 (Animal Health): Coproduct research conducted by ARS biorefining scientists helps to develop and improve the quality and cost-effectiveness of livestock feeds and biobased chemicals that have potential to improve animal health as antimicrobials or as components in veterinary pharmaceuticals.

NP 306 (Quality and Utilization of Agricultural Products): NP 213 has close ties with NP 306, which addresses postharvest quality and processing and the development of value-added nonfood biobased products. In particular, NP 213 and NP 306 scientists co-located in Albany, California; Peoria, Illinois; New Orleans, Louisiana; and Wyndmoor, Pennsylvania closely coordinate work in postharvest quality, processing, and bioconversion of agricultural feedstocks.

HOW THIS REPORT WAS CONSTRUCTED AND WHAT IT REFLECTS

This report assembles some of the many accomplishments of NP 213 from 2013 through 2017, a period that straddles the previous Action Plan for 2010-2014 and the current one for 2015-2019. Reporting on a period that does not match either action plan is necessary because of the need to review past accomplishments before beginning the process of developing a new Action Plan for the next 5-year cycle.

This NP 213 Accomplishment Report is a distillation of some of the most significant research accomplishments achieved by scientists working in this National Program over the past 5 years. By necessity, it is a 5-year snapshot that encompasses ongoing research and the early benefits of that research. The content of this report is mostly derived from the annual reports of the NP 213 projects from the past 5 years. This report stresses the impacts of those accomplishments and, where relevant, cites key publications or Web links documenting those accomplishments.

In the same way that only selected accomplishments are reported, details of those accomplishments are selected and summarized to illustrate the overall variety of products and knowledge generated by this National Program. Individual researchers or projects are not identified by name in the narrative text; rather, their achievements are described in the context of contributions towards accomplishing the Program's stated commitments to U.S. agriculture.

This report was prepared for an external (to ARS) retrospective review of NP 213 to assess how well this National Program attained the projected goals outlined in its current Action Plan.

Accordingly, the purpose of the retrospective review is not to judge the performance of individual NP 213 research projects, but to gauge the overall impact of the National Program. Consequently, the report does not attempt to catalog all the individual accomplishments reported by the NP 213 scientists.

The retrospective panel will be grading the accomplishments against the proposed actions outlined in the Problem Statements, which are more general than the Anticipated Products listed in the Action Plan. An individual accomplishment might be applicable to more than one problem and more than one set of anticipated products. Each accomplishment is matched with a publication to provide additional detail and to demonstrate that it stood up to rigor of scientific peer review. Appendix 1 includes a list of the current projects with scientists in NP 213. Appendix 2 has a complete bibliography of peer-reviewed publications generated by the NP 213 scientists organized by project. Appendix 4 contains a list of patents and licenses.

COMPONENT 1: Biochemical Conversion

Biochemical conversion of agricultural materials typically involves the following steps: feedstock preparation and separation into useable components; production of fermentable sugars; conversion of those sugars with either natural or chemical catalysts; and recovery and purification of the fuels, chemicals, and/or other coproducts.

The research in this Component takes a closer look at those processes to determine what efficiencies can be induced by the use of new catalysts and/or the removal of inhibiting substances from the process. Cost-effective processes are paramount for acceptance by the biofuel industry as it attempts to develop new fuels, oils, and products from plant-based feedstocks to supplement the use of fossil fuels.

Major advantages of biochemical conversion, which involves the use of enzymes and microbial catalysts, are its relative simplicity and environmental friendliness. Biochemical conversions fall into one of three categories, depending on the feedstock and method of conversion.

'First generation' biochemical conversion is the basis for almost all existing bioethanol production that utilizes food crops grown for this purpose, such as sugarcane (Brazil) or corn (United States) as 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 prefermentation fractionation to separate the high-starch endosperm (the portion utilized for ethanol production) from the high-fiber bran and high-oil germ. Enzymes are required to convert the starch in the grains into simple sugars for fermentation. The coproducts from this process can be used in animal feed and high-value oil, and can provide the raw materials for different products such as glues, skin care products, plastics, adhesives, resins, and food preservatives.

'Second generation' biochemical conversion utilizes cellulosic biomass from grasses and other nonfood plants in a three-step process:

(1) Pretreatment of the plant fiber to separate the cellulose and possibly the hemicellulose from the lignin, making both plant sugars in both components available separately for conversion through hydrolysis;
(2) Use of enzymes to convert the cellulose and/or hemicelluloses in the plant fiber into simple sugars; and
(3) Conversion of the sugars to desired products.

Technologies that can convert xylose—a five-carbon sugar, one of the mix of sugars found in hemicellulose and the second most abundant sugar in feedstocks, but currently a waste product—would greatly improve economic efficiencies by turning more of the feedstock into biofuels and coproducts. Currently, biorefining uses glucose, a six-carbon sugar which makes up 100 percent of cellulose.

'Third generation' biochemical conversion utilizes algal feedstocks. This type of conversion is not part of the research portfolio in USDA's biochemical conversion mission.

The current biofuels industry is well established and dominated by corn ethanol. However, existing biorefineries are vulnerable to feedstock and fossil fuel price fluctuations. Commercial viability of a new biorefining technology is linked to its production efficiencies and costs. In light of these and other issues, the NP 213 Action Plan included three Problem Statements 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.

ARS researchers have applied their expertise and creativity while prudently utilizing public resources to address these Problem Statements. This work, highlighted in the following accomplishments, is aimed at expanding biofuel and biobased product markets, improving the economic health of the biorefining industry, and increasing commercial deployment of new biorefining technologies. All of that is expected to contribute to promoting a stable demand for agricultural feedstocks.

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

Research needs identified under this Problem Statement focused ARS research away from traditional corn ethanol production to production of second-generation biofuels created from nonfood biomass. From this research, it was anticipated that new biocatalytic and/or chemical technologies would be developed to produce advanced biofuels, biobased products, and other co-products. The following are a sampling of the many accomplishments by ARS scientists under this Problem Statement, and include a new method to produce butanol from a nonfood feedstock; a pretreatment that turns a bioconversion inhibitor into a coproduct; and a microbe that produces a valuable chemical from orange peel waste.

Cost-effective process technology for butanol production from corn stover. Butanol is an advanced fuel that packs 30 percent more energy than ethanol on a per gallon basis. It is used in paint thinners, as a solvent in chemical and textile processes, and as a component of hydraulic and brake fluids. Traditionally it is distilled from fossil fuels; however, it can also be produced from plant feedstocks via the fermentation of sugars in the biomass. ARS scientists in Peoria, Illinois, worked on improving the process for converting corn stover into butanol and developed a novel three-step method that removes the butanol before it inhibits its own production. The scientists used vacuum distillation during the conversion of sugars to butanol to allow for continuous recovery of the fuel before production could be affected. Researchers estimated the production cost of butanol from corn stover by this process to be $3.42 per gallon, whereas the cost of butanol produced from corn grain was $4.39 per gallon. This compares favorably to the recent (June 2018) cost of butanol from fossil fuels at $3.50-$3.75 per gallon. This new fermentation/recovery process for the first time provides a more cost-effective production method for butanol. Further studies of butanol production from agricultural residues, such as sweet sorghum bagasse, have continued using this novel approach.

Qureshi, N., Singh, V., Liu, S., Ezeji, T.C., Saha, B.C., Cotta, M.A. 2014. Process integration for simultaneous saccharification, fermentation, and recovery (SSFR): Production of butanol from corn stover using *Clostridium beijerinckii* P260. Bioresource Technology 154:222-228.

Production of wax and ethanol from sorghum grains. Sorghum grains contain a wax that has been found to have negative effects on bioconversion processes, though it can be a valuable co-product of the process. ARS researchers in Wyndmoor, Pennsylvania, have developed a process to extract the wax from the sorghum with boiling ethanol in the first step. The wax-free grains are then either used directly in a fermentation process for ethanol production or additionally treated with diluted sulfuric acid under relatively mild conditions prior to mashing and ethanol fermentation. The cellulose component in the hulls of the acid-treated grains is hydrolyzed with a commercial cellulase to generate glucose for additional ethanol production. Researchers found that ethanol yield from dewaxed and acid-treated sorghum grains is increased by 37 percent compared to raw (untreated) grains. This new process could potentially increase profitability for ethanol production from grain sorghum and be used to produce sorghum wax as a new high-value coproduct. Sorghum wax has the potential to replace carnauba wax in industrial applications with a bulk price of about $7 per kilogram. This aspect of sorghum wax commercialization is still being investigated.

Nghiem, N.P., O'Connor, J., Hums, M.E. 2018. Integrated process for extraction of wax as a value-added co-product and improved ethanol production by converting both starch and cellulosic components in sorghum grains. Fermentation 4:1-12.

Orange-peel waste made into nylon. The U.S. citrus industry produces nearly 15 million tons of peel waste annually. Converting citrus peels into value-added products would help eliminate this waste; however, no enzyme system currently exists to convert citrus pectins and other similar polysaccharides into bioproducts. Through genomic mining of bacterial strains, ARS scientists in Albany, California, identified a highly active enzyme called exo-polygalacturonase from *Thermotoga* sp., a non-pathogenic compost microbe that lives at temperatures of 55 °C to 90 °C. Exo-polygalacturonase converts peel waste into an acid that can be used to develop fine chemicals such as adipic acid, which is used to make nylon, the base material for the multi-billion dollar sanitary wipe industry. Exo-polygalacturonase is hyperthermostable and can be combined with methylesterase, another hyperthermostable pectin, to create a dual-enzyme system that permits processing of pectin-rich citrus waste at elevated temperatures. This process could also be used with the pectin from sugar beet peels, which accounts for 240 million tons of waste a year worldwide. With this enzyme process, the production of nylon is cleaner, faster, and well-suited for the use of non-fossil fuels for a greener footprint. Additionally, the process can easily substitute for nylon’s current highly corrosive chemical production process. This discovery has led to new molecular breeding research to improve the enzyme that converts orange peel and sugar beet waste to *dicarboxylic acids*, which will facilitate more cost-effective and efficient industrial processes.

Wagschal, K.C., Stoller, J.R., Chan, V.J., Lee, C.C., Grigorescu, A.A., Jordan, D.B. 2016. Expression and characterization of hyperthermostable exo-polygalacturonase TtGH28 from *Thermotoga thermophilus*. Molecular Biotechnology 58(7):509-519.

Lee, C.C., Kibblewhite, R.E., Paavola, C., Orts, W.J., Wagschal, K.C. 2016. Production of glucaric acid from hemicellulose substrate by rosettasome enzyme assemblies. Molecular Biotechnology. 58:489-496.

Hot-water pretreatment greatly improves conversion of sweet sorghum bagasse to butanol. Sweet sorghum is a high energy biomass crop regarded as one of the most promising crops for biofuel production. ARS scientists in Peoria, Illinois, have developed a novel process to pretreat sweet sorghum bagasse with hot water to generate fermentable sugars after enzymatic hydrolysis. The pretreatment of sweet sorghum bagasse made the bagasse easily fermentable into acetone-butanol-ethanol with butanol as the major biofuel. Heat-pretreated sweet sorghum butanol productivity was found to be between 23 percent and 86 percent higher than the glucose fermentation typically used with corn grain feedstocks. The sweet sorghum conversion industry has shown interest in adopting this technology, which has the potential to lower cellulosic butanol production costs that will ultimately enhance rural economic development. Development of this process has led to continued research to improve the efficiency of butanol production processes.

Qureshi, N., Liu, S., Hughes, S., Palmquist, D., Dien, B., Saha, B. 2016. Cellulosic butanol (ABE) biofuel production from sweet sorghum bagasse (SSB): Impact of hot water pretreatment and solid loadings on fermentation employing *Clostridium beijerinckii* P260. BioEnergy Research. 9(4):1167-1179.

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

Unpredictable feedstock costs and biofuel prices can reduce the economic viability of first-generation biorefineries. To uphold the economic health of the biorefining industry, research activities under Problem Statement 2 developed technologies for existing biorefineries to increase process efficiencies, lower costs, and reduce disruptions to production. Further, the research opened avenues for more feedstock flexibility, expanded second-generation conversion, and increased production of marketable coproducts. The following accomplishments highlight just a few of the ARS research accomplishments addressing this Problem Statement. They show a breadth of achievements that include a new yeast strain that reduces costs in cellulosic ethanol production; a technique that prevents spoilage of sorghum syrup during storage; a nonfood feedstock that outperforms corn in ethanol production; and an antimicrobial bio-oil that can help keep cows, pigs, and even fish healthy.

Novel microbes lower cost of cellulosic ethanol production. Developing cost-effective cellulosic ethanol production is difficult in part due to the expensive cellulolytic enzymes needed to break down feedstock prior to its conversion into fuel. ARS scientists in Peoria, Illinois, worked with partners to develop a new yeast strain with a unique cellulolytic enzyme that more efficiently breaks down feedstock and shows resistance to inhibitory compounds. Additionally, it eliminates the need to add other enzymes to the production process. The scientists assessed the efficiency of this yeast strain in converting pretreated rice straw into cellulosic ethanol, obtaining a production rate of 36.7 grams per liter in 36 hours with a conversion efficiency of 90.1 percent. This translates into reducing enzyme costs in cellulosic ethanol production by around 35 cents per gallon. Due to low gasoline prices, industry is cautiously moving forward on the production of ethanol from lignocellulose, but is optimistically looking to the future when fuel ethanol demands rise.

Chapla, D., Parikh, B.S., Liu, L.Z., Cotta, M.A., Kumar, A.K. 2015. Enhanced cellulosic ethanol production from mild-alkali pretreated rice straw in SSF using *Clavispora* NRRL Y-50464. Journal of Biobased Materials and Bioenergy. 9(4):381-388(8).

Kumar, A.K., Parikh, B.S., Shah, E., Liu, L.Z., Cotta, M.A. 2016. Cellulosic ethanol production from green solvent-pretreated rice straw. Biocatalysis and Agricultural Biotechnology. 7:14-23.

Napier grass produces more bioethanol per acre than corn. Napier grass is a warm season grass with low water and nutrient requirements that can be grown on marginal or uncultivated lands. Its value as a bioenergy crop for the southeastern United States is that it does not compete with food crops for growing space. ARS scientists in Peoria, Illinois, and Tifton, Georgia, assessed the production of bioethanol from converted Napier grass [Figure 1]. Their tests showed that Napier grass demonstrated an estimated yield of 10,300 liters of ethanol per hectare. By comparison, a corn field that typically yields 444 bushels/hectare (179 bushels/acre) produced only 4,640 liters per hectare. As a high-yielding, nonfood ethanol feedstock, Napier grass can be grown alongside corn as a “pull” crop, attracting insects away from corn while improving soil fertility and preventing erosion. This research provides farmers with a feasible alternative to the use of corn in the southeastern United States in the production of liquid biofuels. ARS work on Napier grass has resulted in several invited presentations at conferences on bioplastics, biomass valorization, and an American Chemical Society special session on biofuels.

Figure 1: ARS researchers demonstrated that Napier grass grown in Georgia for ethanol conversion is twice as productive per acre as corn harvested from the Midwest.

Anderson, W.F., Dien B.S., Masterson, S.D., and Mitchell, R.B. Development of near infrared reflectance spectroscopy (NIRS) calibrations for traits related to ethanol conversion from genetically variable Napier grass (*Pennisetum purpureum Schum*.), bioenergy crop (submitted)

Dien, B.S., Anderson, W.F., Lamb, M., O'Bryan, P.J., Slininger, P.J. 2016. Field productivities of Napier grass for production of sugars and ethanol. Biotechnology for Fuels and Chemicals Symposium Proceedings. Paper No.11-2.

Reducing sweet sorghum syrup spoilage during long-term storage. Because of its rich sugar medium, sweet sorghum syrup, which is an excellent feedstock for biofuel production, is highly susceptible to surface microbial spoilage during storage, which can inhibit biofuel production. This is a major impediment to using sweet sorghum syrup for large-scale commercial manufacture of biofuels and bioproducts. ARS scientists in New Orleans, Louisiana, in cooperation with an industrial collaborator, showed that adding a thin layer of inexpensive soybean, canola, or sunflower oil as a surface sealant allowed sweet sorghum syrup containing 65 percent dissolved solids to be stored for at least 1 year at ambient temperature without being contaminated. Delta BioRenewables (Memphis, Tennessee) and Heckemeyer Mill (Sikeston, Missouri) use this novel technology to store their sorghum syrup. Research on sweet sorghum syrup storage and spoilage is continuing on this technique and on different storage times for various Brix (sugar) levels.

Eggleston, G., Andrzejewski, B., Cole, M., Dalley, C., Sklanka, S., St Cyr, E., Chung, Y., Powell, R. 2015. Novel storage technologies for raw and clarified syrup biomass feedstocks from sweet sorghum (*Sorghum bicolor* L. Moench). Biomass and Bioenergy. 81:424-436.

Eggleston, G., Boone, S., Triplett, A., Heckemeyer, M., Powell, R., Wright, M., 2018. Preliminary study on the use of inexpensive, unsaturated vegetable oils as surface sealants in the long - and short-term storage of syrup feedstocks from sweet sorghum. Sugar Tech. 20(3):235-251.

Novel microbial oil has antibacterial activity. Antimicrobial resistance, a major health concern, has reduced the effectiveness of therapeutic drugs to treat and prevent infectious disease. As a result, antibiotic alternatives are needed to maintain the health and welfare of animals. ARS scientists in Peoria, Illinois, collaborated with a scientist from Rangsit University in Thailand to test liamocins, a novel oil produced by the fungus *Aureobasidium pullulans*, for antibacterial activity [Figure 2]. Liamocins was produced during bioconversion of a variety of sugars and lignocellulosic feedstocks and was discovered to preferentially inhibit the growth of strains of the pathogenic bacteria *Streptococcus*. The antibacterial oil can be used to improve animal health in the dairy, swine, and aquaculture industries, and can provide a new high-value product for the biorefining industry for reducing the risks associated with antimicrobial resistance. An ARS Innovation Fund award was issued to advance this oil for commercialization.

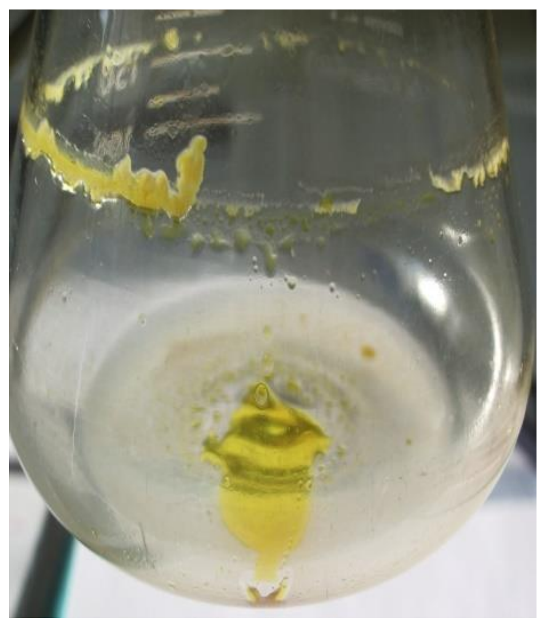


Figure 2: ARS researchers found that an oil produced by the fungus *Aureobasidium pullulans* has antibacterial qualities.

Bischoff, K.M., Leathers, T.D., Price, N.P.J., Manitchotpisit, P. 2015. Liamocin oil from *Aureobasidium pullulans* has antibacterial activity with specificity for species of *Streptococcus*. Journal of Antibiotics. 68:642-645.

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

The potential of many bioconversion processes is related to their economic viability. Understanding and pinpointing conversion process variables that maximize production economics can focus efforts on the development of technologies to increase commercial deployment. In Problem Statement 3, ARS research focuses for the first time on development of cost models to gauge the economic sustainability of biorefining technologies. The following accomplishments exemplify the success of NP 213 in this new focus area. They showcase the development of a computer model to optimize yeast growth and ethanol production from xylose in common bioreactor designs, and leverage successful biomass breeding research from other ARS research to establish the viability of a nonfood crop for ethanol production.

***Computer simulations of ethanol production from xylose by* Scheffersomyces stipitis *reveal paths to low-cost ethanol from plant biomass*.** Hemicellulosic plant biomass is an abundant, renewable feedstock for production of low–cost, fuel-grade ethanol. However, finding ways to ferment the sugar xylose, which comprises approximately 40 percent of hemicellulose, has remained a major technical hurdle. Xylose, a five-carbon sugar, is not fermented by traditional six-carbon sugar fermenting yeasts, but the yeast *Scheffersomyces stipitis* ferments it to economically harvestable concentrations of ethanol. ARS scientists in Peoria, Illinois, formulated a kinetic model for *S. stipitis* that describes growth and ethanol production as a function of ethanol, oxygen, and xylose concentrations. The model was validated for various oxygen-limited growth conditions and accurately predicts the changing levels of yeast biomass, dissolved oxygen, ethanol, and sugar during fermentation in common reactor designs. The new model will improve the processes of producing ethanol with xylose. Simulations show that fermenting xylose to ethanol could reduce the selling price of ethanol from $2.18/gal to $1.35/gal, which would support advances in meeting national renewable fuels goals. The model equations and parameters were published and made available online for use by other researchers working on *S. stipitis* process development, since the consideration of oxygen dependence is key to optimization of ethanol production from xylose.

Slininger, P.J., Dien, B.S., Lomont, J.M., Bothast, R.J., Ladisch, M.R., Okos, M.R. 2014. Evaluation of a kinetic model for computer simulation of growth and fermentation by *Scheffersomyces (Pichia) stipitis* Fed D-Xylose. Biotechnology and Bioengineering. 111(8):1532-1540.

'Liberty' switchgrass produces high yields of bioethanol. Additional sources of nonfood biomass suitable for ethanol production is a continuing industry priority. 'Liberty' switchgrass is a grass cultivar developed by ARS researchers in Lincoln, Nebraska, to be high in cellulose and low in lignin. These characteristics make it more efficient for biofuel production, as well as an excellent perennial crop that provides abundant amounts of biomass. To assess its economic viability, ARS researchers in Peoria, Illinois, harvested an established field of Liberty that was grown on marginal, nonfood cropping land in central Wisconsin and processed it into bioethanol.

The switchgrass harvest produced an average of 4,235 liters of bioethanol per hectare. By comparison, corn grown on nearby good-quality food-cropping land yielded an above-average 200 bushels per acre and produced 5,300 liters of bioethanol per hectare. This was the first study of field-to-fermentation integration and the first study that evaluated Liberty switchgrass. These findings help support the use of switchgrass as a viable industrial crop for U.S. farmers and ethanol processors considering production of lignocellulosic-based advanced biofuels in the northern United States. As research is continuing, there is no published journal article at this time, but the following abstract citation and listing of several journal articles on switchgrass cultivar development for ethanol production in Appendix 2 support this accomplishment.

Dien, B.S., Bowman, M.J., Casler, M.D., Mitchell, R., Quarterman, J.C., Vogel, K.P. 2017. Field productivities of Switchgrass for conversion to sugars and ethanol [abstract]. Biotechnology for Fuels and Chemicals Symposium Proceedings. Paper No. 14-2.

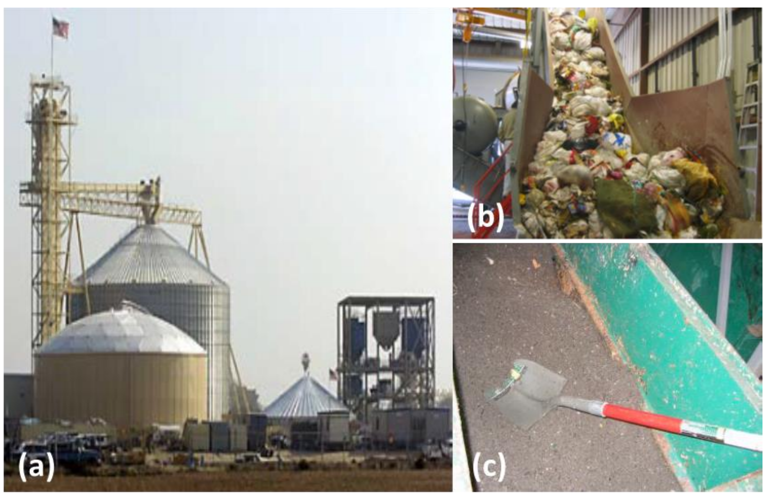


Figure 3: ARS (a) developed a large, pilot-scale biorefinery in Salinas, California that (b) converts co-mingled household solid waste into (c) an autoclaved pulp and eventually into ethanol, biogas, and compost.

Changing landfills into biorefineries. To provide sufficient quantities of biomass sources between growing seasons, ARS researchers in Albany, California, developed a large pilot-scale biorefinery at the Crazy Horse Landfill in Salinas, California, that converts rural and urban solid waste into ethanol, biogas, compost, and/or value-added recyclables [Figure 3]. Each ton of food processing waste at the landfill can currently be converted into 65 gallons of ethanol. Conversely, if the same biomass source is converted to liquefied natural gas (which has the same burn rate as 100 percent ethanol) it yields 108 gallons of transportation fuel, which can be used to power diesel turbines. The City of Salinas is leveraging resources to create an "energy park" that converts both agricultural biomass and curb-collected garbage into bioenergy in the same biorefinery, demonstrating the facility's remarkable flexibility in processing different feedstock supplies into biofuel.

Holtman, K.M., Bozzi, D.V., Franqui-Villanueva, D.M., Offeman, R.D., Orts, W.J. 2016. A pilot-scale steam autoclave system for treating municipal solid waste for recovery of renewable organic content: Operational results and energy usage. Waste Management and Research. 34(5):457-464.

Reza, M., Coronella, C., Holtman, K.M., Franqui-Villanueva, D.M., Poulson, S.R. 2016. Hydrothermal carbonization of autoclaved municipal solid waste pulp and anaerobically treated pulp digestate. ACS Sustainable Chemistry & Engineering. 4(7):3649-3658.

COMPONENT 2: Biodiesel

Recently, global biodiesel consumption has grown to more than 2 billion gallons a year. By far, most of the biodiesel produced in the United States comes from soybeans, canola, and corn oil, but it is also produced from a variety of oils and fats, including byproducts and wastes from vegetable and animal processing. Biodiesel is chemically the same as petroleum-based diesel and can be used as an equivalent substitute. However, biodiesel is normally blended with diesel in various ratios to extend chronically short diesel supplies. Biodiesel has a positive lifecycle carbon reduction impact compared with that of fossil fuels and is often produced in moderately sized facilities, which benefits rural communities. Demand for biodiesel is anticipated to grow to 4 billion gallons, or more than 10 percent of the diesel pool, by 2022.

Because most biodiesel is produced from edible oil feedstocks, the availability and price of raw material supplies are subject to commodity supply and price fluctuations, which has the potential to reduce profit margins for biodiesel producers. Biodiesel performance is affected by cold temperatures, which cause molecules to aggregate and form crystals that cause the diesel to appear cloudy. This temperature is called the cloud point. These crystals, or the tendency for the fuel components to gel at lower temperatures, can restrict flow in engine components. This limitation, known as cold flow performance, can reduce biodiesel use during winter months. In the face of growing demand, the Bioenergy National Program (NP 213) Action Plan included the following Component 2 Problem Statements to address the research needs of the biodiesel and related industries:

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.

ARS scientists in NP 213 have successfully addressed many of the research needs associated with these Problem Statements. Their efforts, illustrated in the following accomplishments, continue to help the biodiesel industry improve biodiesel quality, remain economically viable, increase production and efficiency, and expand development of coproducts and the value of byproducts.

Problem Statement 1: *Improve biodiesel's engine performance.*

Poor cold-flow performance of biodiesel due to contaminants, production intermediates, or crystallized fatty acid methyl esters has a negative impact on biodiesel use, especially in cold months. Research under this Problem Statement focused on improving biodiesel low temperature flowability and quality. The following selected accomplishments recap successes in synthesizing additives from bioresources to improve cold-flow properties. Researchers also developed a simple method to standardize biodiesel cold-flow performance tests.

Sustainable biodiesel additives improve cold weather flow. Biodiesel has many advantages over petroleum-based fuels, including its low toxicity, biodegradability, and the option of using renewable feedstocks in its production. It is usually made from canola, palm, or soybean oil.

However, even when blended with conventional diesel, biodiesel has properties that cause it to plug fuel systems in cold temperatures. This reduces its utility during the winter, especially in the northern United States. ARS researchers from Wyndmoor, Pennsylvania, collaborated with their counterparts in Peoria, Illinois, to examine new compounds (branched-chain fatty acid methyl esters, or BC-FAME) synthesized from oleic acid, a material obtained from plant oils and animal fats. These compounds have specialized chemical structures that lower biodiesel's cloud point temperature. The researchers found that as an additive up to 2 percent of volume, BC-FAME did not greatly affect cold flow properties, including the cloud point, of canola, palm, and soybean oil biodiesels. However, at higher concentrations between 20 percent and 39 percent, BC-FAME significantly improved cold flow properties, including the cloud point, of the biodiesels. It was also found that BC-FAME additives or diluents based on saturated chains may be more effective at improving cold flow properties of mixtures with biodiesel than those based on unsaturated chains. This new finding provides a mechanism to solve the cold-flow issues of diesel, which will directly benefit scientists and engineers seeking to develop additives that improve cold flow properties and other performance factors of biodiesel.

Dunn, R. O., Lew, H. N., Haas, M. J. 2015. Branched-chain fatty acid methyl esters as cold flow improvers for biodiesel. Journal of the American Oil Chemists' Society. 92(6):853-869.

Edible vegetable oils make biodiesel testing more reliable. Biodiesel can precipitate material out of solution when exposed to cold temperatures, causing filters to clog and engines to quit. The American Society for Testing and Materials standard D7501 Cold Soak Filtration Test (CSFT) measures the filter blocking potential of biodiesel. The CSFT results are used to determine biodiesel performance and assess if a biodiesel is marketable. However, methods were needed to assess the reliability of CSFT results. ARS researchers in Wyndmoor, Pennsylvania, investigated refined vegetable oils that are commercially available to identify a readily available calibration standard for the filtration device used for the biodiesel CSFT. They found that soybean oil and other refined edible oils were acceptable reference materials for validating the filtration device, and that soybean was the cheapest of the oils. These commercially available vegetable oils provide readily available and affordable calibration fluids that provide greater uniformity and reliability for CSFT data, thereby ensuring the in-field engine performance of biodiesel for consumers.

Haas, M.J., Barr, M.R., Phillips, J., Wagner, K.M. 2015. A simple standardization method for the biodiesel cold soak. Journal of the American Oil Chemists' Society. 92(9):1357-1363.

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

Volatile agricultural commodity prices, particularly for soybeans, influence biodiesel feedstock costs and diesel selling prices and affect biodiesel producers' profit margins. Scientific work addressing this Problem Statement advanced efforts to lower production costs, expand feedstock flexibility, and increase the value of byproducts and production of coproducts at existing biodiesel facilities. Similar to Component 1, this work by ARS scientists is expected to reduce risk, increase profitability of biodiesel production, and enable biodiesel facilities to generate new products. The following accomplishments summarize examples of ARS achievements that reduced biodiesel production cost, increased the feasibility of using alternative feedstocks, and reduced production risk by utilizing a more robust yeast strain.

"Oily" yeast lowers the cost of biodiesel fuel. Nearly 1.3 billion tons of plant biomass (lignocellulose) could be harvested each year in the United States in the form of energy crops and forest and agricultural residues. This biomass has the potential to be converted into 30 billion gallons of biodiesel a year (62 percent of current U.S. diesel consumption), but current biofuel conversion is too inefficient to take advantage of those potential feedstocks. ARS scientists in Peoria, Illinois, screened numerous yeast strains from the ARS Culture Collection at Peoria, Illinois, to find oleaginous or "oily" yeasts that can produce up to 70 percent of their cell weight in lipids; these lipids can then be used to replace vegetable oils or other feedstocks in biodiesel production. Applying an advanced two-stage process to manage the growing environment, the researchers were able to get the top yeast strains they identified to rapidly accumulate 50-65 percent of their cell biomass as lipid. Based on these unprecedented yields, it is estimated that these "oily" yeasts can produce an estimated 48 gallons of oil per acre from corn stover and 190 gallons per acre from switchgrass that could be made into biodiesel or jet fuel [Figure 1]. Current production using soybeans, a food crop, produces about 68 gallons of oil per acre. This new technology has the potential to advance the economic feasibility of producing high-quality biodiesel and jet fuels from renewable biomass. Using switchgrass as a feedstock, oil derived from these yeasts could supply an estimated 20 percent of the U.S. diesel fuel needs. A patent application for this technology has been submitted.

Figure 1: An ARS "oily" yeast produces unprecedented amounts of oil from switchgrass that can be converted to biodiesel.

Slininger, P. J., Dien, B. S., Kurtzman, C. P., Moser, B. R., Balan, V., Jin, M., da Costa Sousa, L., Bakota, E. L. 2016. Methods and yeast strains for conversion of lignocellulosic biomass to lipids and carotenoids. Patent Application No. US 2016/0265009 A1.

Newly discovered yeast strain with improved robustness to break down biomass. *Yarrowia* yeast strains are critical for the bioconversion of lignocellulosic biomass into diverse lipids that can be processed into biodiesel, food/healthcare applications, organic acids, and as proteinaceous feed supplements for the animal and aquaculture industries. ARS scientists in Peoria, Illinois, screened isolates of *Yarrowia* from the ARS Microbial Culture Collection in a dilute-acid, pretreated switchgrass hydrolyzate media for growth robustness, breadth of sugar metabolism, and lipid production. The top-producing isolate accumulated more than 3-fold greater lipid concentrations than the control, a native *Yarrowia* strain commonly used in commercial bioconversion systems. This level of lipid production is unprecedented. This more robust *Yarrowia* isolate will be used to advance conversion of biomass into lipid biofuels and other bioproducts and will improve the genetic diversity of catalysts available to companies venturing into synthetic biology applications [Figure 2].

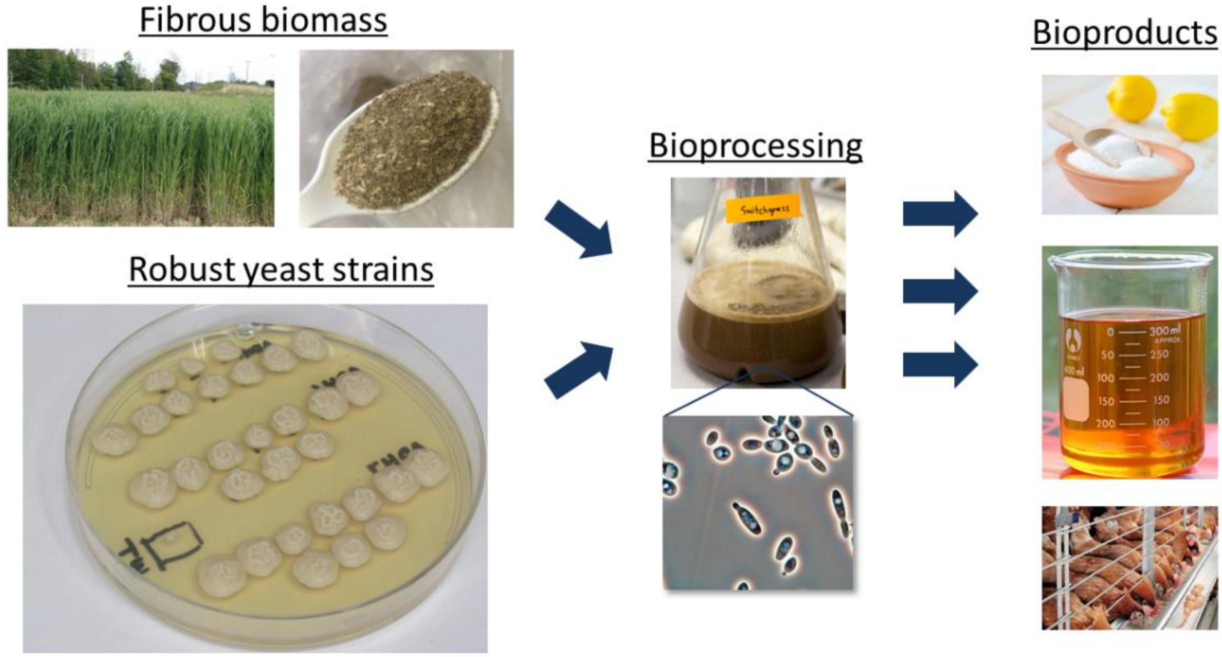


Figure 2: Newly identified *Yarrowia* yeast strains produce three times more lipids from biomass for biodiesel production than the current strain, and also yield coproducts and animal feed. The increased production capacity using these new yeast strains could help improve the profitability of refiners looking to increase biodiesel production.

Quarterman, J., Slininger, P. J., Kurtzman, C. P., Thompson, S. R., Dien, B. S. 2017. A survey of yeast from the *Yarrowia* clade for lipid production in dilute-acid pretreated lignocellulosic biomass hydrolysate. Applied Microbiology and Biotechnology. 101(8):3319-3334.

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

The viability of new biodiesel production processes or products is linked to biorefinery capital and operational costs, and the high costs of finished biorefinery products can limit their production and market value. Knowing the process components and having accurate estimates of their expected impact on production economics allows ARS researchers and industry associates to focus efforts on technologies that maximize impact. This Problem Statement focuses on the development of economic feasibility models for lipid bioconversion that can help producers select options for making these technologies more competitive with petroleum-based processes.

Reducing the cost of biobased lubricants and cosmetics with computer models. Commercial branched-chain fatty acid isomers called isostearic acids (IA) can be produced from vegetable oils and animal fats and are used to improve cosmetics, paints, and lubricants. Current low-yield technology for IA production is not efficient or cost-effective, but a process has been developed that allows the reuse of the costly catalyst. ARS researchers in Wyndmoor, Pennsylvania, constructed and evaluated a techno-economic model for industrial-scale IA production using the new process. The model calculated the economic feasibility of the technology by modeling 19 reuses of the catalyst in consecutive production reactions, assuming IA yields greater than 80 percent at the end of each reaction. According to the techno-economic studies, the difference in the production costs between various catalyst reuse models is substantial and costs are reduced each time the catalyst is reused. This model is being used by manufacturers of biobased lubes and greases.

Lew, H.N., Yee, W.C., McAloon, A.J., Haas, M.J. 2014. Techno-economic analysis of an improved process for producing saturated branched-chain fatty acids. Journal of Agricultural Science. 6(10):158-168.

COMPONENT 3: Pyrolysis (Thermolysis)

One technological platform studied for conversion of biomass to biofuels is pyrolysis, the heating of a material in the absence of oxygen. When applied to biomass, pyrolysis produces a liquid called bio-oil that can be refined into gasoline and jet or diesel fuels identical to those produced from petroleum. The advantages of pyrolysis 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 has the potential to provide small footprint technologies for near- or on-farm production of bio-oils for fuels and chemicals.

Although this process is clearly attractive from an environmental standpoint, for the technology to be adopted commercially it must produce products that are cost competitive with petroleum-based products. There are problems associated with high oxygen levels in pyrolysis bio-oil that promote instability. Biomass resources can also vary in price and availability, and feedstock choice can affect processing efficiency and product quality. The research in this Component attempts to address the problems by finding solutions to economically producing bio-oil with reduced oxygen content; reducing catalyst cost and catalyst deactivation or developing noncatalystic pyrolysis processes; and identifying new feedstocks that improve bio-oil quality, don't poison catalysts, and enable high product yield.

The NP 213 Action Plan identified two Problem Statements to address the research needs of Component 3 and establish pyrolysis as a viable process for the conversion of biomass to hydrocarbon fuels and chemicals at farm scale:

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.*

Researchers working under this Problem Statement focused on new pyrolysis-based technologies and processes to improve pyrolysis processing performance and bio-oil marketability. The solutions they sought enable production of higher value coproducts and identify alternative feedstocks from agricultural process waste. The following accomplishments highlight successes in developing a simple process to reduce the oxygen content of bio-oil, expanding valuable coproduct production through catalyst improvements, and converting agricultural processing wastes to bio-oil.

Low-cost portable process for producing marketable pyrolysis oil. Pyrolysis converts biomass into bio-oil, a petroleum-like liquid that could potentially be refined into renewable, drop-in replacements for petroleum-based fuels. However, bio-oil cannot be used by existing petroleum refiners because it contains too much oxygen. Although oxygen can be removed from bio-oil by catalytic hydrotreating (reacting with hydrogen), that process is expensive and reduces product yield. ARS researchers in Wyndmoor, Pennsylvania, developed and patented a relatively simple non-catalytic process utilizing tail gas from the pyrolysis reactor to reduce the oxygen content of the bio-oil from 35 percent to 12 percent. The new process, called tail gas reactive pyrolysis (TGRP), doubles the yield of distillate product and yields a narrower range of products (5-10 compounds) vs. traditional pyrolysis (hundreds of compounds) [Figure 1]. This system is wholly unique in that it is a portable feedstock pyrolysis unit capable of on- or near-farm biorefining. As a result, it reduces costs normally associated with moving feedstocks to biorefining facilities, sometimes a couple of states away. One portable unit [Figure 2] can process two tons of biomass per day. Industry interests, especially from Canada, are currently seeking licensing.

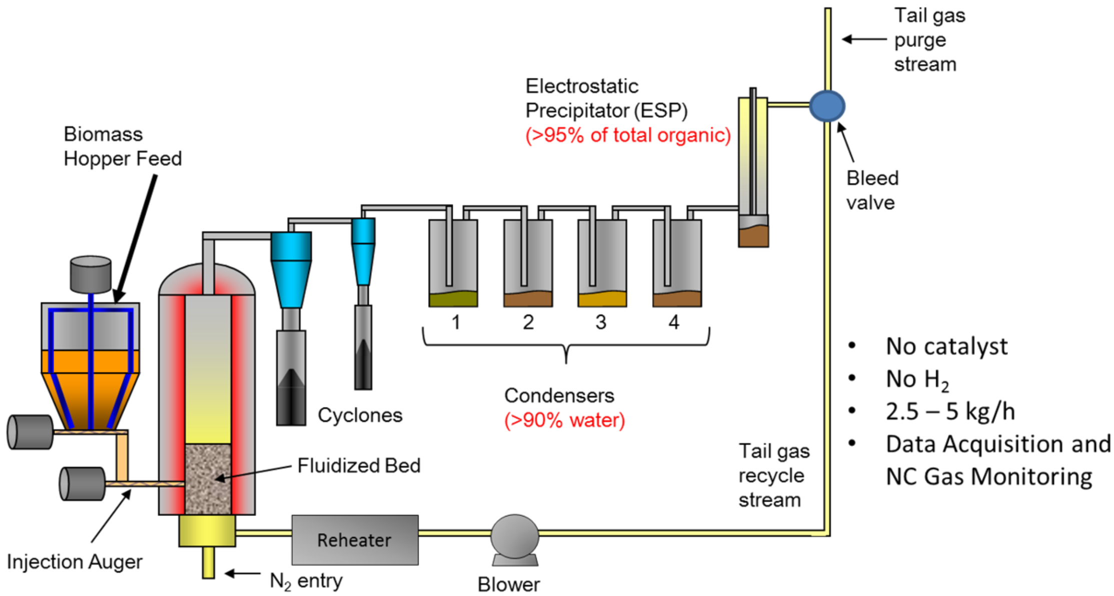


FIGURE 1: tail gas reactive pyrolysis system

FIGURE 2: Portable system for on-farm use can process 2 tons of biomass per day.

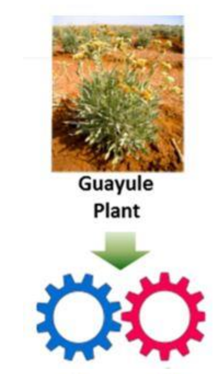
Mullen, C.A., Boateng, A.A., Goldberg, N.M. 2013. Production of deoxygenated biomass fast pyrolysis oils via product gas recycling. Energy and Fuels. 27(7):3867-3874.

Mullen, C.A., Boateng, A.A., Goldberg, N.A. (The United States of America, as represented by the Secretary of Agriculture, Washington, DC). 2016. Methods for Producing Bio-oil. U.S. Patent No. 9,434,885 B2.

High-value phenols and furan coproducts from biomass catalytic pyrolysis. Profit margins from fuel refining for both fossil fuel and biomass refiners are small. However, approximately 80 percent of the profits for the fossil fuel industry comes from nonfuel petrochemicals. For biomass refiners to be successful, they also need to make high-value coproducts. Current biomass conversion processes focus on the production of non-oxygenated hydrocarbons derived from a process that removes oxygen from the biomass. However, since oxygenated analogs are the more valuable coproducts, this restricts the potential coproduct market for biomass refiners. ARS scientists in Wyndmoor, Pennsylvania, modified a zeolite catalyst traditionally used in biomass pyrolysis to increase the production of oxygenated chemicals (phenols and furans) and optimize conditions for production. It was determined that phenols can be produced from both the lignin and cellulosic portions of lignocellulosic biomass by modifying the catalyst. Combining the adoption of this modified zeolite catalyst with processing that does not deoxygenate lignocellulosic biomass reduces biorefining costs, expands the potential production of valuable coproducts from biomass, and improves the profitability of fast pyrolysis biorefining. This was early stage research done on the analytical (mg) scale, and work is continuing to scale up the process.

Mullen, C.A., Tarves, P.C., Boateng, A.A. 2017. Role of potassium exchange in catalytic pyrolysis of biomass over ZSM-5: Formation of alkyl phenols and furans. ACS Sustainable Chemistry and Engineering. 5(3):2154-2162.

***Guayule tire-rubber bagasse is an excellent source of biofuels*.** Guayule, a woody desert shrub cultivated in the southwestern United States, is being commercialized as a source of natural rubber and organic resins, and has the potential to become a viable alternative to imported natural rubber or petroleum-based synthetics. However, only about 5 percent of the guayule plant is rubber latex. For guayule production to become economically viable, industry must find profitable uses for the remaining 95 percent of the guayule plant. ARS researchers in Wyndmoor, Pennsylvania, used guayule bagasse, the residue left after rubber extraction, as feedstock in a pyrolysis process employing a reactive gas environment to formulate a special intermediate bio-oil product for use as a hydrocarbon (drop-in) fuel. This novel guayule bagasse conversion was completed without the use of catalysts and resulted in the production of a high-energy bio-oil with much lower oxygen content than catalyst-generated bio-oils. Combining guayule bagasse with tail gas reactive pyrolysis (TGRP) gave better results than other feedstocks due to the unique chemistry of guayule residues [Figure 3]. As a result of this research, scientists also investigated combining TGRP with normally difficult-to-process feedstocks such as spirulina (algae) and obtained similar results.



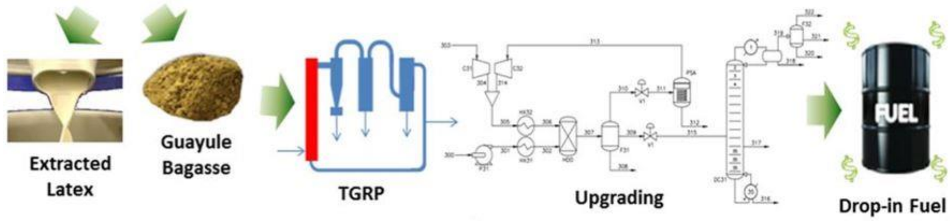


Figure 3: Only 5 percent of the guayule plant is used to make natural rubber, but ARS researchers found that the rest can be converted to bio-oil for use as a hydrocarbon fuel using tail gas reactive pyrolysis.

Boateng, A.A., Mullen, C.A., Elkasabi, Y, McMahan, C.M. 2015. Guayule (*Parthenium argentatum*) pyrolysis biorefining: Production of hydrocarbon compatible bio-oils from guayule bagasse via tail-gas reactive pyrolysis. Fuel. 158:948-956.

Chagas, B. M. E., Mullen, C. A., Dorado, C., Elkasabi, Y., Boateng, A. A., Melo, M.A.F., Ataíde, C.H. 2016. Stable bio-oil production from proteinaceous cyanobacteria: tail gas reactive pyrolysis of spirulina. Industrial & Engineering Chemistry Research. 55(23):6734-6741.

Production of biorenewable calcined coke. To succeed financially, a pyrolysis-based fuel refinery must also produce valuable chemical coproducts. When heated to temperatures of more than 1,200^{o} C, petroleum coke reacts by becoming calcined petroleum coke (CPC), an almost completely pure form of carbon with many useful physical characteristics. Global producers of aluminum and steel rely on CPC for production, and their demand for better CPC continues to increase. However, impurities such as sulfur, nickel, and vanadium have interfered with the efficient use of CPC. ARS researchers in Wyndmoor, Pennsylvania, successfully converted the heaviest fractions of renewable pyrolysis bio-oil, which were recovered after distillation of the volatiles, into a biocoke product similar to CPC, but free of impurities and with improved chemical properties. A patent application has been filed for the technology. In addition, ARS scientists have begun larger-scale experiments for producing biocoke with the goal of pilot-scale testing their product with a cooperator. Rio Tinto Alcan, a global consumer of calcined coke, has expressed interest in continuing cooperative research and development with ARS on this technology.

Elkasabi, Y., Boateng, A.A., Jackson, M.A. 2015. Upgrading of bio-oil distillation bottoms into biorenewable calcined coke. Biomass & Bioenergy. 81:415–423.

Elkasabi, Y., Darmstadt, H., Boateng, A.A. 2017. Coke produced from lower-oxygen fast-pyrolysis bio-oil: A new approach to produce renewable anode raw materials. Light Metals 2017, The Minerals, Metals & Materials Series 1221–1227.

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

Bio-oil is the liquid obtained from pyrolysis, which is the thermal decomposition of biomass. This liquid can be treated or upgraded into fuels identical to those produced from petroleum and other biobased chemicals. For economic sustainability, the industry must identify profitable applications for pyrolysis that utilize cost-competitive feedstocks in ready supply. ARS researchers and university scientist collaborators developed production/economic models to estimate both capital and operational costs associated with pyrolysis conversion of different agricultural wastes into valuable bio-oil products.

Models improve sustainability of tail gas reactive pyrolysis bio-oil production from guayule bagasse. ARS scientists in Wyndmoor, Pennsylvania, teamed with ARS researchers from Albany, California, and researchers at Swarthmore College in Pennsylvania to investigate the economics of processing the guayule waste material bagasse into biofuels. Since only about 5 percent of the guayule plant is rubber latex, industry needs support in finding uses for the rest of the plant. Based on processing a minimum of 200 metric tons of guayule bagasse per day (the current availability of the industry) into biofuels, the analysis estimated a $58.7 million capital cost and annual operating costs of $14.3 million for a tail gas reactive pyrolysis (TGRP) facility co-located with a guayule processing facility. The minimum selling price calculated for the fuel products derived from guayule bagasse was $7.12/gallon for gasoline, $6.97/gallon for jet fuel, and $7.22/gallon for diesel fuel. However, model results indicated that a facility with the capacity to process 2,000 metric tons of bagasse/day could lower the minimum price of gasoline to $3.63/gallon. Two U.S. tire companies are developing guayule natural rubber technology and this information will help support guayule natural rubber production as an economically viable alternative to imported and petroleum-based rubber.

> Sabaini, P.S., Boateng, A.A., Schaffer, M.A., Mullen, C.A., Elkasabi, Y.M., Mcmahan, C.M., and Macken, N. 2018. Techno-economic analysis of guayule (*Parthenium argentatum*) pyrolysis biorefining: production of biofuels from guayule bagasse via tail-gas reactive pyrolysis. Industrial Crops and Products. 112:82-89

Models for using bio-oil to generate electricity in Brazil. ARS scientists in Wyndmoor, Pennsylvania, cooperated with colleagues from the Brazilian Agricultural Research Corporation (Embrapa) to evaluate the economic feasibility of using bio-oil produced from eucalyptus wood tail gas reactive pyrolysis (TGRP) to generate electricity in Brazil. Two different scenarios were modeled: a single bio-oil facility (2,000 metric tons of wood per day) and several distributed small facilities with similar aggregate capacity feeding into one centralized electricity generation facility. From the economic analysis, the estimated breakeven selling price of the electricity generated was $0.11 per kilowatt for the large single facility and $0.20 per kilowatt for the smaller distributed facilities. The results indicate that pyrolysis of eucalyptus wood for electricity in a single facility was competitive with the current electricity cost in Brazil ($0.08-0.13 per kilowatt). When considering auxiliary benefits such as climate change impacts, carbon credits, and increasing electricity market prices in Brazil, even the distributed scenario may someday become competitive with fossil fuel-based electricity. The model was developed in collaboration with Embrapa Agroenergy and has been transferred to them.

> Pighinelli, A.L., Schaffer, M.A., and Boateng, A.A. 2018. Utilization of eucalyptus for bioelectricity production in Brazil via fast pyrolysis: a techno-economic analysis. Renewable Energy. 119:590-597.

Modeling the economics of producing bio-oil from horse manure. ARS researchers in Wyndmoor, Pennsylvania, teamed with scientists from Drexel University, Swarthmore College, and the University of Antwerp to apply their tail gas reactive pyrolysis (TGRP) technology and modeling expertise to utilizing horse manure. Manure, usually considered an agricultural waste, is an apt feedstock for conversion to renewable fuels and chemicals when TGRP is employed. The researchers used production and economics modeling to evaluate converting 200 dry metric tons of horse manure per day to bio-oil and then upgrading the bio-oil to jet fuel and phenolic chemicals [Figure 4]. Their analysis showed that the minimum estimated selling price of the jet fuel created through this process ($1.35-$1.80 per liter) was much greater than that of petroleum-based aviation fuel ($0.42 per liter). A significantly lower price closer to fossil fuel would be possible when the market conditions were optimal and included significantly high selling prices for the coproducts (phenols). However, pyrolysis gases had less impact on the environment, including greenhouse gases, than those from fossil fuels. This information can have significant impact on North American horse owners who could develop a revenue source instead of paying an estimated $50 million dollars per month to properly dispose of 7 million tons of equine waste.

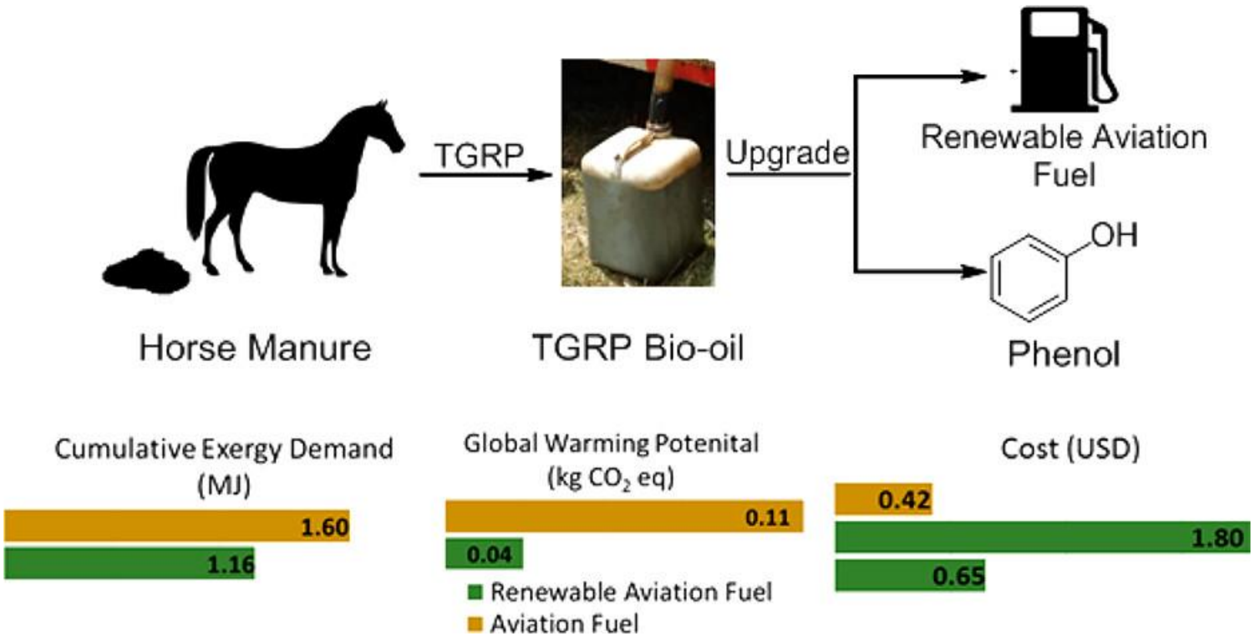


Figure 4: ARS researchers modeled the use of tail gas reactive pyrolysis technology to convert horse manure to aviation fuel and valuable co-product chemicals.

Sorunmu, Y., Billen, P., Elkasabi, Y.M., Mullen, C.A., Macken, N., Boateng, A.A., and Spatari, S. 2017. Fuels and chemicals from equine-waste-derived tail gas reactive pyrolysis oil: Technoeconomic analysis, environmental and exergetic life cycle assessment. ACS Sustainable Chemistry and Engineering. 5:8804-8814.

Investigating sustainability of biofuel production from wood mill waste through modeling. ARS researchers in Wyndmoor, Pennsylvania, worked with University of Maine researchers to develop a model of a biorefinery that could convert 2,000 metric tons of wood mill byproducts per day into gasoline and diesel fuel. The techo-economic analysis allowed varying facility/equipment sizes and estimated both capital and operational costs. The unique aspect of the process simulated pyrolysis char and gases to be used as sources of both thermal energy and hydrogen, thus greatly decreasing the need for fossil-based energy. The total capital investment for a grass-roots plant was estimated to be $266 million with an annual operational cost of $130 million. With a 30-year project life, a minimum fuel selling price (base cost plus internal rate of return) was determined to be $4.86 per gallon. The analysis results showed that the biofuels produced would not be competitive in the current market conditions. However, wood mill waste is still generally an attractive feedstock for pyrolysis processes. This information is critical for anyone considering development of a pyrolysis-based biomass biorefinery. The University of Maine has an extensive relationship with mills and forest owners, and this work is part of their portfolio used to evaluate options for them.

Carrasco, J.L., Gunukula, S., Boateng, A.A., Mullen, C.A., Desisto, W.J., and Wheeler, C.M. 2017. Pyrolysis of forest residues: an approach to techno-economics for biofuel production. Fuel. 193:477-484.

National Program 306
Quality and Utilization of Agricultural Products

NP 306 Accomplishment Report 2013-2017

BACKGROUND AND GENERAL INFORMATION

Thanks to decades of research, U.S. agriculture production is high-yielding, tech-driven, relatively low-cost, and becoming more economical. But according to "Food Prices and Spending," a current analysis conducted by the USDA Economic Research Service, the costs for processing and packaging agricultural commodities into marketable goods we eat or wear are nearly triple production costs and continue to rise. Because of these greater costs associated with processing and packaging, the economic viability of agricultural producers and processors depends on providing consumers with high quality products at competitive prices, producing those goods efficiently and in an environmentally sustainable manner, and maintaining the quality and utilization of agricultural commodities after they are harvested (postharvest). This is accomplished by the direct transport and sale of harvested goods to consumer markets, or by enhancing products to be marketed with packaging, preservation, or other processing.

Consumers usually use at least one sensory response (sight, smell, taste and texture) to assess food quality, while processors or manufacturers may use more quantitative measures such as sugar or moisture content, product durability, or foreign matter content to assess the quality of food or nonfood products. Preserving or improving the postharvest quality of agricultural products for a reasonable amount of time is paramount and requires techniques to define and measure quality characteristics and understand how processing affects these characteristics. Many agricultural products require some level of processing before they are marketable, and many products benefit from postharvest processing to enhance value. To remain economically viable, processors strive to produce high-quality, innovative products that meet consumer demand, improve production efficiency, and improve their environmental footprint by reducing the use of water, chemicals, and energy.

ARS established National Program 306 (NP 306), Quality and Utilization of Agricultural Products, to conduct research on postharvest food and nonfood lifecycles from the field to the consumer. The goal of NP 306 is to enhance the economic viability and competitiveness of U.S. agriculture by maintaining the quality of harvested agricultural commodities, enhancing their marketability, meeting consumer needs, developing environmentally friendly and efficient processing concepts, and expanding domestic and global market opportunities through the development of value-added food and nonfood technologies and products, except energy and fuels.

Consumers care about food quality, safety, and prices, while losses during harvesting, processing, and storage reduce the already-narrow profit margins of agricultural producers and processors. Agricultural industries are also increasingly affected by energy and production costs, regulation, and the loss of market share to synthetic products and foreign competition. By developing knowledge, techniques, and technologies for agricultural producers and processors, NP 306 quality and utilization research benefits agricultural producers and rural communities by increasing the value of agricultural products, reducing postharvest losses, and reducing industry risk. Research conducted by ARS scientists achieved significant accomplishments toward NP 306 goal in three main areas:

1. New knowledge about the attributes contributing to product quality, and new methods and instrumentation for the rapid and accurate assessment of raw, in-process, or completed material quality. This research allows producers and processors to reduce costs, improve consistency, and assess and promote new cultivars.
2. Identifying and understanding biologically active food compounds and developing functional foods and food ingredients that support and enhance human health. This work improves existing agricultural products, creates new market opportunities, and advances the development of new products that increase producer revenue.
3. Increasing profitability and reducing risk for processors with new methods, processes, and technologies that enhance product quality and safety; improve process efficiencies; and reduce waste, energy use, and adverse environmental impacts. This research provides tools that help producers and processors increase productivity, comply with regulatory standards, and remain competitive in global markets.

PLANNING AND COORDINATION FOR THE NP 306 5-YEAR CYCLE

In 2013, NP 306 National Program Leaders and researchers met with stakeholders from agriculture, industry, universities, and other governmental agencies to identify needs for NP 306 research during the next 5-year cycle. Many of the research needs previously identified by stakeholders were still relevant, while new research needs were identified in response to changing societal, economic, and environmental issues and concerns. National Program Leaders obtained input from other ARS scientists and customers/stakeholders and identified priority needs that could be realistically addressed with ARS resources and base funding. These were summarized into problem statements and categorized in two research components under the NP 306 Action Plan that began its current 5-year research cycle in 2015.

ARS research leaders and individual scientists used the Action Plan and direction from the National Program Leader to develop objectives for their research projects. Project lead scientists then developed highly detailed 5-year project plans—similar to those presented in peer-reviewed papers—based on the assigned objectives. These plans were reviewed for relevancy and scientific quality by an external peer panel coordinated by the ARS Office of Scientific Quality Review. Panel suggestions for greater clarity and focus on research approaches and methods of some project plans were addressed by the lead scientists and subsequently approved by the panel.

To expand on the increased demand for agricultural products that benefit both agricultural producers and rural communities, National Program Leaders decided to merge the Biorefining National Program (NP 213) with the Quality and Utilization of Agricultural Products National Program (NP 306) into a new National Program, Product Quality and New Uses (NP 306). This merger will begin with the upcoming 5-year research cycle. The new 5-year research cycle will start with a customer/stakeholder workshop in late 2018. After the workshop, a new Action Plan will be drafted and this will be followed by the establishment of new research objectives, which will be completed in early 2019.

STRUCTURE OF NATIONAL PROGRAM 306

NP 306 categorizes agricultural product quality and utilization research into two basic Components: Food and Nonfood.

COMPONENT 1: Food

A range of factors can be used to assess product quality. For food, these factors include aspects relating to appearance, texture, smell, and taste, but they can also incorporate physical and chemical characteristics such as moisture content or acidity. It is essential to identify and define characteristics that contribute to product quality in order to establish meaningful quality standards or grades. In Component 1, ARS researchers investigate the relationships between chemical, physical, and sensory attributes that affect how consumers perceive and consume food. Researchers develop new detection devices and methods to objectively identify, define, and measure important attributes and defects in grains, vegetables, and fruits. In addition, they study food qualities that enhance human health, identify biologically active food compounds, and determine the role of these compounds in human physiology. This information can be used to guide breeding programs and production practices and to develop products with enhanced bioactive qualities. Food processing research advances technologies for preserving, preparing, and using food products and supports increased production, reduces production costs, and improves environmentally sustainable management. All these results are key to maintaining an adequate, healthy, and affordable food supply, and are essential for ensuring the economic viability of U.S. food providers.

COMPONENT 2: Nonfood

U.S. fiber and hide industries are challenged by increasing energy and labor costs, more stringent environmental regulations, and the demand for higher product quality, and face increasing competition in the global marketplace from synthetic products. To remain viable, the U.S. cotton, hides, and biobased products industries must develop new processes and products and improve the management and use of wastes and secondary products. ARS scientists have enhanced product quality preservation by developing improved harvesting, processing, and storage technologies and improved quality measurement and grading systems. Researchers have also learned more about basic material structures and properties and used this information to facilitate product enhancement. They have also developed more environmentally friendly technologies and new applications and products for hides, agricultural fibers, and associated byproducts.

ARS scientists conduct NP 306 research at 22 locations [Figure 1]. This research includes 58 projects addressing agricultural postharvest needs (36 in Food and 22 in Nonfood). Research in each project is assigned to one or more of the components under the current NP 306 Action Plan specifically targeting research in a priority area of agricultural product quality and utilization.

Figure 1: 306 research locations

RELATIONSHIP OF NP 306 TO OTHER NATIONAL PROGRAMS

NP 306 research helps scientists in other National Programs by quantifying product bionutrients and marketable quality attributes and by developing measurements and processes relevant to associated research. Some of that assistance is illustrated in Figure 2:

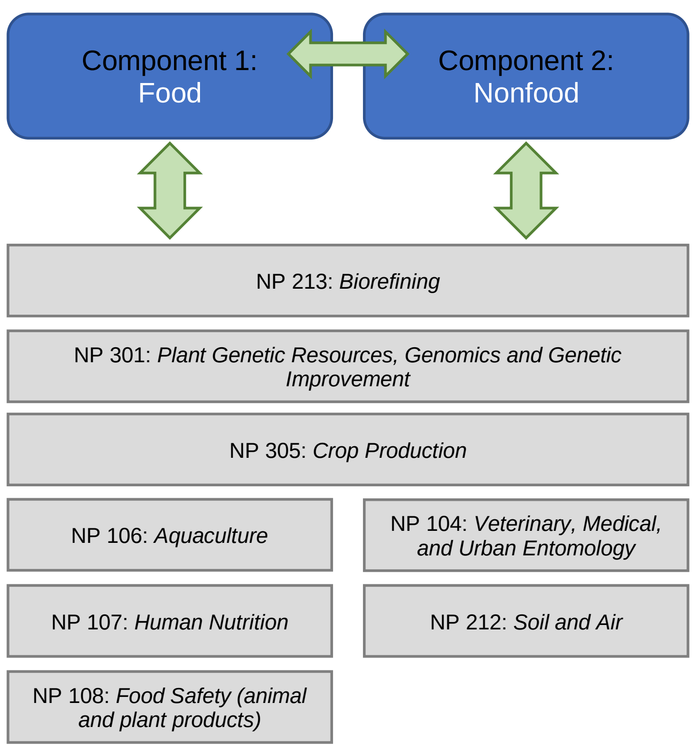


FIGURE 2: Research associations between NP 306 and other ARS National Programs

NP 103 (Animal Health); NP 104 (Veterinary, Medical, and Urban Entomology)**:** NP 306 scientists who develop biobased products collaborate with NP 103 and NP 104 scientist on developing products to combat animal diseases, parasites, and pests.

NP 106 (Aquaculture)**:** NP 106 scientists conduct research to support a domestic aquaculture industry by improving genetic stocks and scientific information on biotechnologies and management practices; they collaborate with NP 306 scientist to ensure the quality, safety, and nutrition of aquaculture food products.

NP 107 (Human Nutrition): Before recommending or using new plant-based foods and varieties, processed foods, or new food-handling procedures, NP 107 researchers rely on NP 306 scientists to establish changes in sensory qualities (consumer acceptance) and nutritional composition (bioactive compounds), and to establish quality standards.

NP 108 (Food Safety): NP 108 scientists develop treatments (chemicals, temperatures, and modified gas atmospheres) to control enteric bacteria, and collaborate with NP 306 scientists on establishing treatment tolerances to avoid adversely affecting the nutritional/marketable quality of agricultural foods and bioproducts.

NP 212 (Soil and Air); NP 305 (Crop Production)**:** NP 212 and NP 305 scientists measure changes in climate, soils, and atmospheric gas emissions and develop conventional and organic production systems. They work closely with and rely on NP 306 scientists to establish “cause-and-effect” changes in food and fiber end-product quality and the suitability of agricultural resources for bioproduct development.

NP 213 (Biorefining)**:** NP 306 scientists select and determine suitable feedstocks and cellulosic plant sources used in technologies developed by NP 213 researchers for hydrolyzing/producing fermentable sugars that can be commercially converted into non-fuel industrial products. In particular, NP 213 and NP 306 scientists colocated in Albany, California; Peoria, Illinois; New Orleans, Louisiana; and Wyndmoor, Pennsylvania, closely coordinate work in postharvest quality, processing, and bioconversion of agricultural feedstocks.

NP 301 (Plant Genetic Resources, Genomics, and Genetic Improvement)**:** NP 306 scientists collaborate with NP 301 scientists in establishing the impact of genetic changes and modifications—intended or unintended—on end-product physiology, as well as on appearance, flavor, bionutrient quality, and functional use of bioproducts.

HOW THIS REPORT WAS CONSTRUCTED AND WHAT IT REFLECTS

This report assembles some of the many accomplishments of NP 306 from 2013 through 2017, a period that straddles the previous Action Plan for 2010-2014 and the current one for 2015-2019. Reporting on a period that does not match either action plan is necessary because of the need to review past accomplishments before beginning the process of developing a new Action Plan for the next 5-year cycle.

This NP 306 Accomplishment Report is a distillation of some of the most significant research accomplishments achieved by scientists working in this National Program over the past 5 years. By necessity, it is a 5-year snapshot that encompasses ongoing research and the early benefits of that research. The content of this report is mostly derived from the annual reports of the NP 306 projects from the past 5 years. This report stresses the impacts of those accomplishments and, where relevant, cites key publications or Web links documenting those accomplishments.

In the same way that only selected accomplishments are reported, details of those accomplishments are selected and summarized to illustrate the overall variety of products and knowledge generated by this National Program. Individual researchers or projects are not identified by name in the narrative text; rather, their achievements are described in the context of contributions towards accomplishing the Program's stated commitments to U.S. agriculture.

This report was prepared for an external (to ARS) retrospective review of NP 306 to assess its overall performance in attaining the projected goals outlined in its current Action Plan. The purpose of the retrospective review is not to judge the specific performance of individual NP 306 research projects, but rather to gauge the larger impact of the Program. Consequently, the report does not attempt to catalogue all the individual accomplishments reported by the scientists assigned to NP 306 research projects.

The retrospective panel will be grading the accomplishments against the proposed actions outlined in the Problem Statements, which are more general than the Anticipated Products listed in the Action Plan. An individual accomplishment might be applicable to more than one problem statement and more than one set of anticipated products. Each accomplishment is matched with a publication or patent to provide additional detail and to demonstrate it has passed rigorous scientific peer review. Appendix 1 includes a list of the current projects with scientists in NP 306. Appendix 3 has a complete bibliography of peer-reviewed publications generated by the NP 306 scientists organized by project. Appendix 5 contains a list of all patents and licenses under each project.

COMPONENT 1: Food

For consumers, food is much more than an essential source of sustenance. People select food based on its taste, nutritional benefits, shelf life, price, convenience, and appearance—all attributes that contribute to food quality. Scientists conducting research to assess food quality or to determine or improve food quality standards or grades must identify, define, measure, and preserve food attributes contributing to appearance, flavor, and nutritional characteristics. These attributes can include color pigments, surface components, aroma, fundamental tastes (sweet, sour, bitter, astringent, and savory), textures, and bioactive compounds that affect human health. In addition, food processing and packaging can greatly influence food quality, safety, and nutrition, while new food processing techniques are needed to preserve and add value to foods, utilize wastes, and reduce costs.

The research under Component 1 is focused on developing technologies that improve food quality, extend product shelf life, and reduce food waste. ARS scientists are also developing innovative processing and packaging methods and techniques that will reduce producer costs. The research in this Component is grouped into three Problem Statements that were identified to address the research needs of food producers:

- 1.A. Define, Measure, and Preserve/Enhance/Reduce Attributes that Impact Quality and Marketability.
- 1.B. New Bioactive Ingredients and Functional Foods.
- 1.C. New and Improved Food Processing and Packaging Technologies.

Problem Statement 1.A: *Define, measure, and preserve/enhance/reduce attributes that impact quality and marketability.*

Measuring attributes that contribute to food quality is essential for understanding their effects and developing tools that preserve and enhance desirable characteristics. To address this Problem, ARS researchers developed methods to accurately assess food quality, and explored connections between food quality attributes and production, manufacturing, and handling processes that affect those attributes. Researchers also developed novel methods and technologies to maintain and improve the quality of food as it is transported to market. The following accomplishments are a sampling of the many results from ARS research conducted under this Problem Statement; these include an egg candling system and supporting software; research into understanding flavors that led to a "better" tomato; and recommendations about optimal storage conditions for peanuts.

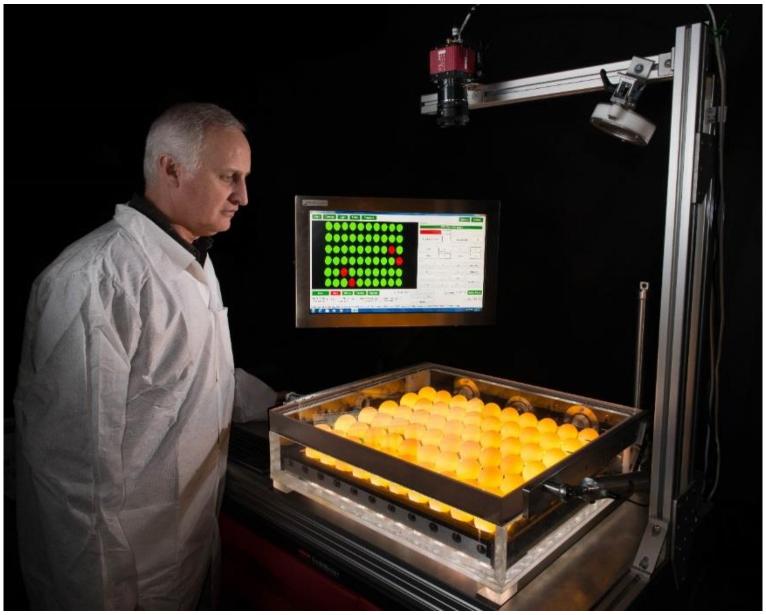


Figure 1: A new egg grading system uses LED light and computerized software.

LED portable egg candling system and online data management software. Commercial egg candling grading systems that used obsolete incandescent bulbs are no longer manufactured. The Agricultural Marketing Service (AMS) needed their egg grading units upgraded to accommodate the use of high intensity LED candling lights. ARS scientists in Athens, Georgia, designed and developed portable and stationary high-intensity, white LED light grading systems and engineered a computerized software system designed to specifically meet AMS needs for egg grading [Figure 1]. The software system, which was developed to monitor, collect, and process egg grading data, replaced the use of paper data forms and collected real-time data suitable for statistical and trend analysis. AMS graders and administrators were impressed with the LED egg candling device and immediately deployed the system for field testing. AMS recently replaced all their candling lights nationwide with the new ARS LED technology, as have many state egg graders. An ARS certification process is under development to ensure security of the Web server application software system. The LED egg candling system was transferred to a commercial partner who is manufacturing the technology and to date has sold more 600 units. ARS scientists conducting this work identified developing and transferring technology that met industry needs as their first priority, so papers describing the research and results are still being drafted.

New tomato variety developed from fruit taste study. Extensive tomato breeding efforts have resulted in the development of varieties with improved disease resistance, yield, and size, but these varieties lack appealing flavor. ARS scientists in Fort Pierce, Florida, collaborated with University of Florida researchers and evaluated 38 tomato varieties over 7 years to better understand how the chemical profiles of different tomato varieties affect flavor and sensory perception by consumers. They found the chemical profiles in tomato are significantly affected by variety and harvest season. Based on this study, University of Florida collaborators developed ‘Tasti-Lee,’ a new tomato variety now readily available in supermarkets across the Southeast and in Texas [Figure 2]. The researchers compared levels of compounds that affect tomato aroma between Tasti-Lee and

Figure 2: ARS researchers study tomato flavors to help develop better tasting varieties.

'Florida 47,' an industry standard. The level of eight compounds that contribute to ripe-fruit and floral aromas were higher in Tasti-Lee, and the level of four compounds that contribute to non-ripe green fruit aromas were higher in Florida 47. This chemical model for tomato flavor quality is available to breeders of other fruits and vegetables who want to develop varieties with improved flavor. ARS researchers continue to work with University of Florida breeders on other produce varieties for the horticulture industry.

Baldwin, E.A., Scott, J.W., Bai, J. 2015. Sensory and chemical flavor analyses of tomato genotypes grown in Florida during three different growing seasons in multiple years. Journal of the American Society for Horticultural Science. 140(5):490-503.

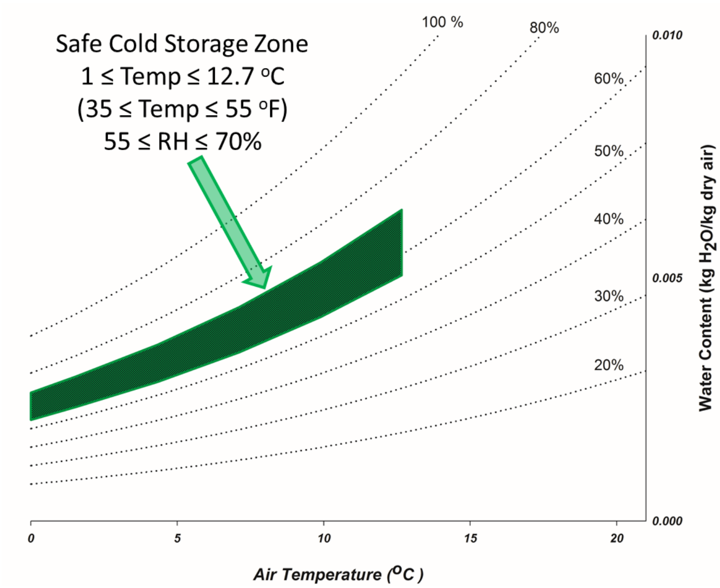


Figure 3: Research established an expanded range of safe temperature and humidity for storing shelled peanuts. Storing peanuts at 55 F° reduces risk of mold during transport from cold storage to market.

Warmer peanut storage improves quality, eliminates mold, and saves energy. Current conventional storage of shelled peanuts at 38° F routinely causes peanuts to become moldy in storage. ARS engineers in Dawson, Georgia, determined that a mold develops within the top region of peanuts in bulk storage containers when shelled peanuts are placed in cold storage at 38° F immediately after harvest and processing. Researchers conducted a 12-month study and determined optimal storage conditions to preserve peanut quality occurred when peanuts were stored at 55° F with 65 percent relative humidity [Figure 3]. The American Peanut Council is in the process of using these findings to update its Good Management Practices for maintaining and operating cold storage facilities for shelled peanuts. Peanut shellers (the first processors) are slowly implementing the change in privately owned cold storage facilities and a major peanut shelling company in Georgia reported that raising the storage temperature from 38° F to 55° F reduced mold growth and also reduced energy consumption by approximately 50 percent.

Butts, C.L., Lamb, M.C., Sorensen, R.B., Powell, S., Cowart, D., Horm, K., Anthony, B., Bennett, J. 2017. Alternative storage environments for shelled peanuts. Peanut Science. 44(2):111-123.

<u>Problem Statement 1.B</u>: *New bioactive ingredients and functional foods.*

Consumers want more from food than just calories and nutrients. They want foods that not only provide fuel but also support good health through improved nutrition. Research under Problem Statement 1.B addresses those expectations by identifying and understanding the effects of biologically active food compounds and then developing bioactive ingredients and foods that support and promote good health. The following accomplishments highlight research that focuses on these issues: ARS scientists produced margarine without saturated fats, used sesame seed oil to protect omega-3 oil, and developed a nutritious snack bar that may help improve obesity-related health issues.

A new imitation margarine without trans-fats or saturated fats. Many food products require fats such as *trans*-fats or saturated fats because of their ability to remain solid at room temperatures, acceptable sensory characteristics, and longer shelf life. Recent regulatory changes requiring the elimination of *trans*-fats from foods has resulted in companies replacing *trans*-fats with saturated fats from imported palm oil. However, these saturated fats present their own long-term risks to human health. ARS scientists in Peoria, Illinois, investigated inexpensive and edible plant waxes that can be added to low-cost unsaturated vegetable oils, such as soybean oil, to create a solid fat product called an 'organogel.' The scientists used organogels made from plant wax and soybean oil to prepare an organogel margarine that had the same spreadable firmness as margarine made from hydrogenated soybean oil, but without any added saturated fats or *trans*-fats [Figure 4]. These results suggest organogels made with soybean oil or other unsaturated plant oils produced in the United States can replace hydrogenated *trans*-fat oils and reduce the need for expensive imported palm oil, which would benefit U.S. farmers and food oil processing companies. Companies that make margarines and shortening have shown interest in using organogels in their products, and ARS is actively seeking industry partners to apply this technology to consumer food products. Research continues on tailoring organogel properties for specific applications.

Figure 4: A process developed by ARS turns a liquid oil into organogel, which can then be used to make margarine without *trans* or saturated fat.

Hwang, H.-S., Singh, M., Bakota, E.L., Winkler-Moser, J.K., Kim, S., Liu, S.X. 2013. Margarine from organogels of plant wax and soybean oil. Journal of the American Oil Chemists' Society. 90:1705-1712.

Hwang, H.-S., Singh, M., Lee, S. 2016. Properties of cookies made with natural wax-vegetable oil organogels. Journal of Food Science. 81(5):C1045-C1054.

Sesamol, an alternative to synthetic antioxidants for protection of omega-3 oils. The use of omega-3 oil supplements and foods fortified with these oils has increased in recent years because omega-3 oils have beneficial health effects in fetal brain development and in reducing the incidence of heart attacks and inflammation. However, omega-3 oils are easily catabolized by oxidation and heat and require antioxidants to protect them from degradation. ARS researchers in Peoria, Illinois, treated fish oil with sesamol, a natural compound found in sesame seed oil, to prevent oxidation in fish oils subjected to heat and oxygen. Sesamol demonstrated stronger antioxidant activity than butylated hydroxytoluene, a widely-used commercial synthetic antioxidant, and rosemary extract, the leading commercial natural antioxidant. Sesamol offers an inexpensive, food label-friendly alternative to synthetic antioxidants for protecting omega-3 oils, and does not present the flavor, odor, color, and solubility issues associated with the use of rosemary extracts. Industry has expressed an interest in sesamol and ARS researchers are seeking industry partnership. Work is continuing on using the antioxidant properties of sesamol for other applications.

Fhaner, M., Hwang, H.-S., Winkler-Moser, J.K., Bakota, E.L., Liu, S.X. 2016. Protection of fish oil from oxidation with sesamol. European Journal of Lipid Science and Technology. 118(6):885-897.

***A fruit-based nutrient bar promotes weight loss and improves insulin resistance in clinical studies*.** One in three U.S. adults is considered obese, and obesity is linked to several serious health issues. ARS scientists in Albany, California, collaborated with Children's Hospital Oakland Research Institute in developing a low-calorie, fruit-based snack bar fortified with micronutrients, fiber, and other critically healthy components lacking in a typical Western diet. Adults who ate two bars daily for 8 weeks without other changes in diet or exercise lost weight and showed other positive changes in cardiovascular health, insulin resistance, and inflammation levels. ARS was issued a patent for this fruit snack bar. It has also been licensed to Keen Growth Capital, which is working on commercializing the bars worldwide as a new healthy food product. Net sales in the next 5 years are anticipated to be around $15M.

McCann, J.C., Shigenaga, M.K., Mietus-Snyder, M.L., Lal, A., Su, J.H., Krauss, R.M., Gildengorin, G.L., Goldrich, A.M., Block, D.S., Shenvi, S.V., McHugh, T.H., Olson, D.A., Ames, B.N. 2015. A multicomponent nutrient bar promotes weight loss and improves dyslipidemia and insulin resistance in the overweight/obese: Chronic inflammation blunts these improvements. Journal of Federation of American Societies for Experimental Biology. 29(8):3287–3301.

Problem Statement 1.C: *New and improved food processing and packaging technologies***.**

The U.S. food industry must meet the challenge of providing secure, nutritious, and affordable food for a growing population while limiting its environmental footprint and remaining economically viable. ARS research under Problem Statement 1.C addresses this challenge with the development of processing, packaging, and preservation technologies that make foods safer and last longer; reduce and/or utilize wastes; increase process efficiency; and enhance nutritional benefits. A novel process to make pickles more environmentally friendly, a low-energy drying method that makes fruits and veggies look and taste better, and an edible packaging film made from milk are a few examples of the research accomplishments in this section.

Supporting the U.S. pickle industry**.** To avoid the possibility of closure, some U.S. pickling processors needed to meet U.S. Environmental Protection Agency mandates for reducing environmentally damaging chloride emissions. ARS scientists in Raleigh, North Carolina, developed a reduced sodium chloride (NaCl) salt or NaCl-free fermentation and bulk storage process by substituting calcium chloride (CaCl) for NaCl [Figure 5]. This novel process uses 90 percent less CaCl to achieve the same fermentation as NaCl and alleviates chloride discharge by 90 percent while significantly reducing the environmental impact of high NaCl waste into water streams. This project was completed in 2015 and the technology was introduced for testing under winter conditions at commercial pickle companies in the Midwest. The North Carolina pickling industry reported substantial savings in production cost and significantly reduced the environmental impacts resulting from pickling processes.

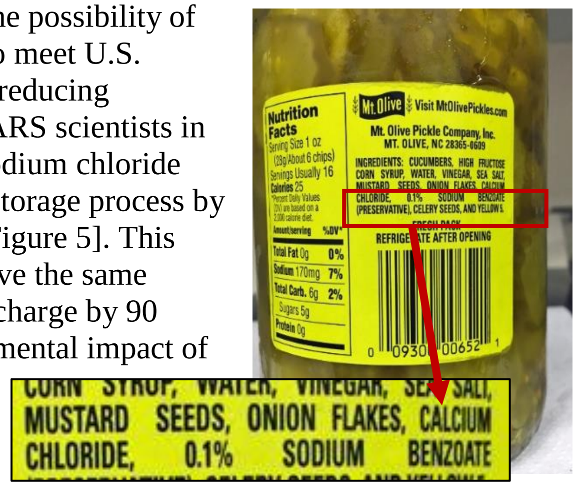


Figure 5: ARS scientists substituted calcium chloride salt for sodium chloride in pickle fermentation, making the process more environmentally friendly.

Perez Diaz, I.M., McFeeters, R.F., Moeller, L., Johanningsmeier, S.D., Hayes, J.S., Fornea, D., Gilbert, C., Custis, N., Beene, K., Bass, D. 2015. Commercial scale cucumber fermentations brined with calcium chloride instead of sodium chloride. Journal of Food Science. 80(12):M2827-M2836.

Crispy, healthy fruit and vegetable-snack drying system is commercialized**.** Healthy, high quality, and safe fruit, vegetable, and nut products can be important components in fighting obesity, improving human health, and supporting farmers and small businesses. Hot-air drying of fruit and vegetables is a U.S. industry worth $50 billion annually, but it is also the third largest industrial energy user in California. To substantially reduce energy usage and improve dried produce appearance and flavor, an ARS scientist in Albany, California, developed an infrared-blanching and hot-air drying system. The system generated affordable, crispy, and healthy snacks from carrots, kale, bell peppers, squashes, pears, and apples at commercial production scales. It also reduced energy use 75 percent, which reduced associated environmental pollution. A patent for the system was exclusively licensed to Treasure8 to produce healthy, crispy fruit and vegetable snacks, and this research provided the foundation for other scientists around the globe to explore infrared food processing. The California Energy Commission provided support for this research.

Pan, Z., McHugh, T.H. 2017. Infrared dry blanching, infrared blanching and infrared drying technologies for food processing. U.S. Patent No. 9,723,851 B2.

Edible packaging film from milk**.** Packaging is a critical part of modern food technology because of increased consumer interest in processed, pre-packaged foods. As a result, the food industry needs to develop cost-effective packaging materials that are consumer- and environmentally-friendly. Most foods are wrapped in petroleum-based plastic packaging, which is poor at preventing spoilage, creates waste, and is not biodegradable. ARS scientists in Wyndmoor, Pennsylvania, developed a biodegradable edible film from casein—a milk protein— made from expired milk. The new film is 500 times more effective than petroleum-based plastic at protecting food from damaging oxygen, making it significantly better at keeping foods fresher for longer periods of time. The milk-based film is versatile and can be made into pouches that dissolve in hot water; it can also be used to coat breakfast cereals and keep them crispy in milk, replacing high-calorie sugar coating that serves the same purpose. This technology can also be used to introduce intense colors, flavors, or textures within or on foods. This cost-effective, sustainable, biodegradable, and edible milk-protein film is currently being tested by a soup company in a food product and by a brewer to hold their products in dissolvable pouches.

Bonnaillie, L., Zhang, H., Akkurt, S., Yam, K., Tomasula, P.M. 2014. Casein films: effects of formulation, environmental conditions, and addition of citric pectin on the structure and mechanical properties. Polymers. 6:2018-2036.

Bonnaillie, L., Tomasula, P.M. 2015. Application of humidity-controlled dynamic mechanical analysis (DMA-RH) to moisture-sensitive edible casein films for use in food packaging. Polymers. 7(1):91-114.

COMPONENT 2: Nonfood (including hides)

The U.S. fiber and hide industries are facing significant challenges from the production and market globalization of raw cotton, wool, yarn and yarn products, raw animal hides, and finished leather products. These challenges include rising energy and labor costs, regulatory compliance, maintaining and improving product quality, developing new processes and products, and improving the management and use of waste and byproducts. ARS scientists enhance product quality by improving harvesting, processing, and storage technologies; improving quality measurement and grading systems; and conducting studies of basic fiber structure and properties. Their research has resulted in processing technologies with reduced environmental footprints and the development of new applications and products for hides and agricultural fibers, including new high-value coproducts.

The NP 306 Action Plan Component 2: Nonfood focuses on developing technologies that improve product quality and reduce the energy needs and environmental impacts of production. As part of this work, ARS researchers have developed new products that enhance the global competitiveness of U.S. producers and processors of cotton, hides, wool, and other nonfood agricultural products and coproducts. Three Problem Statements were identified for Component 2 to address the research needs of agricultural producers of nonfood products and commodities:

2.A. In collaboration with industrial partners, develop new post-harvest technologies: (i) to increase or protect the market demand for [or to increase the value of] existing U.S.-produced nonfood biobased products derived from agricultural products and byproducts, and (ii) to enhance product quality, improve process efficiencies, and reduce processing risks for existing U.S. producers of nonfood biobased products derived from agricultural products and byproducts.

2.B. Enable technologies for (i) expanding market applications for existing biobased products, or (ii) producing new marketable nonfood biobased products derived from agricultural products and byproducts and ensure that these technologies will generate economic impact by estimating their potential economic value**.**

2.C. Collaborate with breeders and production researchers in the development of both new cultivars/hybrids and new production practices/systems that optimize the quality and production traits of crop-derived products and byproducts for conversion into nonfood biobased products.

This report highlights some of the ARS accomplishments under these three Problem Statements.

Problem Statement 2.A: *In collaboration with industrial partners, develop new post-harvest technologies: (i) to increase or protect the market demand for [or to increase the value of] existing U.S.-produced nonfood biobased products derived from agricultural products and byproducts, and (ii) to enhance product quality, improve process efficiencies, and reduce processing risks for existing U.S. producers of nonfood biobased products derived from agricultural products and byproducts.*

Nonfood products such as animal hides or cotton have little or no value until they are processed by tanning, ginning, or other methods. Research under this Problem Statement targeted the development of methods, processes, and technologies to improve producer and processing efficiency, reduce production costs, and enhance product quality and value. This includes collecting production data and devising methods to reduce the environmental impact of nonfood production.

***Improving cotton harvesting machines*.** Stripper-type cotton harvesters are used on approximately half the U.S. cotton crop, but their non-selective harvesting mechanism collects excessive amounts of foreign material along with the cotton fiber. ARS scientists in Lubbock, Texas, developed a new design for harvester on-board cleaners that increases the cleaner's material throughput capacity by 20 percent without increasing fiber rejection rates, increasing harvester productivity by $5 to $10 per bale [Figure 1]. The benefits of the new design were validated in field trials. The CRADA partner, the only manufacturer of stripper harvesters, picked up certain aspects of the field cleaner design and integrated them into a new machine being tested by ARS. This improved harvester is slated to go into production with the 2020 model year. Due to intellectual property concerns, there have not been any publications on this technology to date.

Figure 1: stripper harvested cotton that has not been field cleaned (left); cotton processed by the field-cleaner system developed by ARS scientists (right).

***Low salt method to preserve bovine hides*.** Raw hides are currently preserved with high levels of salt (brine) for storage and shipment to tanneries, a practice that significantly increases tannery wastewater treatment costs. ARS scientists in Wyndmoor, Pennsylvania, developed a low-salt preservation formulation for hides using crude glycerol, a low-cost byproduct of biodiesel production, and polyethylene glycol. The leathers produced from hides preserved with the low-salt method were softer, more stretchable, and stronger than materials produced from hides preserved in traditional high-salt brine [Figure 2]. This work was presented to the American Leather Chemists Association and United States Hide, Skin and Leather Association and hide producers expressed significant interest in scaling up the method for commercial production. ARS worked with a commercial meat packer to validate the preservation method, and this work led to further studies to fine tune the method for commercial operations.

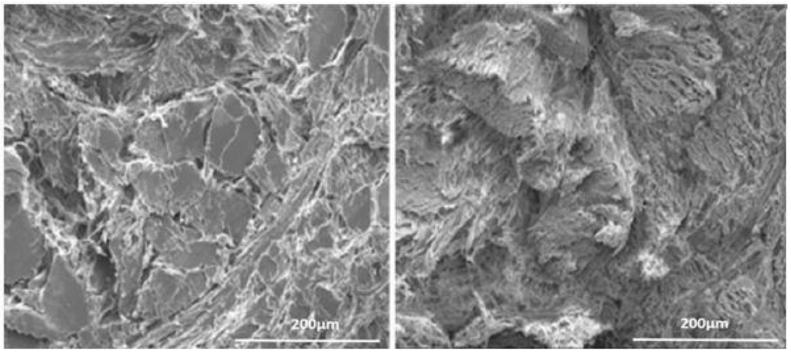


Figure 2:
Left: Cross-sectional view of leather produced from hides preserved with the low-salt method exhibit a more compact, smoother, stronger structure than leather produced from hides preserved in the traditional high-salt method (right).

Aldema-Ramos, M.L., Muir, Z.E., Truong, N., Trusello, J., Uknalis, J. 2015. Development of an alternative low salt bovine hide preservation using PEG and crude glycerol, Part I: Evaluation of PEG molecular weight fractions. Journal of American Leather Chemists Association. 110(4):109-113.

Aldema-Ramos, M.L., Muir, Z.E., Uknalis, J., Truong, N., Trusello, J. 2015. Development of an alternative low salt bovine hide preservation using PEG and crude glycerol, Part II: Mechanical properties of leather products. Journal of American Leather Chemists Association. 110(5):125-129.

***When the dust settles, the emissions are clear for U.S. cotton gins*.** The U.S. Environmental Protection Agency (EPA) establishes stringent limits for industrial dust emissions, and requires state regulatory agencies to submit plans on how they will reduce these emissions. However, there were no published cotton gin emissions data for fine dust particles of 2.5 micrometers in diameter and smaller (PM2.5), so state regulatory agencies ran the risk of overestimating gin emissions and developing regulations that did not reflect real-world emission levels. Regulations based on theoretical estimates could in turn result in additional and unnecessary costs for cotton gins identified as significant sources of PM2.5. As a result, these gins could be required to spend around $1 million each on technology and retrofits that would bring them into mandatory compliance with state emissions regulations. At the urging of cotton ginners and state agencies across the cotton belt, ARS engineers in Las Cruces, New Mexico; Stoneville, Mississippi; and Lubbock, Texas, partnered with university collaborators on a multi-year project to measure dust emissions at cotton gins across the United States [Figure 3]. A California regulatory agency used data from the study to develop their PM2.5 State Implementation Plan required by the EPA and recommended no additional regulatory actions for State cotton gins. Texas used the study results to revise its cotton gin permitting rules,

Figure 3: ARS personnel sampling dust emissions from stack of a dust abatement cyclone at a cotton gin.

and the data have also been used to support permits for gins in Kansas and Australia. These results will help state regulatory agencies develop plans in compliance with EPA regulations and increase the cost-effectiveness of cotton gins by ensuring emissions regulations are developed with accurate data collected in real-world production environments.

Whitelock, D.P., Buser, M.D., Boykin Jr, J.C., Holt, G.A. 2013. First stage seed-cotton cleaning system PM2.5 emission factors and rates for cotton gins: Method 201A combination PM10 and PM2.5 sizing cyclones. Journal of Cotton Science. 17(4):320-332.

Cleaning cotton using ultrasound eliminates chemicals, reduces waste. The process of cleaning cotton after harvest currently requires the use of dangerously hot, caustic substances and large amounts of rinse water, which generates large amounts of waste. ARS scientists in New Orleans, Louisiana, developed a combination of plant-based, sustainable enzymes and ultrasound energy to enhance cleaning conditions without generating waste. In an industrial setting this ultrasound/enzyme bio-cleaning process was applied to cotton fabrics without the need for expensive sound-attenuating enclosures or hearing protection for workers to protect them from potentially hazardous ultrasound waves. This process also reduced costs by 20 percent and alleviated concerns about exposing workers to caustic chemicals. The researchers also designed, manufactured, and tested a new roller system that allows the fabric to be continuously fed into the ultrasonic cleaning system, a significant improvement over the caustic, boiling, batch-dipping system. The process and roller system are being prepared for large-scale commercialization.

Easson, M.W., Wojkowski, S.A., Condon, B.D., Yeater, K.M., Slopek, R.P., Fortier, C.A. 2015. Ultrasound-enhanced bioscouring of greige cotton: regression analysis of process factors. American Association of Textile Chemists and Colorists Journal of Research. 2(1):16-23.

Problem Statement 2.B: *Enable technologies for (i) expanding market applications for existing biobased products, or (ii) producing new marketable nonfood biobased products derived from agricultural products and byproducts, and ensure that these technologies will generate economic impact by estimating their potential economic value.*

Biobased products must be competitive in the marketplace, especially with conventional, petroleum-based products. Agricultural producers and processors increasingly need alternative market opportunities for existing and new products, especially those that increase the value of byproducts. ARS researchers working on Problem Statement 2.B addressed these issues by finding new uses for agricultural products, enhancing existing products for different applications to increase value, or developing completely new and innovative products that use agricultural products or byproducts for production.

Superior cotton-based medical solutions for disinfecting. Disinfecting compounds such as quaternary ammonium salts (quats) are needed to successfully disinfect surfaces contaminated with infectious microorganisms. Wipes made of cellulosic materials such as cotton, rayon, and wood pulp retain quats and prevent the quats from targeting surfaces that need to be disinfected. While this retention is not an issue with synthetic wipes, synthetic materials lack the necessary abrasiveness and strength needed to thoroughly scrub surfaces, and they decompose slowly in landfills. ARS scientists in New Orleans, Louisiana, used statistical modeling and coformulation of quats with other specific chemicals and successfully reduced or eliminated the quat adsorption onto cellulosic substrates. They then combined non-ionic surfactants and electrolytes with 100 percent raw cotton and created strong, abrasive, and easily biodegradable wipes that release quats. These new disinfecting cotton wipes have passed Good Laboratory Practice efficacy testing required for registration with the U.S. Environmental Protection Agency, and are currently certified as killing vancomycin-resistant *enterococci* (VRE) and methicillin-resistant *Staphylococcus aureus* (MRSA), two bacteria that pose particularly high human health risks. The cotton-based wipes are currently being promoted and marketed by ARS research partner Cotton Incorporated and an industry consultant.

Superior cotton-based medical solutions for wound dressing. After blood clotting, low levels of hydrogen peroxide in cotton wound dressings are correlated with enhancing cell regeneration, which is critical in promoting rapid wound healing. ARS scientists in New Orleans varied the physical properties of short-staple nonwoven cotton to increase its blood clotting ability and showed that nonwoven cotton naturally produces more hydrogen peroxide than commercial wound dressings [Figure 4]. This work shows nonwoven cotton has promise as a better rapid blood clotting agent in first responder and battlefield dressings than gauze or other standard care dressings. Furthermore, cotton battlefield dressings comply with the U.S. government mandate for using domestic cotton in Department of Defense materials. The cotton-based wound dressing technology was developed in collaboration with H&H Medical, which is in its final phase of preparing to launch TacGauze, a new hemostatic wound dressing product. The new product will principally be supplied to U.S. and foreign military by the end of 2018; prospective customers include the U.S. Department of Homeland Security and the U.S. Marine Corps. ARS scientists are continuing this work through a CRADA with H&H on two other wound dressings with antimicrobial cotton finish and advanced battlefield hemorrhage control.

Figure 4: ARS scientists developed a new nonwoven cotton battlefield wound dressing that promotes blood clotting and healing better than commercial dressings.

Hinchliffe, D.J., Condon, B.D., Slopek, R.P., Reynolds, M.L. 2017. The adsorption of alkyl-dimethyl-benzyl-ammonium chloride onto cotton nonwoven hydroentangled substrates at the solid-liquid interface is minimized by additive chemistries. Textile Research Journal. 87(1):70-80.

Edwards, J.V., Graves, E.E., Bopp, A.F., Prevost, N.T., Santiago Cintron, M., Condon, B.D. 2014. Electrokinetic and hemostatic profiles of nonwoven cellulosic/ synthetic fiber blends with unbleached cotton. Journal of Functional Biomaterials. 5(4):273-287.

Biobased sponges derived from tannery waste. The U.S. leather and hide industries need to produce new products from raw hides and recycled tannery waste to successfully compete in global markets. Collagen sponges are widely used to stop bleeding in surgery and as scaffold material in tissue regeneration. ARS researchers in Wyndmoor, Pennsylvania, recently used hides and tannery waste to develop novel collagen sponges with unique and beneficial properties that enhance their use in medical applications [Figure 5]. The sponges can be generated from untanned hides, limed hides, and delimed-bated hides, as well as tannery waste of limed splits and their trimmings. This research has the potential to support the U.S. hides and leather industries in diversifying by producing high-value biobased sponges for medical applications.

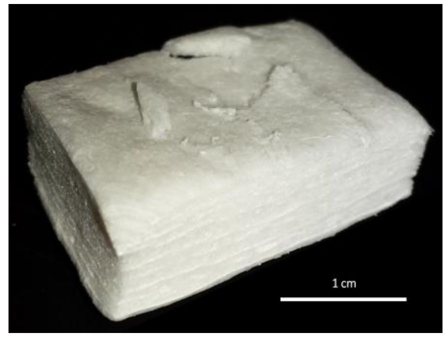


Figure 5: Stereomicroscopic view of the cross section of a biobased sponge derived from tannery waste.

Siddique, A., Latona, N. P., Taylor, M.M., and Liu, C.-K. 2016. Preparation of Biobased sponges from un-tanned hides. Journal of American Leather Chemists Association. 111(5):192-199.

Vegetable oil estolides are high performing, fuel-saving, renewable lubricants. Renewable biobased lubricants are in great demand. Estolides are fluids made from renewable animal- and vegetable-based oils, such as sunflower, canola, lesquerella, and pennycress. ARS scientists in Peoria, Illinois, refined and improved estolide properties and solved large-scale batch-production challenges such as incomplete fatty acid conversion to produce a lubricant that performs better at colder temperatures, reduces friction and wear, and has oxidative stability. Engines using these estolide lubricants are more fuel efficient, stay cooler and have less deposit buildup and sludge formation than with conventional motor oil [Figure 6]. This new technology was licensed to an industrial partner that was granted SAE 5W-20 and 5W-30 passenger car motor oil certification and continues to develop products from the technology.

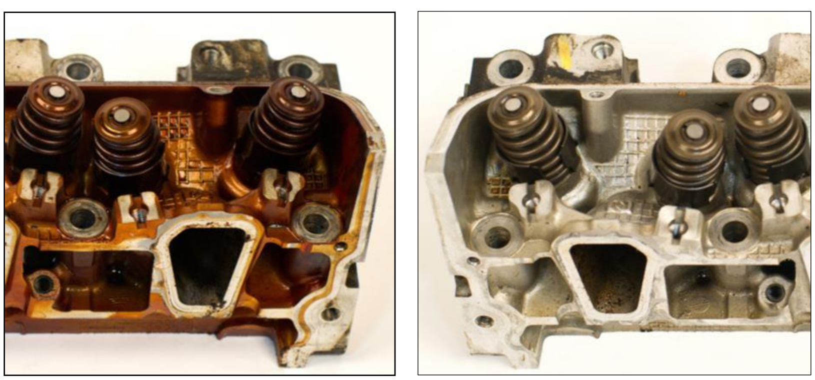


Figure 6: Taxi cab engines that ran 150,000 miles on conventional motor oil (left) and estolide-based formula developed by ARS researchers (right). The engine using the estolide-based formula had less buildup of deposits and showed less wear.

Cermak, S. C., Bredsguard, J. W., John, B. L., McCalvin, J. S., Thompson, T., Isbell, K. N., Feken, K. A., Isbell, T. A., and Murray, R. E. 2013. Synthesis and physical properties of new estolide esters. Industrial Crops Production. 46:386-391.

Cermak, S. C., Durham, A. L., Isbell, T. A., Evangelista, R. L., and Murray, R. E. 2015. Synthesis and physical properties of pennycress estolides and esters. Industrial Crops Production. 67:179-184.

<u>Problem Statement 2.C</u>: *Collaborate with breeders and production researchers in the development of both new cultivars/hybrids and new production practices/systems that optimize the quality and production traits of crop-derived products and byproducts for conversion into nonfood biobased products.*

Postharvest production efficiencies and end product quality are often linked to the quality of the preprocessed agricultural product from the field. The research supporting Problem Statement 2.C seeks ways to optimize processing and improve product quality by enhancing the quality of preprocessed, raw agricultural materials. ARS scientists working under this Problem Statement collaborate with plant breeders and agricultural producers and processors to develop and optimize crop cultivars and production systems to develop specific traits enhancing end product production and quality.

Guayule-rubber tires: Establishing a U.S. rubber production industry. *Parthenium argentatum*, commonly known as guayule (gwai'u'li), is a flowering shrub native to the southwestern United States. The plant has been studied for nearly 150 years as a potential source of natural rubber, organic resins, and as a biofuel feedstock. In the 1920s, after leaf blight destroyed the Brazilian rubber industry, guayule became a potentially important source of rubber. However, no greater effort was made to develop rubber from guayule than during World War II, when Japan cut off U.S. access to rubber imports from Southeast Asia, the source of all U.S. rubber supplies. The U.S. tire industry still completely relies on imported supplies of natural rubber, which comprises up to 80 percent of a tire. Developing guayule rubber for use in modern tires was critical for supplementing the ever-growing global rubber demand, and especially for developing a U.S. natural rubber production industry. With funding from the USDA National Institute for Food and Agriculture, ARS and industry partners led a 5-year collaborative research effort to develop a commercial guayule farming system in Maricopa, Arizona, and to investigate rubber biotechnology and chemistry at Albany, California. With university partners and rubber and tire industry leaders, ARS researchers led breakthroughs in guayule rubber processing, stabilization, and performance, and eventually reached their ultimate goal: passenger tires built with 100 percent guayule rubber that passed both

Figure 7: Guayule rubber passenger car tire made by the Cooper Tire Company.

U.S. Department of Transportation testing and more stringent internal industry testing [Figure 7]. Tires made of 75 percent guayule rubber met all technical performance requirements and are ready for the market, and two U.S. tire companies are continuing to develop guayule natural rubber technology.

McMahan, C. M. and Lhamo, D. 2015. Study of amino acid modifiers in guayule natural rubber. Rubber Chemistry and Technology. 88(2): 310-323.

Rasutis, D., Soratana, K., McMahan, C. M., and Landis, A. 2015. A sustainability review of domestic rubber from the guayule plant. Industrial Crops and Products. 70:383-394.

Native Texas shrub produces potent mosquito repellents that outlast the commercial repellent DEET. Mosquitoes transmit diseases such as malaria, dengue fever, and yellow fever, which pose serious risks to human health. An ARS scientist in Oxford, Mississippi, synthesized an analog of a natural compound called chromene that is more repellent to mosquitoes and lasts longer than DEET. A patent was issued for the compound, which was isolated from *Amyris texana,* a plant native to Texas. In follow-up studies, several chromene derivatives were further synthesized and were found to be more potent and last longer than DEET. This study reveals the potential use of chromene analogs, including their effectiveness as mosquito repellents and their superior performance to DEET. A new CRADA was established with an industry partner, Mozzie Armor, which plans to market the technology. Follow-up research is being planned to conduct bee and fish toxicity assays and to synthetically modify the patented compounds for the development of tick repellents.

Meepagala, K.M., Bernier, U.R., Burandt, C., Duke, S.O. 2013. Mosquito repellents based on a natural chromene analogue with longer duration of action than N,N-diethyl-meta-toluamide (DEET). Journal of Agricultural and Food Chemistry. 61:9293−9297.

APPENDIX 1

National Program 213 – Biorefining
National Program 306 – Quality and Utilization of Agricultural Products

Research Projects and Project Scientists

NP 213

2030-41000-054-00D
Technologies for Improving Industrial Biorefineries that Produce Marketable Biobased Products; William Orts (P), C. Lee, D. Wong, K. Wagschal, W. Hart-Cooper; Albany, California

5010-41000-161-00D
Technologies for Improving Process Efficiencies in Biomass Refineries; Bruce Dien (P), J. Mertens, M. Bowman, N. Nichols, D. Jordan; Peoria, Illinois

5010-41000-162-00D
Biochemical Technologies to Enable the Commercial Production of Biofuels from Lignocellulosic Biomass; Patricia Slininger (P), B. Dien, Z. Liu; Peoria, Illinois

5010-41000-163-00D
Develop Technologies for Production of Platform Chemicals and Advanced Biofuels from Lignocellulosic Feedstocks; Badal Saha (P), N. Qureshi, R. Hector, N. Nichols; Peoria, Illinois

5010-41000-164-00D
New Biobased Products and Improved Biochemical Processes for the Biorefining Industry Project; Joseph Rich (P), S. Liu, T. Leathers, two vacancies; Peoria, Illinois

6054-41000-110-00D
Developing Technologies that Enable Growth and Profitibality in the Commercial Conversion of Sugarcane, Sweet Sorghum, and Energy Beets into Sugar, Advanced Biofuels, and Bioproducts; Kjell Klasson (P), I. Lima, M. Wright, S. Uchimia, two vacancies; New Orleans, Louisiana

8072-41000-093-00D
Enable New Marketable, Value-Added Coproducts to Improve Biorefining Profitability; Robert Moreau (P), N. Lew, V. Wyatt, M. Yadav, R. Stoklosa; Wyndmoor, Pennsylvania

8072-41000-094-00D
Sorghum Biorefining: Integrated Processes for Converting all Sorghum Feedstock Components to Fuels and Co-Products; Nhuan Nghiem (P), D. Johnston, R. Stoklosa; Wyndmoor, Pennsylvania

8072-41000-095-00D
Farm-Scale Pyrolysis Biorefining; Akwasi Boateng (P), Y. Elkasabi, C. Mullen, N. Goldberg; Wyndmoor, Pennsylvania

NP 306

2030-21410-021-00D
Domestic Production of Natural Rubber and Industrial Seed Oils; Colleen McMahan (P), Q. Chen, J.T. Lin, T. McKeon; Albany, California

2030-41000-058-00D
Bioproducts from Agricultural Feedstocks; Gregory Glenn (P), S. Chiou, D. Wood, W. Orts, C. Lee, one vacancy; Albany, California

2030-41000-064-00D
New Sustainable Processing Technologies to Produce Healthy, Value-Added Foods from Specialty Crops; Tara McHugh (P), Z. Pan, J. Berrios, R. Milczarek, M. Friedman; Albany, California

2030-41430-001-00D
Defining, Measuring, and Mitigating Attributes that Adversely Impact the Quality and Marketability of Foods; Ronald Haff (P), G. Takeoka, Y. Zhang; Albany, California

2030-41440-007-00D
Adding Value to Plant-Based Waste Materials through Development of Novel, Healthy Ingredients and Functional Foods; Wallace Yokoyama (P), T. Kahlon, T. McHugh, R. Milczarek, A. Breska; Albany, California

2034-43000-039-00D
Integrate Pre-and Postharvest Approaches to Enhance Fresh Fruit Quality and Control Postharvest Diseases; Chang-Lin Xiao (P), D. Obenland; Albany, California

2090-43440-007-00D
Wheat Quality, Functionality and Marketability in the Western U.S.; Craig Morris (P); Pullman, Washington

2094-43000-007-00D
Developmental Genomics and Metabolomics Influencing Temperate Tree Fruit Quality; James Mattheis (P), D. Rudell, L. Honaas; Wenatchee, Wsahington

3020-43440-001-00D
Impact of the Environment on Sorghum Grain Composition and Quality Traits; Scott Bean (P), T. Herald, M. Tilley, J. Wilson, two vacancies; Manhattan, Kansas

3020-43440-008-00D
Impacting Quality through Preservation, Enhancement, and Measurement of Grain and Plant Traits; Paul Armstrong (P), M. Casada, F. Fowell, D. Brabec, J. Campbell; Manhattan, Kansas

3020-44000-026-00D
Impact of Environmental Variation on Genetic Expression (phenotype) of Hard Winter Wheat Quality Traits; Jeff Wilson (P), Y. Chen, M. Tilley, B. Seabourn, T. Herald, S. Bean; Manhattan, Kansas

3050-41000-009-00D
Enhancing the Quality, Utility, Sustainability and Environmental Impact of Western and Long-Staple Cotton through Improvements in Harvesting, Processing, and Utilization; Derek Whitelock (P), C. Armijo, P. Funk, two vacancies; Las Cruces, New Mexico

3060-21430-007-00D
Improving Potato Nutritional and Market Quality by Identifying and Manipulating Physiological and Molecular Processes Controlling Tuber Wound-Healing and Sprout Growth; vacant (P); E. Lulai; Fargo, North Dakota

3060-43440-013-00D
Improved Potato Market Quality through Germplasm Processing Evaluations and Optimized Storage Technologies; Darrin Haagenson (P); Fargo, North Dakota

3060-43440-014-00D
Enhancement of Hard Spring Wheat, Durum, and Oat Quality; Jae-Bom Ohm (P), L. Dykes; Fargo, North Dakota

3096-21410-008-00D
Enhancing the Profitability and Sustainability of Upland Cotton, Cottonseed, and Agricultural Byproducts through Improvements in Pre- and Post-Harvest Processing; John Wanjura (P), G. Holt, M. Pelletier; Lubbock, Texas

5010-22410-020-00D
New Microbial and Plant-Based Agents for Mosquito Control; Ephantus Muturi (P), J. Ramirez, A. Rooney; Peoria, Illinois

5010-41000-166-00D
Improved Utilization of Proteinaceous Crop Co-Products; Gordon Selling (P), M. Hojillaevangelist, V. Boddu; Peoria, Illinois

5010-41000-167-00D
Evaluation of the Chemical and Physical Properties of Low-Value Agricultural Crops and Products to Enhance their Use and Value; Mark Berhow (P), F. Eller, B. Tisserat, S. Vaughn, S. Liu; Peoria, Illinois

5010-41000-168-00D
Improved Utilization of Low-Value Oilseed Press Cakes and Pulses for Health-Promoting Food Ingredients and Biobased Products; Frederick Felker (P), J. Kenar, J. Byars, M. Singh, S. Liu; Peoria, Illinois

5010-41000-169-00D
Innovative Processing Technologies for Creating Functional Food Ingredients with Health Benefits from Food Grains, their Processing Products, and By-products; Sean Liu (P), J. Byars, M. Singh, one vacancy; Peoria, Illinois

5010-41000-170-00D
Industrial Monomers and Polymers from Plant Oils; Kenneth Doll (P), B. Moser, Z. Liu, R. Murry; Peoria, Illinois

5010-41000-171-00D
Replacement of Petroleum Products Utilizing Off-Season Rotational Crops; Steven Cermak (P), T. Isbell, R. Evangelista, R. Harry; Peoria, Illinois

5010-41000-172-00D
Technologies for Producing Renewable Bioproducts; Christopher Skory (P), G. Cote, N. Price, T. Leathers, J. Rich; Peoria, Illinois

5010-41000-173-00D
Technologies for Producing Biobased Chemicals; David Compton (P), K. Evans, M. Jackson, C. Hou, J. Rich; Peoria, Illinois

5010-41000-174-00D
Conversion of Polysaccharides and Other Bio-based Materials to High-Value, Commercial Products; Atanu Biswas (P), V. Finkenstadt, S. Gordon, V. Boddu; Peoria, Illinois

5010-41000-175-00D
Value-added Bio-oil Products and Processes; Girma Biresaw (P), G. Bantchev, R. Dunn, G. Knothe, R. Murray; Peoria, Illinois

5010-44000-052-00D
Improving Quality, Stability, and Functionality of Oils and Bioactive Lipids; Jill Moser (P), H. Hawang, S. Liu; Peoria, Illinois

5010-44000-053-00D
Renewable Biobased Particles; Lei Jong (P), S. Peterson, S. Kim, G. Fanta, J. Xu, V. Boddu; Peoria, Illinois

5050-43640-002-00D
Nondestructive Quality Assessment and Grading of Fruits and Vegetables; Renfu Lu (P); East Lansing, Michigan

5082-43440-001-00D
Genetic and Biochemical Basis of Soft Winter Wheat End-Use Quality; Byung-Kee Baik (P), B. Penning; Wooster, Ohio

5090-43440-006-00D
Identifying the Next Generation of Malting Barley through Improved Selection Criteria and Quality Analysis of Breeding Lines; Jason Walling (P), C. Henson; Madison, Wisconsin

6034-41000-017-00D
Enhancing Utilization of Citrus Processing Co-Products; Randall Cameron (P), J. Manthey, C. Dorado, one vacancy; Ft. Pierce, Florida

6034-41430-006-00D
Quality, Shelf-life and Health Benefits for Fresh, Fresh-cut and Processed Products for Citrus and other Tropical/Subtropical-grown Fruits and Vegetables; Anne Plotto (P), J. Bai, E. Baldwin, J. Manthey, R. Cameron, vacant, Ft. Pierce, Florida

6040-41440-002-00D
Assessment and Improvement of Poultry Meat, Egg, and Feed Quality; Brian Bowker (P), G. Gamble, K. Lawrence, S. Trabelsi, C. Yoon, H. Zhuang, two vacancies; Athens, Georgia

6044-41430-006-00D
Postharvest Systems to Assess and Preserve Peanut Quality and Safety; Christopher Butts (P), M. Lamb, one vacancy; Dawson, Georgia

6054-41000-103-00D
Increasing the Value of Cottonseed; Michael Dowd (P), H. Cao, H. Cheng, Z. He, K. Klasson, J. Shockey; New Orleans, Louisiana

6054-41000-106-00D
Cotton-based Nonwovens; Doug Hinchliffe (P), S. Nam, B. Condon, two vacancies; New Orleans, Louisiana

6054-41000-107-00D
Nutritional and Sensory Properties of Rice and Rice Value-Added Prodcuts; Stephen Boue (P), J. Beaulieu, G. Bett, C. Grimm; New Orleans, Louisiana

6054-41430-007-00D
*Chemical Modification of Cotton for Value Added Application*s; Judson Edwards (P), S. Chang, M. Easson, B. Condon; New Orleans, Louisiana

6054-43440-046-00D
Reducing Peanut and Tree Nut Allergy; Soheila Maleki (P), C. Mattison, B. Hurlburt, one vacancy; New Orleans, Louisian

6054-44000-078-00D
Postharvest Sensory, Processing and Packaging of Catfish; Peter Bechtel (P), C. Grimm, K. Bett; New Orleans, Louisiana

6054-44000-079-00D
Improved Quality Assessment of Cotton from Fiber to Final Products; Christopher Delhom (P), C. Fortier, Y. Liu, C. Santiago, D. Peralta, two vacancies; New Orleans, Louisiana

6060-41000-012-00D
Discovery and Development of Natural Products for Pharmaceutical and Agrochemical Applications II; Stephen Duke (P), Oxford, Mississippi

6060-41000-013-00D
Health-Promoting Bioactives and Biobased Pesticides from Medicinal and Herbal Crops; Agnes Rimando (P), C. Cantrell, D. Wedge, K. Meepagala, S. Duke; University, Mississippi

6066-41440-008-00D
Cotton Ginning Research to Improve Processing Efficiency and Product Quality in the Saw-Ginning of Picker-Harvested Cotton; three vacancies, including P; Stoneville, Mississippi

6070-41000-008-00D
Improved Processes for the Preservation and Utilization of Vegetables, Including Cucumber, Sweetpotato, Cabbage, and Peppers to Prodce Safe, High Quality Products with Reduced Energy Use and Waste; Van Den Truong (P), F. Breidt, S. Johanningsmeier, I. Diaz; Raleigh, North Carolina

6070-43440-012-00D
Improvement and Maintenance of Flavor, Shelf Life, Functional Characteristics, and Biochemical/Bioactive Components in Peanuts, Peanut Products and Related Commodities through Improved Handling, Processing, and Use of Genetic/Genomic Resources; Ondulla Toomer (P), L. Dean, one vacancy; Raleigh, North Carolina

8042-43000-015-00D
Enhancing Fruit and Vegetable Nutritional Quality with Improved Phenolics Contents; Tianbao Yang (P), two vacancies; Beltsville, Maryland

8042-43440-005-00D
Evaluation and Maintenance of Flavor, Nutritional and Other Quality Attributes of Fresh and Fresh-Cut Produce; Yaguang Luo (P), two vacancies; Beltsville, Maryland

8042-44000-001-00D
Rapid Methods for Quality and Safety Inspection of Small Grain Cereals; Stephen Delwiche (P); Beltsville, Maryland

8072-41000-096-00D
Improving the Sustainability and Quality of Food and Dairy Products from Manufacturing to Consumption via Process Modeling and Edible Packaging; Peggy Tomasula (P), L. Bonnaillie, one vacancy; Wyndmoor, Pennsylvania

8072-41000-097-00D
Effect of Processing of Milk on Bioactive Compounds in Fresh High-Moisture Cheeses; Diane Van Hekken (P), P. Tomasula, A. Bucci; Wyndmoor, Pennsylvania

8072-41000-099-00D
Commercial Products from Microbial Lipids; Daniel Solaiman (P), R. Ashby; Wyndmoor, Pennsylvania

8072-41000-100-00D
Bioactive Food Ingredients for Safe and Health-Promoting Functional Foods; Arland Hotchkiss (P), P. Qi, J. Renye; Wyndmoor, Pennsylvania

8072-41000-102-00D
In Vitro Human Intestinal Microbial Ecosystem: Effects of Diet; Lin Liu (P), one vacancy, J. Firrman; Wyndmoor, Pennsylvania

8072-41440-023-00D
Commercial Flocculants from Low-Value Animal Protein; Rafael Garcia (P), G. Piazza, one vacancy; Wyndmoor, Pennsylvania

8072-41440-024-00D
Improving the Quality of Animal Hides, Reducing Environmental Impacts of Hide Production, and Developing Value-Added Products from Wool; Cheng Kung Liu (P), E. Brown, M. Sarker; Wyndmoor, Pennsylvania

APPENDIX 2

National Program 213 – Biorefining
Publications by Research Project
October 2012 – September 2017

2030-41000-054-00D – ***Technologies for Improving Industrial Biorefineries that Produce Marketable Biobased Products*** **– William Orts (P), W. Hart-Cooper, K. Wagschal, C. Lee, D. Wong; Albany, California**

<u>2017</u>
Holtman, K.M., Bozzi, D.V., Franquivillanueva, D.M., Offeman, R.D., Orts, W.J. 2017. Pilot scale high solids anaerobic digestion of steam autoclaved municipal solid waste (MSW) pulp. Renewable Energy. 113(113):257-265.

Lee, C.C., Kibblewhite, R.E., Paavola, C., Orts, W.J., Wagschal, K.C. 2017. Production of D-xylonic acid from hemicellulose using artificial enzyme complexes. Journal of Microbiology and Biotechnology. 27(1):77 83 doi: 10.4014/jmb.1606.06041.

Wagschal, K.C., Stoller, J.R., Chan, V.J., Jordan, D.B. 2017. Expression and characterization of hyperthermostable exo-polygalacturonase RmGH28 from Rhodothermus marinus. Applied Biochemistry and Biotechnology. doi: 10.1007/s12010-017-2518-0.

<u>2016</u>
Cal, A.J., Ponce, M.I., Franquivillanueva, D.M., Orts, W.J., Pieja, A., Lee, C.C. 2016. Methanotrophic production of copolymer, poly(hydroxybutyrate-co-hydroxyvalerate), with high hydroxyvalerate content. International Journal of Biological Macromolecules. 87:302.

Holtman, K.M., Bozzi, D.V., Franqui-Villanueva, D.M., Offeman, R.D., Orts, W.J. 2016. A pilot-scale steam autoclave system for treating municipal solid waste for recovery of renewable organic content: Operational results and energy usage. Waste Management and Research. 34(5):457-464. doi: 10.1177/0734242x16636677.

Lee, C.C., Kibblewhite, R.E., Paavola, C., Orts, W.J., Wagschal, K.C. 2016. Production of glucaric acid from hemicellulose substrate by rosettasome enzyme assemblies. Molecular Biotechnology. 58:489.

Reza, M., Coronella, C., Holtman, K.M., Franqui-Villanueva, D.M., Poulson, S.R. 2016. Hydrothermal carbonization of autoclaved municipal solid waste pulp and anaerobically treated pulp digestate. ACS Sustainable Chemistry & Engineering. 4(7):3649-3658. doi: 10.1021/acssuschemeng.6b00160.

Tonoli, G., Holtman, K.M., Glenn, G.M., Fonseca, A., Wood, D.F., Williams, T.G., Sa, V., Torres, L., Klamczynski, A., Orts, W.J. 2016. Properties of cellulose micro/nanofibers obtained from eucalyptus pulp fiber treated with anaerobic digestate and high shear mixing. Cellulose. 23(2):1239-1256. doi: 10.1007/s10570-016-0890-5.

Wagschal, K.C., Stoller, J.R., Chan, V.J., Lee, C.C., Grigorescu, A.A., Jordan, D.B. 2016. Expression and characterization of hyperthermostable exo-polygalacturonase TtGH28 from Thermotoga thermophilus. Molecular Biotechnology. 58(7):509-519. doi: 10.1007/s12033-016-9948-8.

Wong, D., Rafique, N., Tabassum, R., Awan, S., Orts, W.J. 2016. Cloning and expression of Pectobacterium carotovorum endo-polygalacturonase gene in Pichia pastoris for production of oligogalacturonates. BioResources. 11(2):5204-5214.

2015

Biely, P., Malovikova, A., Uhliarikova, I., Li, X., Wong, D. 2015. Glucuronoyl esterases are active on polymeric substrate, methyl esterified glucuronoxylan. FEBS Letters. 589:2334-2339.

Jordan, D.B., Braker, J.D., Wagschal, K.C., Stoller, J.R., Lee, C.C. 2015. Isolation and divalent-metal activation of a ß-xylosidase, RUM630-BX. Enzyme and Microbial Technology. 82:158-163. doi: 10.1016/j.enzmictec.2015.10.001.

Santos, C.R., Cordeiro, R.L., Wong, D., Murakami, M.T. 2015. Structural basis for xyloglucan specificity within GH5 family and the molecular determinants for a-D-Xylp(1¿6)-D-Glcp recognition at the -1 subsite. Biochemistry. 54:1930-1942.

Torres, L., McMahan, C.M., Ramadan, L.E., Holtman, K.M., Tonoli, G.H., Flynn, A., Orts, W.J. 2015. Effect of multi-branched PDLA additives on the mechanical and thermomechanical properties of blends with PLLA. Journal of Applied Polymer Science. doi: 10.1002/app.42858.

Wong, D., Takeoka, G.R., Chan, V.J., Liao, H., Marakami, M. 2015. A novel feruloyl esterase from rumen microbial metagenome: Gene cloning and enzyme characterization in the release of mono- and diferulic acids. Protein and Peptide Letters. 22(2):681-688.

2014

Sathitsuksanoh, N., Holtman, K.M., Yelle, D.J., Morgan, T., Stavila, V., Pelton, J., Blanch, H., Simmons, B.A., George, A. 2013. Lignin fate and characterization during ionic liquid biomass pretreatment for renewable chemicals and fuels production. Green Chemistry. 3(3):1236-1247. doi: 10.1039/c3gc42295j.

Schauer-Gimenez, A., Cal, A.J., Morse, M., Pieja, A., Holtman, K.M., Orts, W.J. 2014. Quantifying landfill biogas production potential in the U.S.. Biocycle. 55(10):43.

2030-41000-049-00D - *Biorefining Processes* – William Orts (P), Delilah Wwood, Kevin Holtman, Kurt Wagschal, Richard Offeman, Charles Lee, Dominic Wong; Albany, Calilfornia (Project Terminated and Replaced by Project No. 2030-41000-054-00D)

2015

Holtman, K.M., Offeman, R.D., Franquivillanueva, D.M., Bayati, A.K., Orts, W.J. 2015. Countercurrent extraction of soluble sugars from almond hulls and assessment of the bioenergy potential. Journal of Agricultural and Food Chemistry. 63(9):2490-2498. doi: 10.1021/jf5048332.

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Offeman, R.D., Dao, G.T., Holtman, K.M., Orts, W.J. 2014. Leaching behavior of water-soluble carbohydrates from almond hulls. Industrial Crops and Products. 65(65):488-495.

Offeman, R.D., Holtman, K.M., Covello, K.M., Orts, W.J. 2014. Almond hulls as a biofuels feedstock: Variations in carbohydrates by variety and location in California. Industrial Crops and Products. 54(54):109-114.

Olivera, J.E., Brichi, G.S., Marconcini, J.M., Mattoso, L.H., Glenn, G.M., Medeiros, E. 2014. Effect of solvent on the physical and morphological properties of poly(lactic acid) nanofibers obtained by solution blow spinning. Journal of Engineered Fibers and Fabrics. 9(4):117-125.

Santos, C., Polo, C., Costa, M., Nascimento, A., Mezal, A.N., Cota, J., Hoffmam, Z.B., Honorato, R., Oliveira, P.S., Goldman, G.H., Prade, R.A., Ruller, R., Squina, F.M., Wong, D., Murakami, M. 2014. Mechanistic strategies for catalysis adopted by evolutionary distinct family 43 arabinanases. Journal of Biological Chemistry. 289(11):7362-7373.

Wagschal, K.C., Jordan, D.B., Lee, C.C., Younger, A.R., Braker, J.D., Chan, V.J. 2014. Biochemical characterization of uronate dehydrogenases from three Pseudomonads, Chromohalobacter salixigens, and Polaromonas naphthalenivorans. Enzyme and Microbial Technology. 69:62-68.

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Lee, C.C., Braker, J.D., Grigorescu, A.A., Wagschal, K.C., Jordan, D.B. 2013. Divalent metal activation of a GH43 ß-xylosidase. Enzyme and Microbial Technology. 52(2):84-90.

Majeed, T., Tabassum, R., Orts, W.J., Lee, C.C. 2013. Expression and characterization of Coprothermobacter proteolyticus alkaline serine protease. The Scientific World. doi: 10.1155/2013/396156.

Olivera, J.A., Moraes, E.A., Marconini, J.M., Mattoso, L.H., Glenn, G.M., Medeiros, E.S. 2013. Miscibility of poly(lactic acid) and poly(ethylene oxide) solvent polymer blends and nanofibers made by solution blow spinning. Polymer Journal. 129(6):3672-3681.

Singh, S.K., Heng, C., Braker, J.D., Chan, V.J., Lee, C.C., Jordan, D.B., Yuan, L., Wagschal, K.C. 2013. Directed evolution of GH43 ß-xylosidase XylBH43 thermal stability and L186 saturation. Journal of Industrial Microbiology and Biotechnology. 41(3):489-498. doi: 10.1007/s10295-013-1377-0.

Wong, D., Chan, V.J., Liao, H., Zidwick, M. 2013. Cloning of a novel feruloyl esterase gene from rumen microbial metagenome and enzyme characterization in synergism with endoxylanases. Journal of Industrial Microbiology. 40:287-295.

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Wong, D., Tenkanen, M., Vrsanaka, M., Sika-Aho, M., Puchart, V., Penttila, M., Salohelmo, M., Biely, P. 2012. Xylanase XYN IV from Trichoderma reesei showing exo- and endo-xylanase activity. FEBS Journal. 280: 295-301.

5010-41000-161-00D – *Technologies for Improving Process Efficiencies in Biomass Refineries;* Bruce Dien (P), J. Mertens, M. Bowman, N. Nichols, D. Jordan; Peoria, Illinois

2017

Quarterman, J., Slininger, P.J., Kurtzman, C.P., Thompson, S.R., Dien, B.S. 2017. A survey of yeast from the Yarrowia clade for lipid production in dilute-acid pretreated lignocellulosic biomass hydrolysate. Applied Microbiology and Biotechnology. 101(8):3319-3334. doi: 10.1007/s00253-016-8062-y.

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Dien, B.S., Zhu, J.Y., Slininger, P.J., Kurtzman, C.P., Moser, B.R., O'Bryan, P.J., Gleisner, R., Cotta, M.A. 2016. Conversion of SPORL pretreated Douglas fir forest residues into microbial lipids with oleaginous yeasts. RSC Advances. 6(25):20695-20705. doi: 10.1039/c5ra24430g.

de Souza, A.R., de Araujo, G.C., Zanphorlin, L.M., Ruller, R., Franco, F.C., Torres, F.A.G., Mertens, J.A., Bowman, M.J., Gomes, E., Da Silva, R. 2016. Engineering increased thermostability in the GH-10 endo-1,4-ß-xylanase from Thermoascus aurantiacus CBMAI 756. International Journal of Biological Macromolecules. 93:20-26. doi: 10.1016/j.ijbiomac.2016.08.056.

Jordan, D.B., Stoller, J.R., Lee, C.C., Chan, V.J., Wagschal, K.C. 2016. Biochemical characterization of a GH43 ß-xylosidase from Bacteroides ovatus. Applied Biochemistry and Biotechnology. 182: 250-260. doi: 10.1007/s12010-016-2324-0.

Kim, D., Ximenes, E.A., Nichols, N.N., Cao, G., Frazer, S.E., Ladisch, M.R. 2016. Maleic acid treatment of biologically detoxified corn stover liquor. Bioresource Technology. 216:437-445. doi: 10.1016/j.biortech.2016.05.086.

Mertens, J.A., Bowman, M.J. 2016. Kinetic properties of Rhizopus oryzae RPG1 endo-polygalacturonase hydrolyzing galacturonic acid oligomers. Biocatalysis and Agricultural Biotechnology. 5:11-16. doi: 10.1016/j.bcab.2015.12.005.

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Bowman, M.J., Dien, B.S., Vermillion, K.E., Mertens, J.A. 2015. Isolation and characterization of unhydrolyzed oligosaccharides from switchgrass (Panicum virgatum, L.) xylan after exhaustive enzymatic treatment with commercial enzyme preparations. Carbohydrate Research. 407:42-50.

Cao, G., Ximenes, E., Nichols, N.N., Frazer, S.E., Kim, D., Cotta, M.A., Ladisch, M. 2015. Bioabatement with hemicellulase supplementation to reduce enzymatic hydrolysis inhibitors. Bioresource Technology. 190:412-415.

Jordan, D.B., Braker, J.D. 2015. Rate-limiting steps of stereochemistry retaining ß-d-xylosidase from Geobacillus stearothermophilus acting on four substrates. Archives of Biochemistry and Biophysics. 583:73-78. doi: 10.1016/j.abb.2015.08.004.

Saunders, L.P., Bowman, M.J., Mertens, J.A., Da Silva, N.A., Hector, R.E. 2015. Triacetic acid lactone production in industrial Saccharomyces yeast strains. Journal of Industrial Microbiology and Biotechnology. 42:711-721.

Xue, S., Uppugundla, N., Bowman, M.J., Cavalier, D., Da Cousta Sousa, L., Dale, B.E., Balan, V. 2015. Sugar loss and enzyme inhibition due to oligosaccharides accumulation during high solids-loading enzymatic hydrolysis. Biotechnology for Biofuels. 8:195. doi: 10.1186/s13068-015-0378-9.

5010-41000-133-00D – *Advanced Conversion Technologies for Sugars and Biofuels: Superior Feedstocks, Pretreatments, Inhibitor Removal, and Enzymes* – Bruce Dien (P), Michael Bowman, Nancy Nichols, Jeffrey Mertens, Michael Cotta, Douglas Jordan; Peoria, Illinois (Project and Terminated Replaced by 5010-41000-161-00D)

<u>2016</u>

Ditty, J.L., Nichols, N.N., Parales, R.E. 2016. Protocal for the measurement of hydrocarbon transport in bacteria. Handbook of Hydrocarbon and Lipid Microbiology. 55-67. doi: 10.1007/8623_2014_11.

<u>2015</u>

Jordan, D.B., Braker, J.D., Wagschal, K., Lee, C.C., Chan, V.J., Dubrovska, I., Anderson, S., Wawrzak, Z. 2015. X-ray crystal structure of divalent metal-activated ß-xyloisdase, RS223BX. Applied Biochemistry and Biotechnology. 177:637-648. doi: 10.1007/s12010-015-1767-z.

Ramchandran, D., Wang, P., Dien, B.S., Liu, W., Cotta, M.A., Singh, V. 2015. Improvement of dry fractionation ethanol fermentation by partial germ supplementation. Cereal Chemistry. 92:218-223.

<u>2014</u>

Chen, M.-H., Bowman, M.J., Dien, B.S., Rausch, K.D., Tumbleson, M.E., Singh, V. 2014. Autohydrolysis of Miscanthus x giganteus for the production of xylooligosaccharides (XOS): Kinetics, characterization and recovery. Bioresource Technology. 155:359-365.

Chen, M., Dien, B.S., Vincent, M.L., Below, F.E., Singh, V. 2014. Effect of harvest maturity on carbohydrates for ethanol production from sugar enhanced temperate x tropical maize hybrid. Industrial Crops and Products. 60:266-272.

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Nichols, V.A., Miguez, F.E., Jarchow, M.E., Liebman, M.Z., Dien, B.S. 2014. Comparison of cellulosic ethanol yields from midwestern maize and reconstructed tallgrass prairie systems managed for bioenergy. BioEnergy Research. 7:1550-1560.

Zhou, H., Lan, T., Dien, B.S., Hector, R.E., Zhu, J.Y. 2014. Comparisons of five Saccharomyces cerevisiae strains for ethanol production from SPORL pretreated lodgepole pine. Biotechnology Progress. 30(5):1076-1083.

2013

Cao, G., Ximenes, E., Nichols, N.N., Zhang, L., Ladisch, M. 2013. Biological abatement of cellulase inhibitors. Bioresource Technology. 146:604-610

Chen, M.-H., Kaur, P., Dien, B.S., Below, F., Vincent, M.L., Singh, V. 2013. Use of tropical maize for bioethanol production. World Journal of Microbiology and Biotechnology. 29:1509-1515.

Dien, B.S., O'Bryan, P.J., Hector, R.E., Iten, L.B., Mitchell, R.B., Qureshi, N., Sarath, G., Vogel, K.P., Cotta, M.A. 2013. Conversion of switchgrass to ethanol using dilute ammonium hydroxide pretreatment: influence of ecotype and harvest maturity. Environmental Technology. 34(13-14):1837-1848.

Khullar, E., Dien, B.S., Rausch, K.D., Tumbleson, M.E., Singh, V. 2013. Effect of particle size on enzymatic hydrolysis of pretreated Miscanthus. Industrial Crops and Products. 44:11-17.

Jordan, D.B., Lee, C.C., Wagschal, K., Braker, J.D. 2013. Activation of a GH43 ß-xylosidase by divalent metal cations: Slow binding of divalent metal and high substrate specificity. Archives of Biochemistry and Biophysics. 533:79-87.

Jordan, D.B., Vermillion, K., Grigorescu, A.A., Braker, J.D. 2013. Rehabilitation of faulty kinetic determinations and misassigned glycoside hydrolase family of retaining mechanism ß-xylosidases. Archives of Biochemistry and Biophysics. 537(2):176-184.

Jordan, D.B., Wagschal, K.C., Grigorescu, A.A., Braker, J.D. 2013. Highly active ß-xylosidases of glycoside hydrolase family 43 operating on natural and artificial substrates. Applied Microbiology and Biotechnology. 97:4415-4428.

Lan, T.Q., Gleisner, R., Zhu, J.Y., Dien, B.S., Hector, R.E. 2013. High titer ethanol production from SPORL-pretreated lodgepole pine by simultaneous enzymatic saccharification and combined fermentation. Bioresource Technology. 127:291-297.

Mertens, J.A. 2013. Kinetic properties of two Rhizopus exo-polygalacturonase enzymes hydrolyzing galacturonic acid oligomers using isothermal titration calorimetry. Applied Biochemistry and Biotechnology. 170(8):2009-2020.

Zhou, H., Zhu, J.Y., Luo, X., Leu, S.-Y., Wu, X., Gleisner, R., Dien, B.S., Hector, R.E., Yang, D., Qiu, X., Horn, E., Negron, J. 2013. Bioconversion of beetle-killed lodgepole pine using SPORL: Process scale-up design, lignin co-product, and high solids fermentation without detoxification. Industrial and Engineering Chemistry Research. 52:16057-16065.

2012

Agler, M.T., Werner, J.J., Iten, L.B., Dekker, A., Cotta, M.A., Dien, B.S., Angenent, L.T. 2012. Shaping reactor microbiomes to produce the fuel precursor n-butyrate from pretreated cellulosic hydrolysates. Environmental Science and Technology. 46(18):10229-10238.

Bowman, M.J., Dien, B.S., O'Bryan, P.J., Sarath, G., Cotta, M.A. 2012. Comparative analysis of end point enzymatic digests of arabino-xylan isolated from switchgrass (Panicum virgatum L) of varying maturities using LC-MS(n). Metabolites. 2(4):959-982.

5010-41000-161-00D – *Technologies for Improving Process Efficiencies in Biomass Refineries;* Bruce Dien (P), J. Mertens, M. Bowman, N. Nichols, D. Jordan; Peoria, Illinois

2017

Quarterman, J., Slininger, P.J., Kurtzman, C.P., Thompson, S.R., Dien, B.S. 2017. A survey of yeast from the Yarrowia clade for lipid production in dilute-acid pretreated lignocellulosic biomass hydrolysate. Applied Microbiology and Biotechnology. 101(8):3319-3334. doi: 10.1007/s00253-016-8062-y.

2016

Chen, M.H., Bowman, M.J., Cotta, M.A., Dien, B.S., Iten, L.B., Whitehead, T.R., Rausch, K.D., Tumbleson, M.E., Singh, V. 2016. Miscanthus x giganteus xylooligosaccharides: Purification and fermentation. Carbohydrate Polymers. 140:96-103. doi: 10.1016/j.carbpol.2015.12.052.

Dien, B.S., Zhu, J.Y., Slininger, P.J., Kurtzman, C.P., Moser, B.R., O'Bryan, P.J., Gleisner, R., Cotta, M.A. 2016. Conversion of SPORL pretreated Douglas fir forest residues into microbial lipids with oleaginous yeasts. RSC Advances. 6(25):20695-20705. doi: 10.1039/c5ra24430g.

Dien, B.S., Slininger, P.J., Kurtzman, C.P., Moser, B.R., O'Bryan, P.J. 2016. Identification of superior lipid producing Lipomyces and Myxozyma yeasts. AIMS Environmental Science. 3(1):1-20. doi: 10.3934/environsci.2016.1.1.

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Kim, D., Ximenes, E.A., Nichols, N.N., Cao, G., Frazer, S.E., Ladisch, M.R. 2016. Maleic acid treatment of biologically detoxified corn stover liquor. Bioresource Technology. 216:437-445. doi: 10.1016/j.biortech.2016.05.086.

Mertens, J.A., Bowman, M.J. 2016. Kinetic properties of Rhizopus oryzae RPG1 endo-polygalacturonase hydrolyzing galacturonic acid oligomers. Biocatalysis and Agricultural Biotechnology. 5:11-16. doi: 10.1016/j.bcab.2015.12.005.

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5010-41000-162-00D – *Biochemical Technologies to Enable the Commercial Production of Biofuels from Lignocellulosic Biomass;* Patricia Slininger (P), B. Dien, Z. Liu; Peoria, Illinois

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5010-41000-162-00D – *Biochemical Technologies to Enable the Commercial Production of Biofuels from Lignocellulosic Biomass;* Patricia Slininger (P), B. Dien, Z. Liu; Peoria, Illinois

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5010-41000-147-00D – *Genomics and Engineering of Stress Tolerant Microbes for Lower Cost Production of Ethanol from Lignocellulose* – Patricia Watson Slinger (P), Zonglin Liu; Peoria, Ilinois (Project and Terminated Replaced by 5010-41000-162-00D)

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5010-41000-163-00D – *Develop Technologies for Production of Platform Chemicals and Advanced Biofuels from Lignocellulosic Feedstocks;* Badal Saha (P), N. Qureshi, R. Hector, N. Nichols; Peoria, Illinois

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5010-41000-164-00D – *New Biobased Products and Improved Biochemical Processes for the Biorefining Industry Project;* Joseph Rich (P), S. Liu, T. Leathers, 2 vacancies; Peoria, Illinois

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5010-41000-135-00D – *Improving Biochemical Processes for the Production of Sustainable Fuels and Chemicals* – Kenneth Bischoff (P), Timothy Leathers, Joseph Rich, Siqing Liu, Stephen Hughes; Peoria, Illinois (Project and Terminated Replaced by 5010-41000-164-00D)

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6435-41000-103-00D – *Postharvest Quality and Processing of Sugarcane and Sweet Sorghum for Sugar and Ethanol Production* – Gillian Eggelston (P), Isabel Lima, Sophie Uchimiya, Kjell Klasson, Marueen Wright; New Orleans, Louisiana (Project Terminated and Replaced by Project No. 6054-41000-110-0D)

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2013

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8072-41000-084-00D – *Expanding the Use of Fats and Oils as Replacements for Fossil-Derived Fuels, Lubricants, and Polymers* – Helen Lew (P), vacant, Victor Wyatt, Jonathan Zerkowski; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41000-093-00D)

2015

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2014

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8072-41000-094-00D – *Sorghum Biorefining: Integrated Processes for Converting all Sorghum Feedstock Components to Fuels and Co-Products;* Nhuan Nghiem (P), D. Johnston, R. Stoklosa; Wyndmoor, Pennsylvania

2017

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Nghiem, N.P., Senske, G.E., Kim, T.H. 2016. Pretreatment of corn stover by low moisture anhydrous ammonia (LMMA) in a pilot-scale reactor and bioconversion to fuel ethanol and industrial chemicals. Applied Biochemistry and Biotechnology. 179(1):111-125.

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2015

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8072-41000-083-00D – ***From Barley to Biomass – the Development of a Regional Multi-Feedstock Biorefinery*** **– Nhuan Nghiem (P), Robert Moreau, vacant, Madhav Yadav, Andrew Mcaloon; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41000-094-00D)**

2015

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2014

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2013

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2017

Carrasco, J.L., Gunukula, S., Boateng, A.A., Mullen, C.A., Desisto, W.J., Wheeler, C.M. 2017. Pyrolysis of forest residues: an approach to techno-economics for bio-fuel production. Fuel. 193:477-484.

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Chung, S., Liu, Q., Joshi, U.A., Regalbuto, J.R., Boateng, A.A., Smith, M.A., Coe, C.G. 2017. Using polyfurfuryl alcohol to improve the hydrothermal stability of mesoporous oxides for reactions in the aqueous phase. Journal of Porous Materials Select Science. doi: 10.1007/s10934-017-0451-9.

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Mullen, C.A., Tarves, P.C., Boateng, A.A. 2017. Role of potassium exchange in catalytic pyrolysis of biomass over ZSM-5: Formation of alkyl phenols and furans. ACS Sustainable Chemistry & Engineering. 5:2154-2162.

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2016

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Chagas, B.M., Mullen, C.A., Dorado, C., Elkasabi, Y.M., Boateng, A.A., Melo, M.A., Ataide, C.H. 2016. Stable bio-oil production from proteinaceous cyanobacteria: tail gas reactive pyrolysis of spirulina. Industrial and Engineering Chemistry Research. 55:6734-6741.

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2015

Boateng, A.A., Mullen, C.A., Elkasabi, Y.M., Mcmahan, C.M. 2015. Guayule (parthenium argentatum) pyrolysis biorefining: production of hydrocarbon compatible bio-oils from guayule bagasse via tail-gas reactive pyrolysis. Fuel. 158:948-956.

Dorado, C., Mullen, C.A., Boateng, A.A. 2015. Co-processing of agricultural plastic waste and switchgrass via tail gas reactive pyrolysis. Industrial and Engineering Chemistry Research. 54:9887-9893.

Elkasabi, Y.M., Mullen, C.A., Boateng, A.A. 2015. Aqueous extractive upgrading of pyrolysis bio-oils to produce pure hydrocarbons and phenols in high yields. ACS Sustainable Chemistry & Engineering. 3(11):2809-2816.

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8072-41000-082-00D – ***Distributed-Scale Pyrolysis of Agricultural Biomass for Production of Refinable Crude Bio-Oil and Valuable Coproducts*** **– Akwasi Boateng (P), vacant, Yaseen Elkasabi, Neil Goldberg, Charles Millen; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41000-095-00D)**

2015

Elkasabi, Y.M., Boateng, A.A., Jackson, M.A. 2015. Upgrading of bio-oil distillation bottoms into biorenewable calcined coke. Biomass and Bioenergy. 81:415-423.

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Mullen, C.A., Boateng, A.A., Dadson, R.B., Hashem, F.M. 2015. Biological mineral range effects on biomass conversion to aromatic hydrocarbons via catalytic fast pyrolysis over HZSM-5. Energy and Fuels. 28:7014-7024.

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Elkasabi, Y.M., Mullen, C.A., Boateng, A.A. 2014. Distillation and isolation of commodity chemicals from Bio-oil made by tail-gas reactive prolysis. ACS Sustainable Chemistry & Engineering. 2(8):2042-2052.

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Keedy, J., Prymak, E., Macken, N., Pourhashem, G., Spatari, S., Mullen, C.A., Boateng, A.A. 2014. An exergy based assessment of the production and conversion of switchgrass, equine waste and forest residue to bio-oil using fast pyrolysis. Journal of Industrial and Engineering Chemical Research. 54:529-539.

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Martin, J.A., Mullen, C.A., Boateng, A.A. 2014. Maximizing the stability of pyrolysis oil/diesel fuel emulsions. Energy and Fuels. 28(9):5918-5929.

Mullen, C.A., Boateng, A.A., Schweitzer, D., Sparks, K., Snell, K. 2014. Mild pyrolysis of P3HB/Switchgrass blends for the production of bio-oil enriched with crotonic acid. Journal of Analytical & Applied Pyrolysis. 107:40-45.

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Serapiglia, M., Mullen, C.A., Smart, L.B., Boateng, A.A. 2014. Variability in pyrolysis product yield from novel shrub willow genotypes. Global Change Biology Bioenergy. 72:74-84.

2013

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Hammer, N.L., Boateng, A.A., Mullen, C.A., Wheeler, C.M. 2013. ASPEN+ and economic modeling of equine waste utilization for localized hot water heating via fast pyrolysis. Journal of Environmental Management. 128:594-601.

Han, Y., Boateng, A.A., Qi, P.X., Lima, I.M., Jainmin, C. 2013. Heavy metal and phenol adsorption properties of biochars from pyrolyzed switchgrass and woody biomass in correlation with surface properties. Environmental Management. 118:196-204.

Mullen, C.A., Boateng, A.A. 2013. Accumulation of inorganic impurities on HZSM-5 during catalytic fast pyrolysis of switchgrass. Journal of Industrial and Engineering Chemical Research. 52:17156-17161.

Mullen, C.A., Boateng, A.A., Goldberg, N.M. 2013. Production of deoxygenated biomass fast pyrolysis oils via product gas recycling. Energy and Fuels. 27:3867-3874.

Mullen, C.A., Boateng, A.A., Reichenbach, S.E. 2013. Hydrotreating of fast pyrolysis oils from protein-rich pennycress seed presscake. Fuel. 111, 797-804.

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2012

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Nsimba, R.Y., West, N., Boateng, A.A. 2012. Structure and radical scavenging activity relationships of pyrolytic lignins. Journal of Agricultural and Food Chemistry. 60:12525-12530.

6209-13610-007-00D – *Production of Quality Power and/or Heat for On-Farm Operations* – Brian Vick (P), vacant; Bushland, Texas (Project Terminated and Replaced by Project No. 3090-31630-005-00D – National Program 212)

2013

Vick, B.D., Broneske, S. 2013. Effect of blade flutter and electrical loading on small wind turbine noise. Renewable Energy. 50:1044-1052.

Vick, B.D., Moss, T.A. 2013. Adding concentrated solar power plants to wind farms to achieve a good utility electrical load match. Solar Energy. 92:298-312.

3655-41000-006-00D – *Adding Value to Biofuels Production Systems Based on Perennial Forages* – Paul Weimer (P); Madison, Wisconsin) (Project Terminated and Replaced by Project No. 5090-31000-026-00D – National Program 101)

2014

Christopherson, M.R., Dawson, J., Stevenson, D.M., Cunningham, A., Bramhacharya, S., Weimer, P.J., Kendziorski, C., Suen, G. 2014. Unique aspects of fiber degradation by the ruminal ethanologen Ruminococcus albus 7 revealed by physiological and transcriptomic analysis. Biomed Central (BMC) Genomics. DOI: 0.1186/1471-2164-15-1066.

Cook, D.E., Shinners, K.J., Weimer, P.J., Muck, R.E. 2014. High dry matter whole-plant corn as a biomass feedstock. Biomass and Bioenergy. 94:230-236.

2013

Bliss, D.Z., Weimer, P.J., Jung, H.G., Savik, K. 2013. In vitro degradation and fermentation of three dietary fiber sources by human colonic bacteria. Journal of Agricultural and Food Chemistry. 61:4614-4621.

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Weimer, P.J., Digman, M.F. 2013. Fermentation of alfalfa wet-fractionation liquids to volatile fatty acids by Streptococcus bovis and Megasphaera elsdenii. Bioresource Technology. 142:88-94.

Weimer, P.J., Moen, G.N. 2013. Quantitative analysis of growth and volatile fatty acid production by the anaerobic ruminal bacterium Megasphaera elsdenii T81. Applied Microbiology and Biotechnology. 97(9):4075-4081.

2012

Verdonk, J.C., Hatfield, R.D., Sullivan, M.L. 2012. Proteomic analysis of cell walls of two developmental stages of alfalfa stems. Frontiers in Plant Science. DOI: 10.3389/fpls.2012.00279.

APPENDIX 3

National Program 306 – Quality and Utilization of Agricultural Products
(New Title: Product Quality and New Uses)
Publications by Research Project
October 2012 – September 2017

2030-21410-021-00D
***Domestic Production of Natural Rubber and Industrial Seed Oils;* Colleen McMahan (P), Q. Chen, J.T. Lin, T. McKeon; Albany, California**

2017
Chen, G.Q., Riiff, T.J., Johnson, K., Morales, J.S., Kim, H.U., Lee, K., Lin, J.T. 2017. Seed development and hydroxy fatty acid biosynthesis in physaria lindheimeri. Industrial Crops and Products. 108(108):410-415.

Dong, N., Dong, C., Ponciano, G.P., Holtman, K.M., Placido, D.F., Coffelt, T.A., Whalen, M.C., McMahan, C.M. 2017. Fructan reduction by downregulation of 1-SST in guayule. Industrial Crops and Products. doi: 10.1016/j.indcrop.2017.04.034.

Lhamo, D., McMahan, C.M. 2017. Study of protein addition on properties of guayule natural rubber. Rubber Chemistry and Technology. doi: 10.5254/rct.17.83746.

Lin, J.T., Chen, G.Q. 2017. Structural characteristics of the molecular species of tetraacylglycerols in lesquerella (Physaria fendleri) oil elucidated by mass spectrometry. Biocatalysis and Agricultural Biotechnology. 10(10):167-173. doi: 10.1016/j.bcab.2017.03.005.

Sikandar, S., Ujor, V.C., Ezeji, T.C., Rossington, J.L., Michel, F.C., Mcmahan, C.M., Ali, N., Cornish, K. 2017. Thermomyces lanuginosus STm: a source of thermostable hydrolytic enzymes for novel application in extraction of high-quality natural rubber from Taraxacum kok-saghyz (rubber dandelion). Industrial Crops and Products. 103(2017):161-168. doi:10.1016/j.indcrop.2017.03.044.

2016
Brandon, D.L., McKeon, T.A., Patfield, S.A., He, X. 2016. Analysis of castor by ELISAs that distinguish Ricin and Ricinus communis agglutinin (RCA). Journal of the American Oil Chemists' Society. 93:359-363.

Chen, G.Q., Johnson, K., Morales, E., Mackey, B.E., Lin, J.T. 2016. Rapid development of a castor cultivar with increased oil content. Industrial Crops and Products. 94:586-588. doi:10.1016.j.indcrop.2016.09.020.[Corrigendum: Industrial Crops and Products: 2017, p.101:103.]

Chen, G.Q., Van Erp, H., Martin-Moreno, J., Johnson, K., Morales, J.S., Browse, J., Eastmond, P.J., Lin, J.T. 2016. Expression of castor LPAT2 enhances ricinoleic acid content at the sn-2 position of triacylglycerols in lesquerella seed. International Journal of Molecular Sciences. 17(4):507. doi: 10.3390/ijms17040507.

Kim, H., Lee, K., Donghwan, S., Lee, J., Chen, G.Q., Hwang, S. 2016. Transcriptome analysis and identification of genes associated with omega-3 fatty acid biosynthesis in Perilla frutescens (L.) var. frutescens. Biomed Central (BMC) Genomics. 17:474. doi: 10.1186/s12864-016-2805-0.

Lin, J.T., Fagerquist, C.K., Chen, G.Q. 2016. Ratios of regioisomers of the molecular species of triacylglycerols in lesquerella (Physaria fendleri) oil estimated by mass spectrometry. Journal of the American Oil Chemists' Society. 93(2):183-191. doi: 10.1007/s11746-015-2769-2.

Monadjemi, S., McMahan, C.M., Cornish, K. 2016. Effect of non-rubber constituents on Guayule and Hevea rubber intrinsic properties. Journal of Research Updates in Polymer Science. 5(5):87-96. doi: 10.6000/1929-5995.2016.05.03.1.

<u>2015</u>
McKeon, T.A., Brandon, D.L., He, X. 2015. Improved method for extraction of castor seed for toxin determination. Biocatalysis and Agricultural Biotechnology. 5:56-57. doi: 10.1016/j.bcab.2015.12.007.

Mcmahan, C.M., Lhamo, D. 2015. A study of amino acid modifiers in guayule natural rubber. Rubber Chemistry and Technology. 88:310-323.

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2030-21410-020-00D – *Improvement and Utilization of Natural Rubber- and Castor Oil-producing Industrial Crops* – Colleen McMahan (P), G. Chen, J. Lin, T. McKeon; Albany, California (Project Terminated and Replaced by Project No. 2030-21410-021-00D)

<u>2016</u>
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2030-41000-058-00D
***Bioproducts from Agricultural Feedstocks;* Gregory Glenn (P), S. Chiou, D. Wood, W. Orts, C. Lee, one vacancy; Albany, California**

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5325-41000-044-00D – *Development of Agriculturally-Derived Biopolymer Composites for Non-Food Applications* – Gregory Glenn (P), B.S. Chiou, S. Imam, W. Orts, G. Robertson,

D. Wood; Albany, California (Project Terminated and Replaced by Project No. 2030-41000-058-00D)

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Robertson, G.H., Cao, T., Gregorski, K.S., Hurkman II, W.J., Tanaka, C.K., Chiou, B., Glenn, G.M., Orts, W.J. 2014. Modification of vital wheat gluten with phosphoric acid to produce high free-solution capacity. Journal of Applied Polymer Science. 131(2):1-11.

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2030-41000-064-00D*New Sustainable Processing Technologies to Produce Healthy, Value-Added Foods from Specialty Crops;* Tara McHugh (P), Z. Pan, J. Berrios, R. Milczarek, M. Friedman; Albany, California

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Albertos, I., Martín-Diana, A., Jaime, I., Avena-Bustillos, R.D., McHugh, T.H., Rico, D. 2017. Antioxidant effect of olive leaf powder on fresh Atlantic horse mackerel (Trachurus trachurus) minced muscle. Journal of Food Processing and Preservation. 42:e13397 (8 pages). https://doi.org/onlinelibrary.wiley.com/doi/abs/10.1111/jfpp.13397

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2030-41440-007-00D - *Adding Value to Plant-Based Waste Materials through Development of Novel, Healthy Ingredients and Functional Foods;* Wallace Yokoyama (P), T. Kahlon, T. McHugh, R. Milczarek, A. Breska; Albany, California

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2090-43440-007-00D – *Wheat Quality, Functionality and Marketability in the Western U.S.;* Craig Morris (P); Pullman, Washington

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2094-43000-007-00D – *Developmental Genomics and Metabolomics Influencing Temperate Tree Fruit Quality;* James Mattheis (P), D. Rudell, L. Honaas; Wenatchee, Washington

<u>2017</u>

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2094-43000-006-00D *Genetic, Metabolic, and Physiological Factors Regulating Deciduous Tree Fruit Quality* – James Mattheis (P), D. Rudell, one vacancy; Wenatchee, Washington (Project Terminated and Replaced by Project No. 2094-43000-007-00D)

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3020-43440-001-00D – ***Impact of the Environment on Sorghum Grain Composition and Quality Traits;*** **Scott Bean (P), T. Herald, M. Tilley, J. Wilson, two vacancies; Manhattan, Kansas**

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3020-44000-023-00D – ***Improve Grain Sorghum End-Use Quality & Utilization by Identifying the Physical, Chemical & Environmental Factors Related to Food and Feed*** **– Scott Bean (P), T. Herald, M. Tilley, J. Wilson; Manhattan, Kansas (Project Terminated and Replaced by Project No. 3020-43440-001-00D)**

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3020-43440-008-00D – *Impacting Quality through Preservation, Enhancement, and Measurement of Grain and Plant Traits;* Paul Armstrong (P), M. Casada, F. Fowell, D. Brabec, J. Campbell; Manhattan, Kansas

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3020-44000-026-00D – *Impact of Environmental Variation on Genetic Expression (phenotype) of Hard Winter Wheat Quality Traits;* Jeff Wilson (P), Y. Chen, M. Tilley, B. Seabourn, T. Herald, S. Bean; Manhattan, Kansas

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3050-41000-008-00D – *Enhancing Quality, Utility, Sustainability, Environmental Impact of Cotton and its Byproducts through Improvement in Harvest/Gin Processing* – Derek Whitelock (P), C. Armijo, K. Baker, P. Funk, S. Hughs; Las Cruces, New Mexico (Project Terminated and Replaced by Project No. 3050-41000-009-00D)

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3060-43440-014-00D – ***Enhancement of Hard Spring Wheat, Durum, and Oat Quality;*** **Jae-Bom Ohm (P), L. Dykes; Fargo, North Dakota**

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3096-21410-008-00D – *Enhancing the Profitability and Sustainability of Upland Cotton, Cottonseed, and Agricultural Byproducts through Improvements in Pre- and Post-Harvest Processing;* John Wanjura (P), G. Holt, M. Pelletier; Lubbock, Texas

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5010-22410-020-00D – *New Microbial and Plant-Based Agents for Mosquito Control;* Ephantus Muturi (P), J. Ramirez, A. Rooney; Peoria, Illinois (New Project, thererfore, there are no accomplishments for this time frame 2012-2017)

5010-41000-166-00D – *Improved Utilization of Proteinaceous Crop Co-Products;* Gordon Selling (P), M. Hojillaevangelist, V. Boddu; Peoria, Illinois

2017

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5010-22410-018-00D – *New Ovicidal Microbial Agents for the Biological Control of Mosquitoes* – Ephantus Muturi (P), J. Ramirez, A. Rooney; Peoria, Illinois (Project Terminated and Replaced by Project No. 5010-41000-166-00D)

<u>2017</u>

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5010-41000-156-00D – *Improved Utilization of Proteinaceous Crop Co-Products and Residues* – Gordon Selling (P), S. Gordon, M. Hojiliaevangellis, three vacancies (Project Terminated and Replaced by Project No. 5010-41000-166-00D)

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5010-41000-167-00D – *Evaluation of the Chemical and Physical Properties of Low-Value Agricultural Crops and Products to Enhance their Use and Value;* Mark Berhow (P), F. Eller, B. Tisserat, S. Vaughn, S. Liu; Peoria, Illinois

2017
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5010-41000-150-00D – *Discovery and Utilization of Bioactive Components from New Crops and Agricultural Co-Products* – Mark Berhow (P), F. Eller, B. Tisserat, S. Vaughn; Peoria, Illinois (Project Terminated and Replaced by Project No. 5010-41000-167-00D)

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<u>2013</u>

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5010-41000-168-00D – *Improved Utilization of Low-Value Oilseed Press Cakes and Pulses for Health-Promoting Food Ingredients and Biobased Products;* Frederick Felker (P), J. Kenar, J. Byars, M. Singh, S Liu; Peoria, Illinois

2017

Byars, J.A., Singh, M., Kenar, J.A. 2017. Effect of hydrocolloids on functional properties of navy bean starch. Starch/Starke. doi: 10.1002/star.201600305.

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5010-41000-152-00D – *Amylose Helical Inclusion Complexes for Food and Industrial Applications* – Frederick Felker (P), J. Byars, J. Kenar, S. Liu, M. Sigh; Peoria, Illinois (Project Terminated and Replaced by Project No. 5010-41000-168-00D)

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5010-41000-169-00D – *Innovative Processing Technologies for Creating Functional Food Ingredients with Health Benefits from Food Grains, their Processing Products, and By-products;* Sean Liu (P), J. Byars, M. Singh, one vacancy; Peoria, Illinois

2016
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5010-41000-151-00D – *Improving Human Health Using Functional Food Ingredients from By-Products of Grain Milling Industries Using Innovative Technologies* – George Inglett (P), J. Byars, S. Liu M. Singh; Peoria, Illinois (Project Terminated and Replaced by Project No. 5010-41000-169-00D)

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5010-41000-170-00D – *Industrial Monomers and Polymers from Plant Oils;* Kenneth Doll (P), B. Moser, Z. Liu, R Murry; Peoria, Illinois

<u>2017</u>

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5010-41000-171-00D – *Replacement of Petroleum Products Utilizing Off-Season Rotational Crops;* Steven Cermak (P), T. Isbell, R. Evangelista, R. Harry; Peoria, Illinois

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5010-41000-172-00D – *Technologies for Producing Renewable Bioproducts;* Christopher Skory (P), G. Cote, N. Price, T. Leathers, J. Rich; Peoria, Illinois

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5010-41000-174-00D – *Conversion of Polysaccharides and Other Bio-based Materials to High-Value, Commercial Products;* Atanu Biswas (P), V. Finkenstadt, S. Gordon, V. Boddu; Peoria, Illinois

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5010-41000-157-00D – *Novel Starch-Based Materials* – Victoria Finkenstadt (P), S. Gordon, F. Momany, one vacancy; Peoria, Illinois (Project Terminated and Replaced by Project No. 5010-41000-174-00D)

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5010-41000-160-00D – *Modification of Natural Polymers by Novel Processes* – Antanu Biswas (P), G. Fanta, V. Finkenstadt, S. Gordon, G. Selling, J. Xu, two vacancies; Peoria, Illinois (Project Terminated and Replaced by Project No. 5010-41000-174-00D)

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5010-41000-175-00D – *Value-added Bio-oil Products and Processes;* Girma Biresaw (P), G. Bantchev, R. Dunn, G. Knothe, R. Murray; Peoria, Illinois

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5010-41000-165-00D – *Vegetable Oil-Based Fuels, Additives and Coproducts* – Gerhard Knothe (P), B. Moser, R. Dunn, R. Murray; Peoria, Illilnois (Project Terminated and Replaced by Project No. 5010-41000-175-00D)

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5010-41000-148-00D – *Vegetable Oil-Based Fuels, Additives and CoProducts* – Gerhard Knothe (P), R. Dunn, B. Moser, R. Murray; Peoria, Illinois (Project Terminated and Replaced by Project No. 5010-41000-175-00D)

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5010-41000-155-00D – *Bio-Based Lubricants from Farm-Based Raw Materials* – Girma Biresaw (P), G. Bantchev; Peoria, Illinois (Project Terminated and Replaced by Project No. 5010-41000-175-00D)

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5010-44000-052-00D – *Improving Quality, Stability, and Functionality of Oils and Bioactive Lipids;* Jill Moser (P), H. Hawang, S. Liu; Peoria, Illinois

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5010-44000-050-00D – *Improving Stability and Healthfullness of U.S. Commodity Vegetable Oils and Products* – Jill Moser (P); E. Bakota, H.S Hwang, S. Liu; Peoria, Illinois (Project Terminated and Replaced by Project No. 5010-44000-052-00D)

2017

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5010-44000-053-00D – *Renewable Biobased Particles;* Lei Jong (P), S. Peterson, S. Kim, G. Fanta, J. Xu, V. Boddu; Peoria, Illinois

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5010-44000-051-00D - *Visoelastic Properties and Polymer Composite Applications of Nano-Materials Derived from Agricultural Byproducts and Feedstocks* – Lei Jong (P), S. Kim, S. Peterson; Peoria, Illinois (Project Terminated and Replaced by Project No. 5010-44000-053-00D)

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5050-43640-002-00D – *Nondestructive Quality Assessment and Grading of Fruits and Vegetables;* Renfu Lu (P), East Lansing, Michigan

<u>2017</u>

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5050-43640-001-00D – *Technologies for Quality Measurement and Grading of Fruits and Vegetables* – Renfu Lu (P); East Lansing, Michigan (Project Terminated and Replaced by Project No. 5050-43640-002-00D)

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5082-43440-001-00D – *Genetic and Biochemical Basis of Soft Winter Wheat End-Use Quality;* Byung-Kee Baik (P), B. Penning; Wooster, Ohio

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5082-43440-007-00D – *Genetic and Biochemical Basis of Soft Winter Wheat Quality* – Byung-Kee Baik (P), M. Reindbaugh, one vacancy; Wooster, Ohio (Projejct Terminated and Replaced by Project No. 5082-43440-001-00D)

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5442-21440-006-00D – *Quality Characteristics of High Beta-Glucan Oat Cultivars* – Douglas Doehlert (P); Fargo, North Dakota (Project Terminated and Replaced by Project No. 3060-43440-014-00D)

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5090-43440-005-00D – *Identifying the Next Generation of Malting Barley through Improved Selection Criteria and Quality Analysis of Breeding Lines* – Vacant (P), C. Henson; Madison, Wisconsin (Project Terminated and Replaced by 5090-43440-006-00D)

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6034-41000-017-00D – *Enhancing Utilization of Citrus Processing Co-Products;* Randall Cameron (P), J. Manthey, C. Dorado, one vacancy; Ft. Pierce, Florida

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6034-41000-016-00D – *Enhanced Utilization of Carbohydrates and Polysaccharides from Citrus Processing Waste Streams* – Randall Cameron (P), J. Bai, G. Luzio, J. Manthey, one vacancy; Fort Pierce, Florida (Project Terminated and Replaced by Project No. 6034-41000-017)

<u>2015</u>
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<u>2013</u>
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6034-41000-015-00D – *Bioactive Constituents and Speciality Food Fibers as Value-Added Products from Citrus Processing Waste* – John Manthey (P), J. Bai, R. Cameron, G. Luzio, one vacancy; Fort Pierce, Florda (Project Terminated and Replaced by Project No. 6034-41000-017-00D)

<u>2016</u>
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6621-41000-013-00D – *Enhanced Utilizationof Carbohydrates and Polysaccarides from Citrus Processing Waste Streams*; Winter Haven, Florida (Project Terminated and Replaced by Project No. 6034-41000-017-00D)

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6034-41430-006-00D – *Quality, Shelf-life and Health Benefits for Fresh, Fresh-cut and Processed Products for Citrus and other Tropical/Subtropical-grown Fruits and Vegetables;* Anne Plotto (P), J. Bai, E. Baldwin, J. Manthey, R. Cameron, one vacancy, Ft. Pierce, Florida

2017

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6034-41430-005-00D – *Metabolomic and Microbial Profiling of Tropical/Subtropical Fruits and Small Fruits for Quality Factors and Microbial Stability* – Anne Plotto (P), J. Bai, E. Baldwin, G. Luzio, J. Manthey; Fort Pierce, Florida (Project Terminated and Replaced by Project No. 6034-41430-006-00D)

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Bai, J., Baldwin, E.A., McCollum, T.G., Plotto, A., Manthey, J.A., Widmer, W., Luzio, G., Cameron, R.G. 2016. Changes in volatile and non-volatile flavor chemicals of "Valencia" orange juice over the harvest seasons. Foods. 5,4;doi:10.3390/foods5010004.

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6040-41440-002-00D – *Assessment and Improvement of Poultry Meat, Egg, and Feed Quality;* Brian Bowker (P), G. Gamble, K. Lawrence., S. Trabelsi, C. Yoon, H. Zhuang, two vacancies; Athens, Georgia

2017

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6040-41440-001-00D – *Develop Methods to Assess and Improve Poultry and Eggs Quality* – Brian Bowker (P), G. Gamble, K. Lawrence, S. Trabelsi, S. Yoon, H. Zhuang, R. Holser, one vacancy; Athens, Georgia (Project Terminated and Replaced by Project No. 6040-41440-002-00D

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6054-41000-103-00D – *Increasing the Value of Cottonseed;* Michael Dowd (P), H. Cao, H. Cheng, Z. He, Z. Klasson, J. Shockey; New Orleans, Louisiana

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6054-41000-106-00D – *Cotton-based Nonwovens;* Doug Hinchliffe (P), S. Nam, B. Condon, two vacancies; New Orleans, Louisiana

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6054-41000-104-00D – *Cotton-based Nonwovens* – Amar Sawhney (P), B. Condon, D. Hinchliffe; New Orleans, Louisiana (Project Terminated and Replaced by Project No. 6054-41000-106-00D

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6054-41000-107-00D – *Nutritional and Sensory Properties of Rice and Rice Value-Added Prodcuts;* Stephen Boue (P), J. Beaulieu, G. Bett, C. Grimm; New Orleans, Louisiana

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6054-41000-105-00D – *Rice as a Source and Delivery System for Nutrients and Lipophilic Bioactive Compounds* – Stephen Boue (P), J. Beaulieu, K. Brett Garber, C. Grimm; New Orleans, Louisiana (Project Terminated and Replaced by Project No. 6054-41000-107-00D)

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6054-41430-007-00D – *Chemical Modification of Cotton for Value Added Application*s; Judson Edwards (P), S. Chang, M. Easson, B. Condon; New Orleans, Louisiana

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6054-41430-006-00D – *Chemical Modification of Cotton for Value Added Applications* – Judson Edwards (P), S. Chang, B. Condon, M. Easson; New Orleans, Louisiana (Project Terminated and Replaced by Project No. 6054-41430-007-00D)

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6054-43440-046-00D – *Reducing Peanut and Tree Nut Allergy;* Soheila Maleki (P), C. Mattison, B. Hurlburt, one vacancy; New Orleans, Louisiana

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6054-44000-078-00D – *Postharvest Sensory, Processing and Packaging of Catfish;* Peter Bechtel (P), C. Grimm, K. Bett; New Orleans, Louisiana

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6054-44000-079-00D – *Improved Quality Assessment of Cotton from Fiber to Final Products;* Christopher Delhom (P), C. Fortier, Y. Liu, C. Santiago, D. Peralta, two vacancies; New Orleans, Louisiana

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6054-44000-075-00D – *New and Improved Assessments of Cotton Quality* – James Rogers III (P), C. Delhom, C. Fortier, Y. Liu, J. Montalvo, one vacancy; New Orleans, Louisiana (Project Terminated and Replaced by Project No. 6054-44000-079-00D)

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6645-41000-005-00D – *Improved Processes for Cucumbers, Cabbage, Sweetpotatoes, and Peppers to Make High-Quality, Nutritious Products and Reduce Pollution*; Roger McFeeters (P) F. Breidt, I. Perez Diaz, V. Truong; Raleigh, North Carolina (Project Terminated and Replaced by Project No. 6070-41000-008-00D)

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8042-43000-015-00D – *Enhancing Fruit and Vegetable Nutritional Quality with Improved Phenolics Contents;* Tianbao Yang (P), two vacancies; Beltsville, Maryland

2017

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8042-43000-012-00D – *Genetic and Biochemical Mechanisms Determining Fresh Produce Quality and Storage Life;* Tianbao Yang (P), one vacancy; Beltsville, Maryland (Project Terminated and Replaced by Project No. 8042-43000-015-00D)

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8042-43440-005-00D – *Evaluation and Maintenance of Flavor, Nutritional and Other Quality Attributes of Fresh and Fresh-Cut Produce;* Yaguang Luo (P), two vacancies; Beltsville, Maryland

2017

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8042-43440-004-00D – *Evaluation and Maintenance of Flavor, Nutritional and other Attributes of Fresh and Fresh-Cut Produce* – Yaguang Luo (P), two vacancies; Beltsville, Maryland (Project Terminated and Replaced by Project No. 8042-43440-005-00D)

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8042-44000-001-00D – *Rapid Methods for Quality and Safety Inspection of Small Grain Cereals;* Stephen Delwiche (P); Beltsville, Maryland

2017

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8042-44000-009-00D – *Optical and Mechanical Instrumentation for Quality Assessment of Small Grains* – Stephen Delwiche (P); Beltsville, Maryland (Project Terminated and Replaced by Project No. 8042-44000-001-00D)

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8072-41000-096-00D – *Improving the Sustainability and Quality of Food and Dairy Products from Manufacturing to Consumption via Process Modeling and Edible Packaging;* Peggy Tomasula (P), L. Bonnaillie, one vacancy; Wyndmoor, Pennsylvania

2016

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8072-41000-087-00D – *Sustainable Strategies to Lower the Environmental and Economic Impacts of Food Processing Using Fluid Milk as a Template* – Peggy Tomasula (P), L. Bonnaillie, M. Tunick; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41000-096-00D)

2016

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8072-41000-097-00D – *Effect of Processing of Milk on Bioactive Compounds in Fresh High-Moisture Cheeses;* Diane Van Hekken (P), P. Tomasula, A. Bucci; Wyndmoor, Pennsylvania

2017

Van Hekken, D.L., Tunick, M.H., Renye Jr, J.A., Tomasula, P.M. 2017. Characterization of starter-free Queso Fresco made with sodium-potassium salt blends over 12 weeks of 4 degrees C storage. Journal of Dairy Science. doi: 10.3168/jds.2016-12081.

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8072-41000-091-00D – *Processing Methods to Modify the Levels of Biologically Active Compounds in Milk and Cheese* – Diane Van Hekken (P), M. Tunick, M. Paul; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41000-97-00D)

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1935-41000-080-00D – *Processing Methods for Hispanic-Style Cheeses with Unique Functional Properties* – Diane Van Hekken (P), M. Paul, M. Tunick; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41000-097-00D)

2012
Paul, M., Nunez, A., Van Hekken, D.L., Renye Jr, J.A. 2012. Protein & sensory analysis to characterize mexican chihuahua cheeses. Journal of Food Science and Technology. DOI: 10.1007/s13197-012-0868-8.

8072-41000-099-00D – *Commercial Products from Microbial Lipids;* Daniel Solaiman (P), R. Ashby; Wyndmoor, Pennsylvania

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8072-41000-090-00D – *Production and Value Enhancement of Biosurfactants and Biopolymers Derived from Agricultural Lipids and Coproducts* – Daniel Solaiman (P), R. Ashby, J. Zerkowski; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41000-099-00D)

2015

Solaiman, D., Ashby, R.D., Crocker, N.V. 2015. High-titer production and strong antimicrobial activity of sophorolipids from Rhodotorula bogoriensis. Biotechnology Progress. DOI: 10.1002/btpr.2101.

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1935-41000-067-00D – *Integrative Processes for the Bioconversion of Fats, Oils and their Derivatives into Biobased Materials and Products* – Daniel Solaiman (P), J. Zerkowski, R. Ashby; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41000-099-00D)

<u>2014</u>

Solaiman, D., Liu, Y., Moreau, R.A., Zerkowski, J.A. 2014. Cloning, characterization, and heterologous expression of a novel glucosyltransferase gene from sophorolipid-producing Candida bombicola. Gene. 540:46-53. DOI: 10.1016/j.gene.2014.02.029.

8072-41000-100-00D – *Bioactive Food Ingredients for Safe and Health-Promoting Functional Foods;* Arland Hotchkiss (P), P. Qi, J. Renye; Wyndmoor, Pennsylvania

<u>2017</u>

Di, R., Vakkalanka, M.S., Onumpai, C., Chau, H.K., White, A.K., Rastall, R.A., Yam, K., Hotchkiss, A.T. 2017. Pectic oligosaccharide structure-function relationships: prebiotics, inhibitors of Escherichia coli O157:H7 adhesion and reduction of Shiga toxin cytotoxicity in HT29 cells. Food Chemistry. 227:245-254.

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8072-41000-088-00D - *Functional Food Development by Microbial Biotechnology* – Arland Hotchkiss (P), J. Reyne, P. Qi; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41000-100-00D)

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8072-41000-089-00D – *New Bioactive and Biobased Products from Plant Cell Wall Polysaccharides in Sugar Beef Pulp, Citrus Peel and other Processing Residues* – Arland Hotchkiss (P), L. Liu; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41000-100-00D)

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Sousa, A.M., Souza, H.S., Latona, N.P., Liu, C., Goncalves, M.P., Liu, L.S. 2014. Choline chloride based ionic liquid analogues as tool for the fabrication of agar films with improved mechanical properties. Carbohydrate Polymers. DOI: 10.1016/j.carbpol.2014.04.019.

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8072-41000-102-00D – *In Vitro Human Intestinal Microbial Ecosystem: Effects of Diet;* Lin Liu (P), one vacancy, J. Firrman; Wyndmoor, Pennsylvania

8072-41000-086-00D – *Microstructured and Health-Functionalized Food Proteins* – Lin Liu (P), P. Qi, one vacancy; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41000-102-00D)

2017

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2017

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8072-41440-023-00D – *Commercial Flocculants from Low-Value Animal Protein;* Rafael Garcia (P), G. Piazza, one vacancy; Wyndmoor, Pennsylvania

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8072-41440-022-00D – *Biobased Industrial Products from Food Animal Processing By-Products* – Rafael Garcia (P), M. Taylor, G. Piazza; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41440-023-00D)

2016
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1935-41440-021-00D – *Biobased Industrial Products from Food Animal Processing By-products* – Rafael Garcia (P), G. Piazza; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41440-023-00D)

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8072-41440-024-00D – *Improving the Quality of Animal Hides, Reducing Environmental Impacts of Hide Production, and Developing Value-Added Products from Wool;* Cheng Kung Liu (P), E. Brown, M. Sarker; Wyndmoor, Pennsylvania

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8072-41440-019-00D – *Environmentally Friendly Processes and New Applications for Animal Hides and Leather* – Cheng Kung Liu (P), E. Brown, M. Ramos; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41440-024-00D)

2015
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2014

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Merkel, R.C., Liu, C., Latona, N.P., El A'Mma, A., Goetsch, A.L. 2013. Effects of level and length of supplementation on leather characteristics of yearling Boer and Spanish wethers. Journal of American Leather Chemists Association. 108(4):139-145.

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2012

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1935-41440-016-00D – *New and Efficient Processes for Making Quality Leather* – Cheng Liu (P), M. Ramos, E. Brown, M. Taylor; Wyndmoor, Pennsylvania (Project Terminated and Replaced by Project No. 8072-41440-024-00D)

2013

Ramos, M., Muir, Z.E., Wheeler, T.L., Kalchayanand, N., McAloon, A.J. 2013. Economic assessment and pathogenic bacteria inhibition of bovine hide presoaking solutions formulated with enzymes that can remove adobe-type manure. Journal of American Leather Chemists Association. 108(9):319-344.

5010-43000-007-00D – *Coordinated Analysis of Soybean Breeding Germplasm* – Terry Isbell (P); Peoria, Illinois (National Program 301 - Project Terminated and Replaced by Project No. 5010-43000-008-00D)

2013

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6435-41000-107-00D – *Novel Microbial Sensing and Elimination Technologies for Protection of Agricultural Commodities* – Deepak Bhatnagar (P), K. Rajasekaran; New Orleans, Louisiana (National Program 108 - Project Terminated and Replaced by Project No. 6054-42000-025-00D)

2013

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APPENDIX 4

National Program 213
Biorefining
Accomplishment Report 2012 – 2017
Selected Supporting Information and Documentation for Accomplishments and Impact

How This National Program Supports the ARS Strategic Plan:

Outputs of NP 213 research support the “Actionable Strategies” associated with the performance measures shown below from the ARS Strategic Plan for FY 2012-2017.

> **Performance Measure 1.2.3** Enable new commercially-viable technologies to (1) convert agricultural materials and byproducts into fuels and other marketable products, and (2) reduce risks and increase profitability in existing industrial biorefineries.
>
> **Target:** By 2017, ARS will characterize 10 important feedstock traits, create 3 enhanced germplasm pools, and establish 5 significant public-private partnerships for advancing feedstock variety improvement.

Patents:

There were 14 patents, 2 of which were licensed; they are listed by title/inventor.

2017
- Fluidised Bed Pyrolysis Apparatus and Method (Akwasi Boateng)

2016
- Synthetic Promoter for Xylose-Regulated Gene Expression (Ronald Hector)
- Methods for Producing Bio-Oil (Charles Mullen)
- Bio-Based Fiber Gums (Bfgs) and Processes for Producing Bfgs (Madhav Yadav)
- Novel Ferulate Esterase Isolated from Lactobaccillus Fermentum (Siqing Liu)
- Novel Yeast Strains (Patricia Slininger)

2015
- Process for Preparing Saturated Branched Chain Fatty Acids (Helen Ngo)

- Novel Yeast Strains and Method for Lignocellulose to Ethanol Production (Zonglin Liu)
- Fast Pyrolysis Catalytic Cracking Pipe for Producing Bio-Oils (Neil Goldberg)

2014

- Novel Kluyveromyces Marxianus Strains and Method of Using Strains (Stephen Hughes)
- Prevotella Ruminicola Xylose Isomerase and Co-Expression with Xylulokinase in Yeast for Xylose Fermentation (Ronald Hector)
- A New Tolerant Yeast Producing Beta-Glucosidase for Low-Cost Cellulosic Ethanol Production Using SSF (Zonglin Liu)

2013

- Scheffersomyces Stipitis Strain for Increased Ethanol Production and Uses Thereof (Stephen Hughes)

2012

- Production of Stable Pyrolysis Bio-Oil from Mustard Family Seeds, Mustard Family Seed Presscake, and Defatted Mustard Family Seed Presscake (Akwasi Boateng)

APPENDIX 5

National Program 306
Quality and Utilization of Agricultural Products
Accomplishment Report 2012 – 2017
Selected Supporting Information and Documentation for Accomplishments and Impact

How This National Program Supports the ARS Strategic Plan:

Outputs of NP 306 research support the “Actionable Strategies” associated with the performance measures shown below from the ARS Strategic Plan for FY 2012-2017.

> **Performance Measure 1.1.3** Develop methods and technologies to better define, measure, preserve or enhance quality and improve utilization of food crops, animals, and agricultural fibers, as well as non-food, non-fuel biobased products, and sustainable technologies/processes.
>
> **Target:** Cumulatively, 20 new technologies were developed by ARS and adopted for uses that provide food crops and products with higher quality and extended shelf life; convenient and acceptable healthy foods; non-food, non-fuel biobased products with cost and performance features comparable or superior to petroleum-based products; high quality agricultural fibers; and valuable coproducts from agricultural residues and processing wastes.

Patents: There were 73 patents, 17 of which were licensed; they are listed by title/inventor.

2017

- Elastomer Derived From Epoxidized Vegetable Oil (Zengshe Liu)
- Novel Infrared Dry Blanching (Idb), Infrared Blanching, and Infrared Drying Technologies for Food Processing (Zhongli Pan)
- Olive Leaf Powder (Tara Mchugh)
- Nanoparticles and Films Composed of Water-Insoluble Glucan (Ryan Cormier)
- Charcoal-Foam Heating Material (Gregory Glenn)
- Modified Glucansucrase and Related Methods (Gregory Cote)
- Boron Complexes With Gradual 1- Methylcyclopropene Releasing Capability (Majher Sarker)

- Methods and Apparatuses for Thermal Treatment of Foods and Other Biomaterials, and Products Obtained Thereby (Van Den Truong)
- Bacteriocin with Novel Activity (John Renye Jr.)
- Transgenic Guayule for Enhanced Isoprenoid Production (Niu Dong)
- Heavy Metal Remediation via Sulfur-Modified Bio-Oils (Rex Murray)

2016

- Engineering Rubber Production in Plants (Maureen Whalen)
- Anxiolytic Effect of Pterostilbene (Agnes Rimando)
- Novel Use of Glucosyltransferase Gene (Daniel Solaiman)
- Cranberry Xyloglucan Oligosaccharide Composition (Arland Hotchkiss)
- Nanolipoprotien Particles Comprising a Natural Rubber Biosynthetic Complex and Related Products, Methods and Systems (Maureen Whalen)
- Elastomeric Conductive Materials and Processes of Producing Elastomeric Conductive Materials (Colleen Mcmahan)

2015

- Bioderived Compatibilizer and Plasticizer for Biopolymers (William Orts)
- Heavy Metal Remediation via Thiolated Bio-Oils (Rex Murray)
- Cottonseed Delinters and Methods (Gregory Holt)
- Cereal-Based Charcoal Binder (Syed Imam)
- Process for Producing Improved Zein Articles (Gordon Selling)
- Utilization of Non-Nutritive Adsorbents to Sequester Mycotoxins During Extraction of Protein or other Value Added Components from Mycotoxin Contaminated Cereal or Seed Oil Meal (Jack Davis)
- Protein-Cyanoacrylate Nanoparticles that Improve Wetting Property of Materials (Sanghoon Kim)
- Anti-Corrosion Coating Utilizing Bacterial Precipitated Exopolysaccharides (Victoria Finkenstadt)
- Method to Improve Spatial Memory via Pterostilbene Administration (Agnes Rimando)

- Transformation Methods for Guayule Using Agrobacterium and Reduced Light to Slow Metabolism and Enhance Recovery (Katrina Cornish)
- Production of Tunable Polyhydroxyalkanoate Biopolymers Using Glycerol and Levulinic Acid (Richard Ashby)
- Cross-Linked Biofiber Products and Processes for their Manufacture (Gregory Holt)
- Infra Red Based Peeling of Fruits and Vegetables (Zhongli Pan)

2014

- X-Ray Irradiation System For Sterilization of Insects (Ronald Haff)
- Bioactive Gypsum Starch Composition (Syed Imam)
- Process for Preparation ff Nitrogen-Containing Vegetable Oil-Based Lubricant Additive (Atanu Biswas)
- Starch-Based Fire Retardant (Gregory Glenn)
- Oligomerization of Jojoba Oil in Super-Critical Co2 for Different Applications (Zengshe Liu)
- Process To Prepare a Phosphorous Containing Vegetable Oil Based Lubricant Additive (Kenneth Doll)
- Method to Ameliorate Oxidative Stress and Imporve Working Memory via Pterostilbene Administration (Agnes Rimando)
- Method and Apparatus for Measuring Protein Quality (Craig Morris)
- Cottonseed Delinters and Methods (Gregory Holt)
- Compositions and Methods for Treating a Keratin Based Substrate (Jeanette Cardamone)
- An Interrogation Measurement System and Method Providing Accurate Permittivity Measurements via Ultra-Wideband Removal of Spurious Reflectors (Mathew Pelletier)
- Methods and Devices for Validation of Thermal Processes Using Time-Temperature Integrators and Temperature Level Detection (Van Den Truong)
- Carbohydrate and Polyol Ethers as Renewable Oils, Greases, and Liquid Fuels (Neil Price)
- Fruit and Vegetable Films and Uses Thereof (Tara Mchugh)
- Superabsorbent Materials from Chemically Modified Gluten (Bor Sen Chiou)

- Carbonate Phase Change Materials (James Kenar)
- Solution Blow Spinning (William Orts)
- Microwave Sensor and Algorithm for Moisture and Density Determination (Samir Trabelsi)

2013

- Method and Apparatus for Measuring Peanut Moisture Content (Chari Kandala)
- Elastomer Product from Epoxidized Vegetable Oil and Gliadin (Rogers Harry-O'Kuru)
- A Method for Synthesis of Ketones From Plant Oils (Michael Jackson)
- Methods To Produce Keratin Elastomer (Jeanette Cardamone)
- Pectin Extraction From Sunflower Head Residues (Marshall Fishman)
- New Method of Pectin Extraction (Marshall Fishman)
- Method to Extract Pectin From Sunflower Heads (Lin Liu)
- Production of Stable Polyesters by Microwave Heating of Carboxylic Acid: Polyol Blends (Brent Tisserat)
- Molecular Gel-Based Control Release Devices for Pheromones (Gregory Glenn)
- Fungicidal Properties of Three Saponins from Capsicum Frutescens (Anthony De Lucca II)
- Non-Transgenic Soft Textured Tetraploid Wheat Plants Having Grain With Soft Textured Endosperm, Endosperm Therefrom and Uses Thereof (Craig Morris)
- Vegetable Oil Esterified Lipoic Acid (Joseph Laszlo)
- Colon Cancer Treatment and Prevention By Pterostilbene (Agnes Rimando)
- Use of a Pre-Harvest Carnauba Spray Combined with Copper Sulfate to Reduce Incidence of Citrus Canker in the Field (Jan Narciso)
- Biopolymer Additive (William Orts)
- Ethanol Production from Solid Citrus Processing Waste (Wilbur Widmer)
- Composition Comprising a Uv-Absorbing Chromophore (Joseph Laszlo)
- Semi-Rigid Gel Cleansing Article and Uses Thereof (Gregory Glenn)
- Carbonate Phase Change Materials (James Kenar)

- Furanocoumarin Removal from Grapefruit Juice by Edible Fungal Hyphae (John Manthey)

2012

- Modified Aspergillus Niger Phytase (Edward Mullaney)
- Method for Flocculating Suspensions Using Biobased Renewable Flocculants (George Piazza)
- Methods of Promothing the Growth of Beneficial Bacteria in the Gut (Arland Hotchkiss)
- Green Detergents from Agriculture-Based Lipids and Sugars (Neil Price)
- One Dimensional Linescan X-Ray Detector Array (Ronald Haff)