Progress and Plans of National Nanotechnology Initiative (NNI) Agencies

December 2018[1]

U.S. Department of Agriculture (USDA)[2]

Agriculture Research Service (ARS)

Summary

The USDA Agriculture Research Service has a limited program addressing research relative to nanotechnology, or those sciences directly related to nanotechnology. For example, projects address the development of new commercial cotton-based nonwoven products; the chemical modification of cotton for value added applications; the application of novel imaging methodologies for livestock production research; phytochemical intervention of foodborne pathogens utilizing nanoemulsions; the production of bioproducts from agricultural feedstocks; the development of rapid optical detection methods for food hazards; the development of functional bio-based particles using renewable agricultural byproducts; the development of new sustainable processing technologies to produce healthy, value added foods from specialty crops; and the addition of value to plant-based waste material through the development of novel, healthy ingredients and functional foods.

Plans and Priorities by Program Component Area (PCA)

PCA 3. Nanotechnology-Enabled Applications, Devices, and Systems

ARS will be pursuing R&D aimed at the following objectives:

- Enabling new commercial processes for the development and production of new commercial cotton products, including cotton-containing nonwoven materials for the production of durable antimicrobial wound dressings; nanoscale metal particles inside cotton fibers providing increased flame-retardant and moisture-control properties; and products with enhanced flame-retardant and moisture-control properties.
- Developing new commercial processes for manufacturing cotton-based body-contacting materials for use in biomedical, biosensor, and hygienic applications.
- Developing new *in vitro* and *ex vivo* approaches for cellular and tissue biophotonic imaging using nanoparticles.
- Using biopolymers to develop sustainable technologies and bioproducts that will not negatively impact food reserves.
- Developing nanoparticles for the tracking of pathogens to address bacterial abundance and persistence related to livestock well-being and production performance, and developing mitigation

[1] Text dated December 2018 except as elsewhere noted.

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strategies. Developing nanobiosensors for pathogen detection in food animals and plants and their derived products.

- Enabling the development and production of nanoparticle biopolymers for composite, coating, cosmetic, and medical applications.
- Enabling the commercial production of new products based on nanoparticles for controlled release of chemicals, products based on biodegradable nanoparticles from starch, lignin, and cellulose.
- Applying the tools of nanoscience to the casting of edible films to improve safety, extend shelf life, and improve quality.

Examples of Specific ARS Nanotechnology Projects[3]

Eastern Regional Research Center, Wyndmoor, PA

- Nanoemulsions containing antimicrobials are being developed for use as edible film wraps for ready-to-eat meats.

Northern Center for Agricultural Utilization Research, Peoria, IL

- Nanosponge (polyurethane/cyclic sugar material with nanoscale cavities) filters out compounds that interfere with detection of toxins in fruit juice and wine.
- Nanoporus silica (functionalized with thiol groups) is a non-soluble particle that binds with fruit juice toxins, then is filtered out.
- Nano-lipid-polymer (soybean oil hydrogel) loads and delivers multidrug-resistant anti-breast cancer drugs.
- Nanocellulose/lignin complex improves functional properties for controlled release of active ingredients in cosmetics, chemicals, and pesticides.
- Nanoamylose-oil complex improves stability of food (e.g., salad dressings, sauces, ice cream) and industrial products (e.g., paints, glues, cleaners).

Southern Regional Research Center, New Orleans, LA

- Nanosilver (a “green” antimicrobial agent) reduces odor-forming bacteria in cotton fabric.
- Nanocellulose adds strength to cottonseed protein wood adhesives.
- Nanocellulose (from processing waste cottonseed hulls) improves viscosity of polyvinyl alcohol suspensions used in paper making, textiles, and food packaging.
- Nanocellulosic hemostatic wound dressings accelerate clotting and contain protease biosensors that stimulate healing.
- Nanoclay particles can be incorporated into cotton fabrics imparting anti-flammability and moisture control.

Richard B. Russell Agricultural Research Center, Athens, GA

- Nanorod-biosensor selectively detects Ricin and enteric bacteria.
- Nanobioassay detects *Salmonellae* serotypes.
- Nanoemulsions of plant-based antimicrobial aromatics (e.g., eugenol, carvacol, cinnamaldehyde) can control enteric bacteria (*Salmonella* & *Campylobacter*) in poultry processing.

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[3] Projects list updated as of July 2019.

Western Regional Research Center, Albany, CA

- Nanofibers from food processing waste (almonds, grapes, and citrus) encapsulate beneficial microbes to improve crop production.
- Nano-fibrillated pulp, produced at low cost, improves renewable plastic/fiber composite strength.

Key Technical Accomplishments

- High-tech applications of cotton have the ability to increase cotton's market share. Aerogels are lightweight materials that feature very low density and high specific surface area, and that consist of a coherent open-porous network of loosely packed, bonded particles or fibers. Aerogels based on nanocellulose have attracted interest for use in different materials from biocompatible scaffolds for tissue engineering to biodegradable packaging foams and sensors. Cotton-based nanocellulosic aerogels have been prepared as sensors for harmful proteins found in chronic wounds and also can be interfaced with chronic wound dressings. The cotton-based aerogel sensors have a high specific surface area, porosity, and fluid uptake capacity. They function well as sensitive detectors of protease activity when derivatized with fluorescent protease substrates. The potential impact may be realized as an application in bedside wound care, and in other biomaterial areas where biocompatible porous substances are needed.
- Layer-by-layer (LbL) coating has been used to develop low-cost, simple approaches to confer flame-retardant and moisture-control properties to semidurable cotton textiles (fabrics that can be used multiple times without discarding). LbL coating is a simple method to incorporate different forms of clay-based formulations into cotton fabrics using clay particles as a dispersing matrix. These clay treatments provide a variety of different physical and chemical properties to cotton, including moisture management, strength, and absorptivity. By treating the cotton fabric with nanocoatings composed of phosphorous-nitrogen-rich polymers prepared via LbL assembly, the cotton fabric can be rendered anti-flammable. The coatings, which also include nanomaterial, are thought to have intumescent (initiated swelling due to an increase in thermal contact) properties that render them flame retardant when applied to cotton. The novel approach provides a low-cost alternative to existing flame-retardant materials. The commercial use of LbL self-assembly processing would provide excellent thermal protection for medical, military, and large-scale emergency material use demands where a low-cost, semi-durable product is desired. These materials are designed to be permanently attached to the cotton to stop wash-off during laundering. The commercial availability of this approach to making fire-retardant treatments would confer a safe and semi-durable finish.
- Foodborne pathogens increasingly exhibit drug resistance against antibiotics, and despite the broad spectrum of antibiotics developed during the last few decades, bacteria still show multidrug-resistance. Advances in nanotechnology and microbiology provide promising applications in the inhibition of bacterial growth. ARS, in collaboration with Mississippi State University, tested the antimicrobial properties of silver magnetic nanoparticles (Ag-MNPs) against various foodborne pathogens (*Escherichia coli* and *Salmonella*) that were rendered bioluminescent for real-time monitoring of bacterial growth inhibition and survival. Molecular changes were also evaluated. The results demonstrated the antimicrobial effects of Ag-MNPs, which were likely exerted through protein changes affecting critical bacterial functions. These proteins can serve as novel biomarkers for further targeting of bacterial contamination, with potential impacts in livestock production.
- Fibrillated nanofibers have been shown to improve the strength of plastic composites but are prohibitively expensive. ARS, in collaboration with Brazilian scientists, has demonstrated that

degradative enzymes from crude digestate are effective in making fibrillated nanofibers from pulp fiber. Different incubation times yielded correspondingly varied degrees of fibrillation. This research could lead to greater production of low-cost fibrillated nanofibers that can improve the strength of fiber composites and increase their renewable material content.