Materials Post Processing

Challenges addressing replacing PFAS in food packaging and fabrics

Matthew B. Hillyer and Sunghyun Nam
Cotton Fiber Bioscience & Utilization Research, USDA-ARS, SRRC, New Orleans, LA

USDA ARS PFAS Research Enterprise
Detecting, Mitigating and Remediating PFAS in Agricultural and Food Systems:
Identifying and Prioritizing Research, Programmatic, and Socio-economic Gaps

Materials Post Processing
Outline

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- PFAS properties for food packaging and textiles
- PFAS release from textiles
- PFAS alternatives – food contact materials
- PFAS alternatives – textiles
- Recent research advancements

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Market Split by On-The-Go Food Packaging Type (2021)

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Bags & Sacks

Trays

Other (Folding Cartons, etc.)

24%	21%	17%	16%	15%	7%

Pouches & Sachets

Bottles & Jars

Cans

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Properties of PFAS in Food Packaging

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PFAS Properties – Food Packaging

- *Water and Oil Resistance*
  PFAS create a barrier that prevents grease, oil, and water from penetrating the packaging, keeping food fresh and preventing leaks.

- *Heat Resistance*
  PFAS can withstand high temperatures, making food packaging suitable for microwaveable and oven-safe packaging.

- *Chemical Resistance*
  PFAS are resistant to many chemicals, ensuring the packaging does not degrade or react with the food.

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Fast-Food and Grocery Chains Phasing Out PFAS

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Restaurant Brands International (RBI) will ban added PFAS in food packaging **globally by 2025**.

- Will *"… work with packaging vendors to test incoming raw materials to ensure added PFAS is not included in our packaging,* ***including in the recycled content*** *of some of our paper packaging."*

McDonald's announced in January 2021 that it would remove added PFAS from "guest packaging materials **globally by 2025**."

Chick-fil-A disclosed in March 2022 it eliminated **intentionally added PFAS** from all newly produced packaging going forward in its supply chain.

- They clarified that while "*some* ***legacy packaging may still be in restaurants****, it is expected to be* ***phased out*** *by the end of summer of 2022*."

In late 2020, Whole Foods Market adopted a restricted substance list that **restricts intentionally added PFAS** in all food service and exclusive brand packaging and reported that it had already **discontinued or reformulated food service packaging** containing intentionally added PFAS, including molded fiber plates and bowls.

Technical Textile Fibers and Market Sectors

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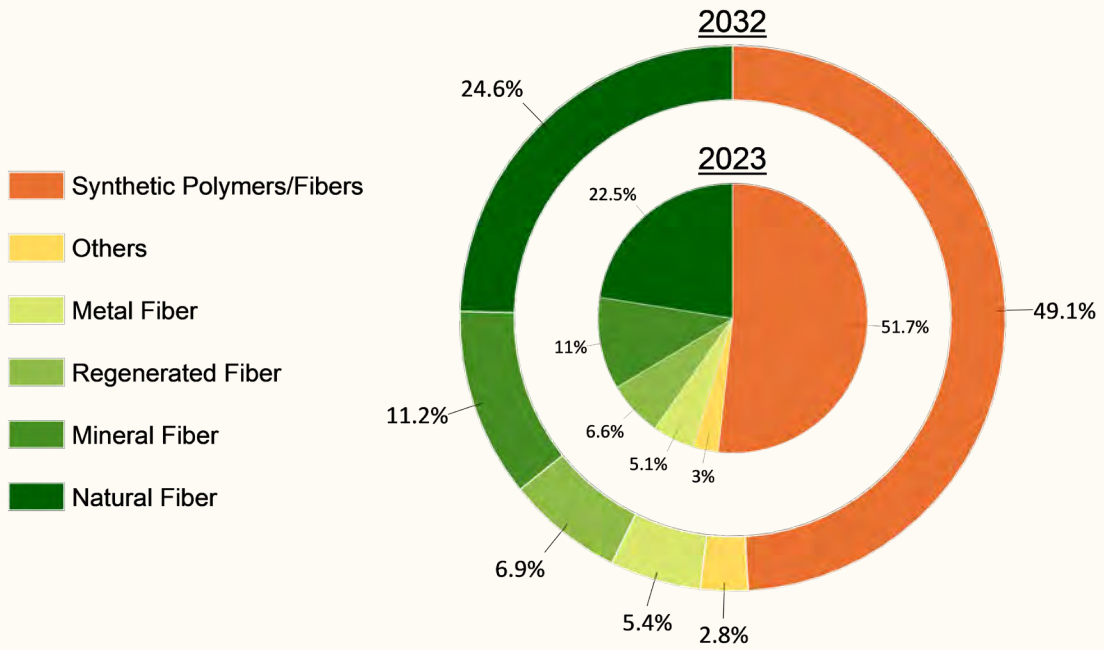
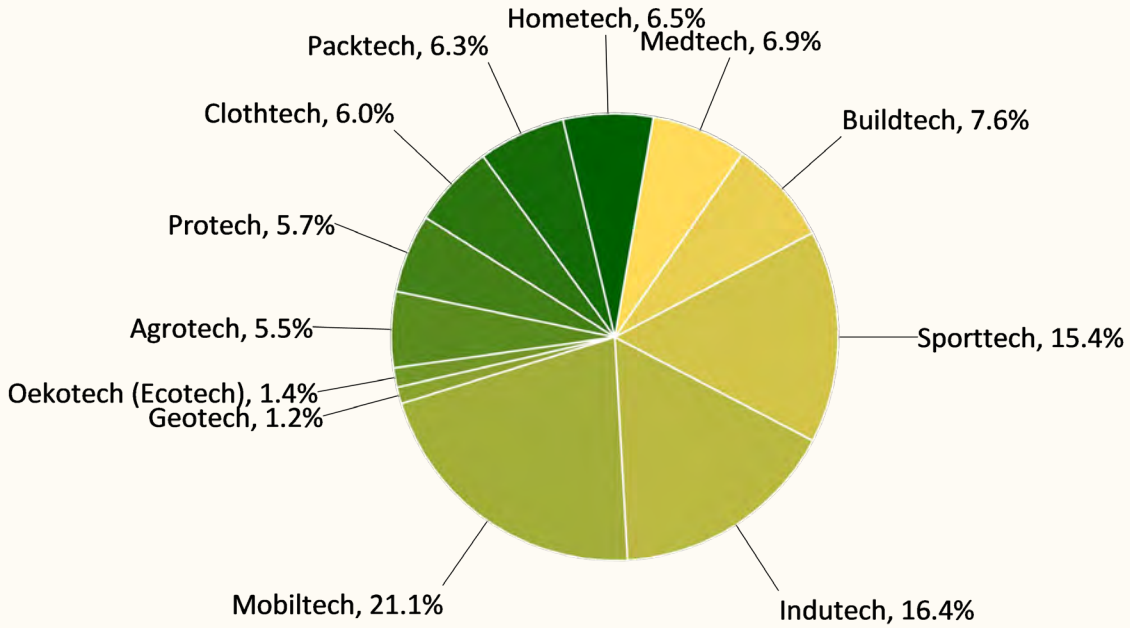
Fiber market distribution, 2023 & 2032



Technical Textiles by Market - 2023



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Properties of PFAS in Textiles

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Direct PFAS Properties – Textiles

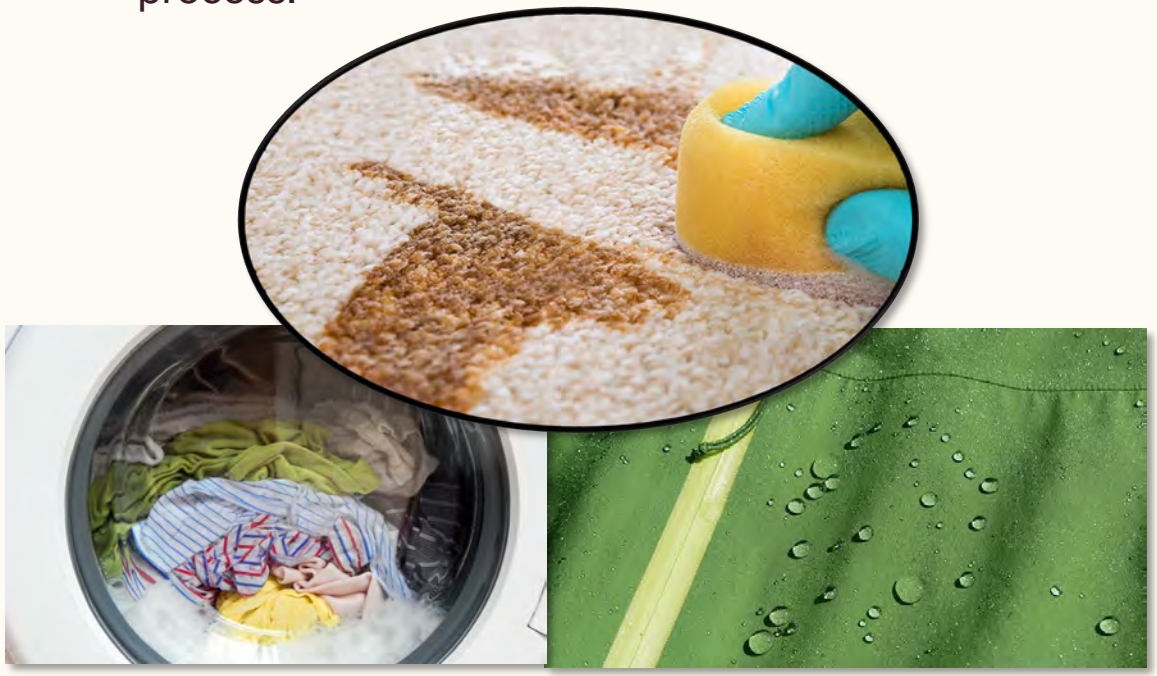
- *Water Repellency*
  PFAS create a barrier that prevents water from penetrating fabrics, making them ideal for waterproof clothing and outdoor gear.

- *Stain Resistance*
  These chemicals help fabrics resist stains from oils, grease, and other substances, which is why they're used in carpets and upholstery.

- *Durability*
  PFAS-treated textiles maintain their protective properties even after multiple washes and prolonged use, ensuring long-lasting performance.

- *Flammability resistance*
  PFAS-treated textiles exhibit flame retardance and self- extinguishing properties; used in carpets and high-performance uniforms (e.g., firefighters, military).

- *Fiber lubricant*
  PFAS chemicals reduce friction between fibers allowing for easier industrial weaving of threads and yarns. The chemicals may be removed after this process.



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Properties of PFAS in Textiles

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Indirect PFAS Properties – Textiles

- *Emulsifier*
  PFAS can enhance the application of finishing agents, such as other water repellents, flame retardants, and antimicrobial treatments.

- *Antifoaming agents*
  These chemicals help reduce the amount of foam produced during sulfur dyeing.

- *Wetting agents*
  PFAS-containing dye vats can assist in the wettability of certain fibers for improved dye deposition

- *Bleaching aids*
  Allows for chemical bleaches to penetrate deeper into fiber interiors for enhanced bleaching.

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Textile Fabrication Processes

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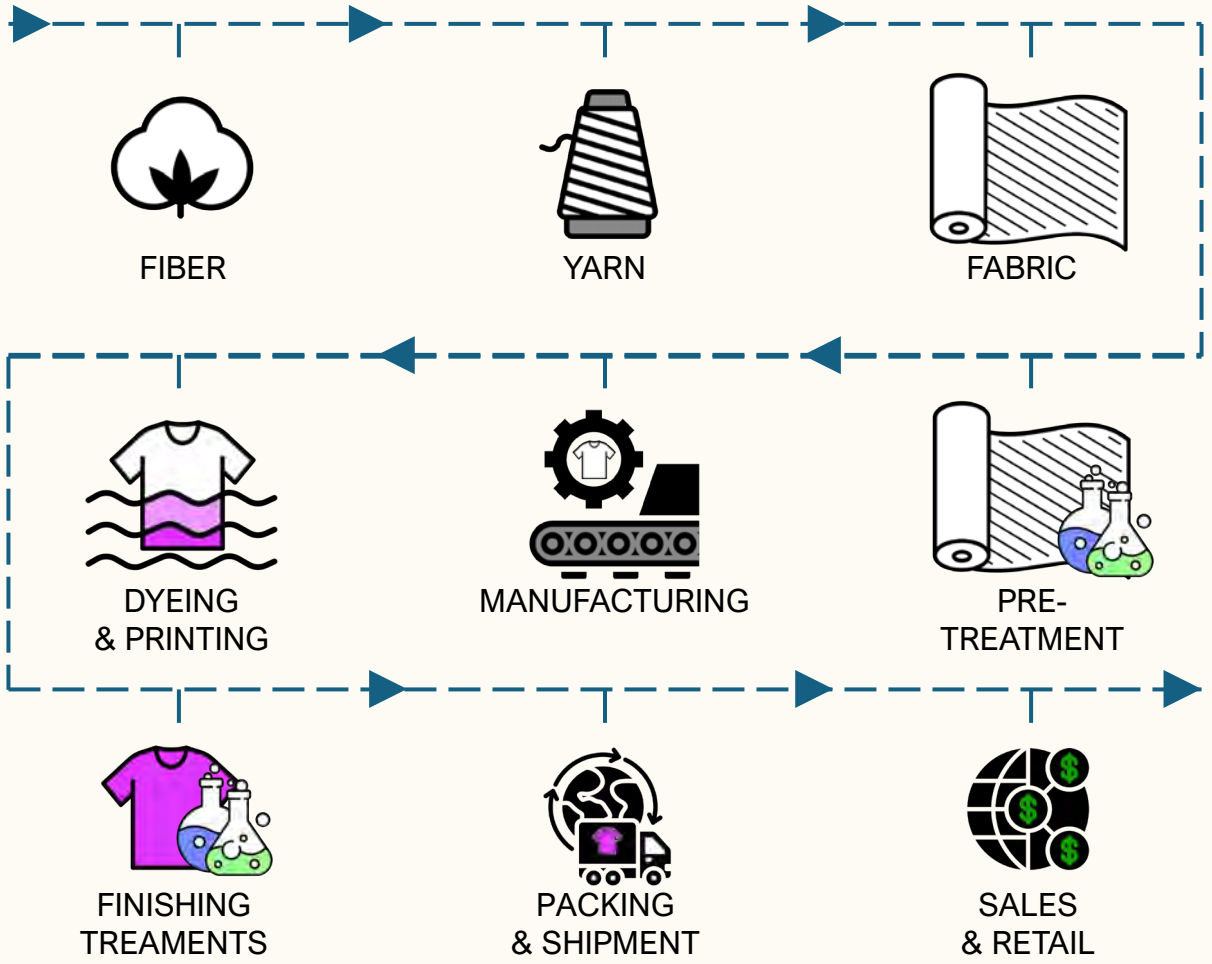

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Materials Post Processing
PFAS detection at Textile Manufacturing Facility

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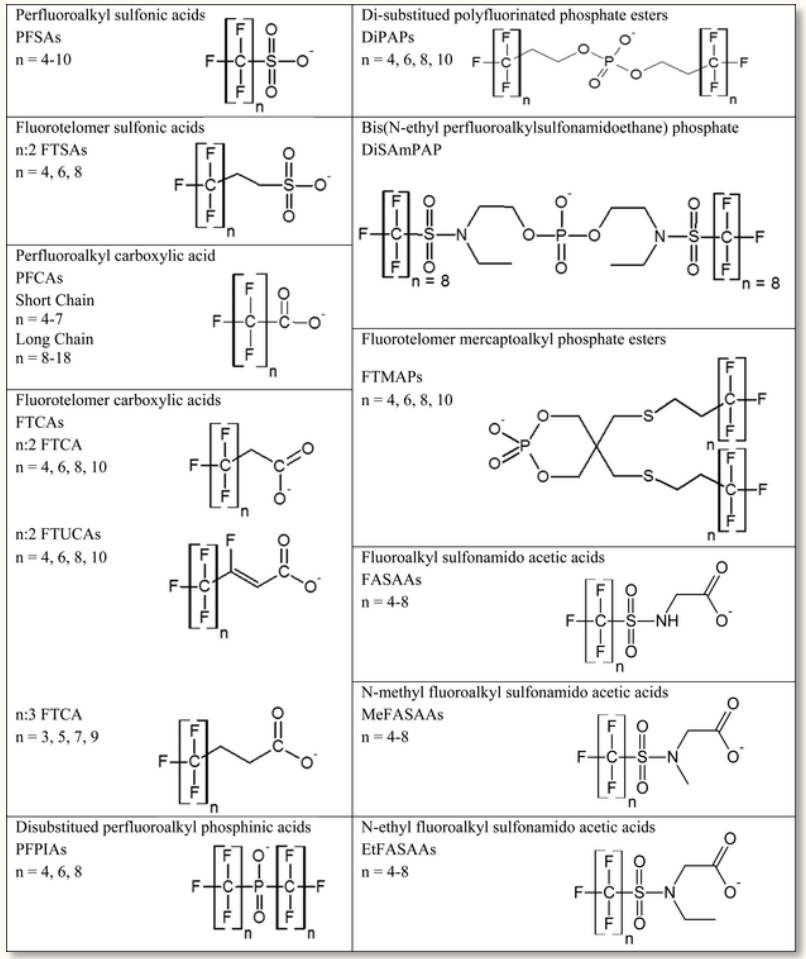

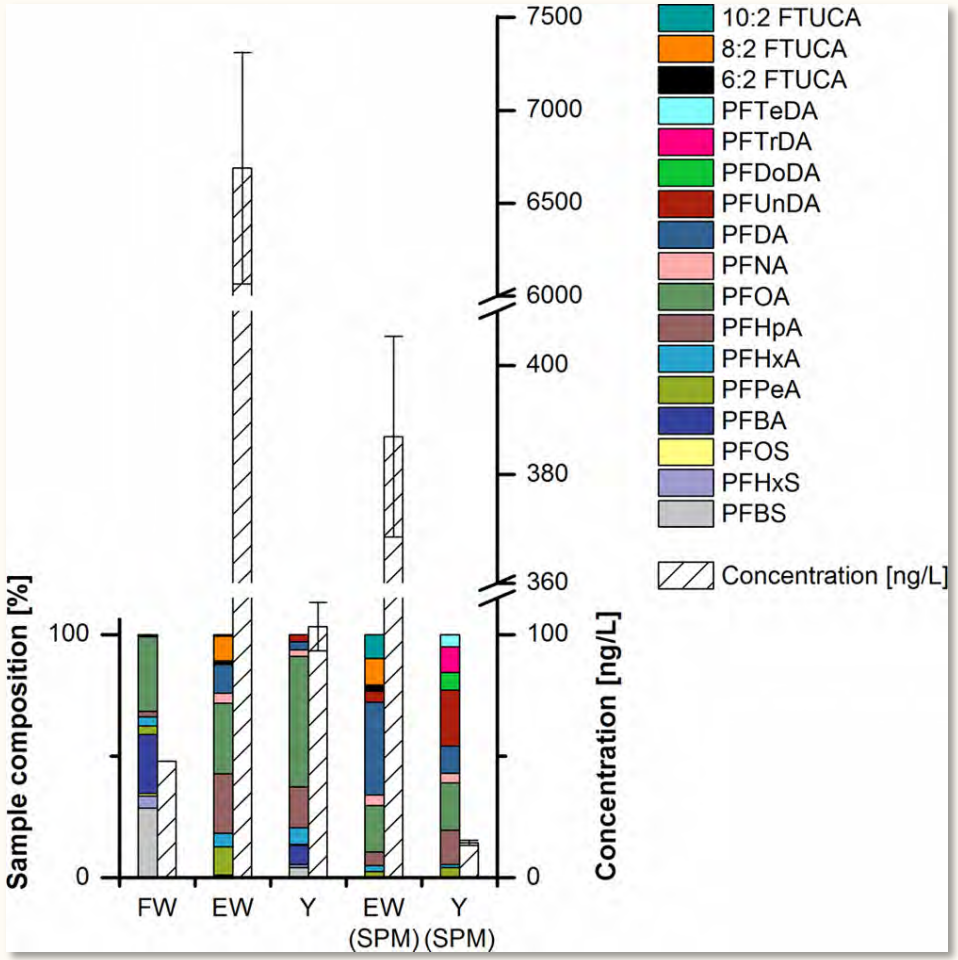

Left: J.R. Lang, *et al*. *Environ Sci Technol*. **2016**, *50*, 5024-5032. 10.1021/acs.est.5b06237
Right: F. Heydebreck, *et al*. *Environ Sci Technol*. **2016**, *50*(19), 10386-10396. 10.1021/acs.est.6b03213

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PFAS detection at Textile Manufacturing Facility

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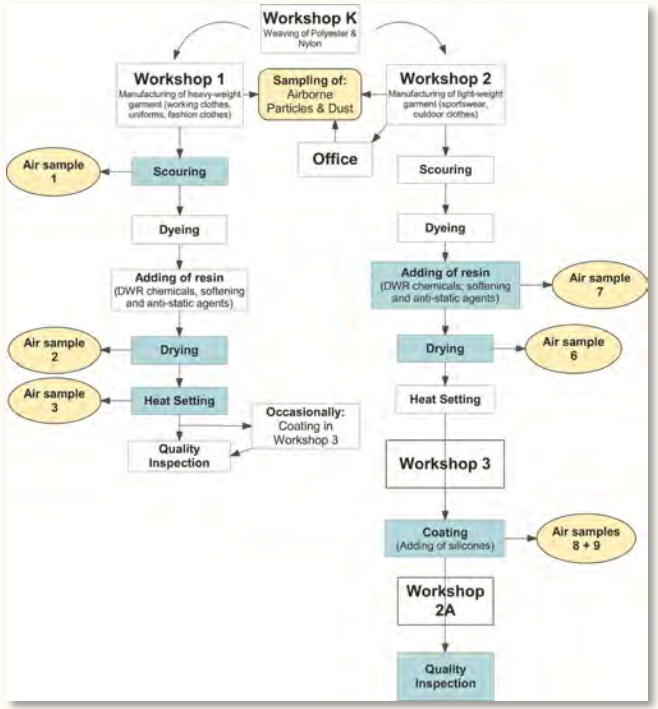
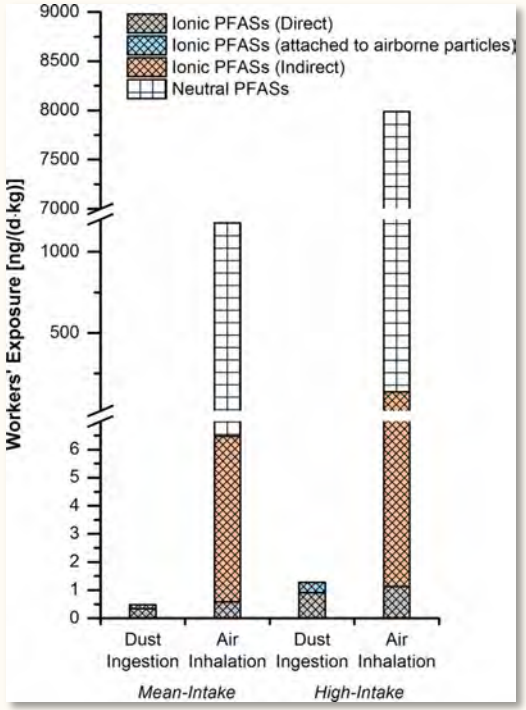
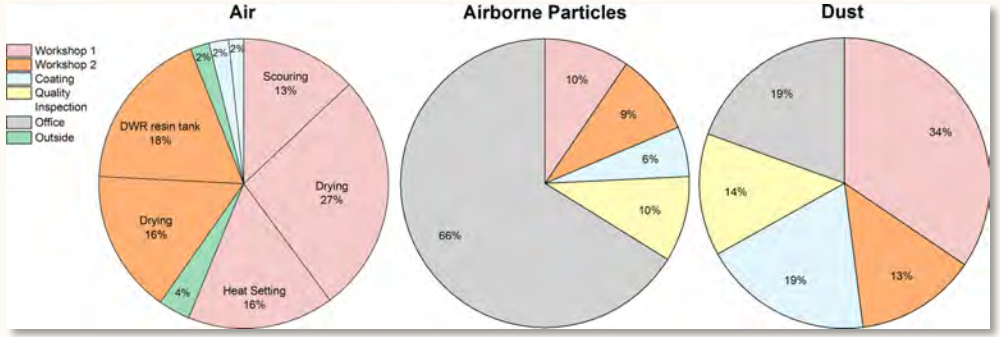


Caption: Production steps during the manufacturing of textiles, including sampling plan.





Caption: Distribution of PFASs in air, airborne particles, and settled dust along the textile manufacturing chain.

F. Heydebreck, *et al*. *Environ Sci Technol*. **2016**, *50*(19), 10386-10396. 10.1021/acs.est.6b03213

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Materials Post Processing
PFAS Alternatives

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Food Packaging

- *Moulded pulp fibers*
  Bagasse, bamboo fiber, wheat, palm leaf, seaweed, bioplastics

- *Fiber bonding strength additives*
  High MW cationic starch, e.g., potato starch
  Plant proteins, cellulose nanofibers, enzymatic hydrolysis lignin

- *Oil and grease resistance*
  Bagasse + bamboo fiber, enzymatic hydrolysis lignin (EHL),* biowaxes, plant starches,* clay coatings, polylactic acid coatings, ceramic coatings (e.g., Fe_xO_y, SiO_2).

Textiles

	SiO_2	Dendrimers	Silanes	Modified Polyester	Waxes
Water Repellency	+	+	+	+	+
Oil Repellency	–	–	–	–	–
Stain Removal	–	–	–	+	–
Self Cleansing	–	+	–	–	–

K.E. Semple, *et al*. *Food Packag. Shelf Life*. **2022**, *33*, 100908. 10.1016/j.fpsl.2022.100908

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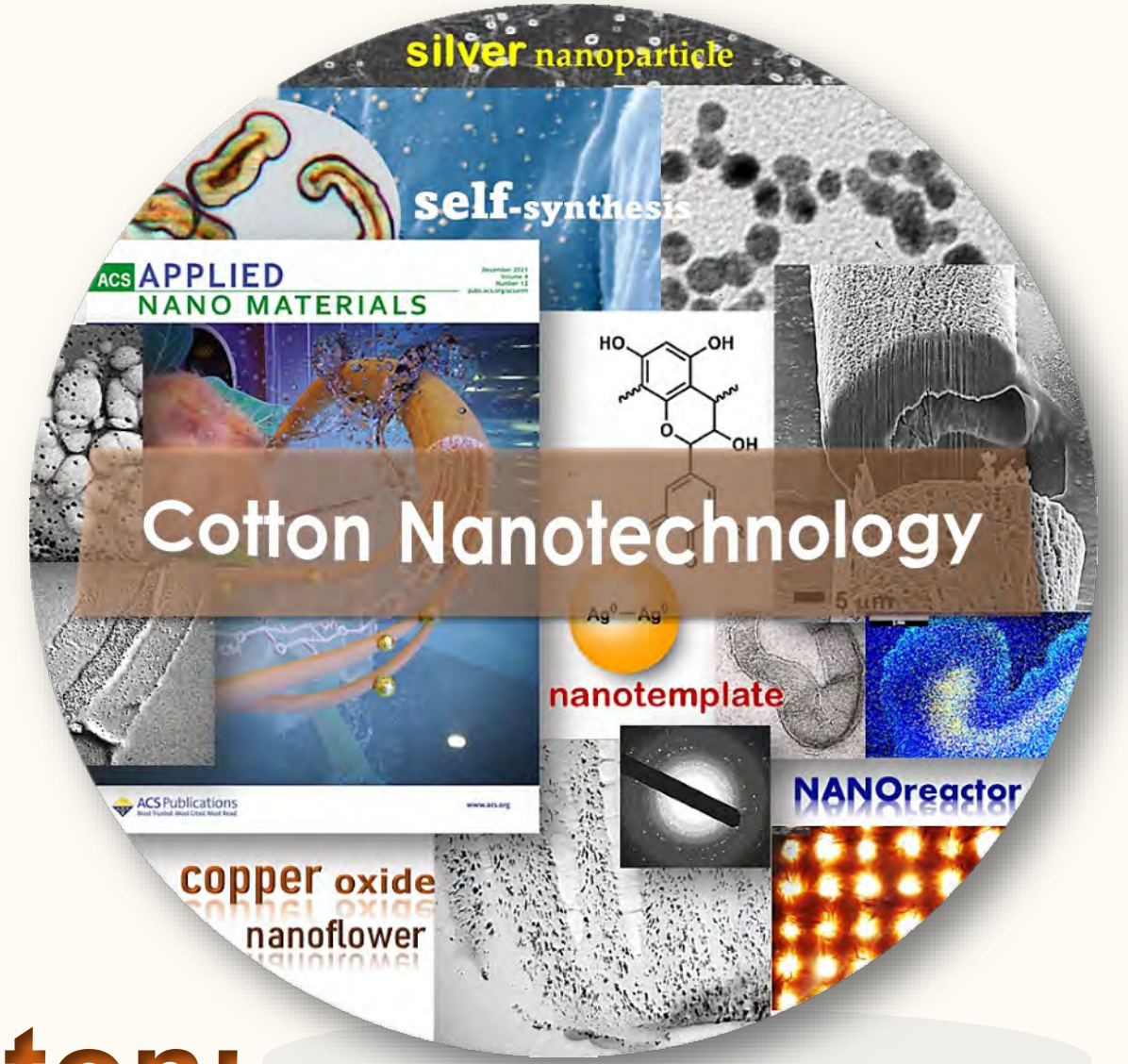
Cotton Fiber Bioscience
& Utilization
ARS-USDA, SRRC



Revolutionize Cotton:
A Tool for New Technology

Materials Post Processing
Cotton Fiber Bioscience & Utilization

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Research Leader

Doug Hinchliffe, Ph.D.
Research Molecular Biologist
Lead Scientist

- **Crista Madison, M.S.**
  Molecular Biologist
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  Mechanical Engineer Technician
- **Pablo Salame**
  Textile Equipment Operator

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- **Md Nayeem Hasan Kashem, Ph.D.**
  Postdoc Chemical Engineer

Matthew Hillyer, Ph.D.
Research Chemist

- **Faqrul Hassan, Ph.D.**
  Postdoc Textile Scientist

National Program 306: Product Quality and New Uses

National Program Leader: Jonn Foulk, Ph.D.

Research Project: Increased Sustainability and Utilization of Cotton and Other Natural Fiber-Based Textiles and Commercial Goods

Project Number: 6054-41000-108-000-D

- **Objective 1:** Identification of novel natural fiber traits including enhanced flame resistance and antimicrobial properties for value-added products.
- **Objective 2:** Nanoengineering of natural fibers and by products for advanced and expanded applications.
- **Objective 3:** Development of new chemical and mechanical processes and technologies to produce cotton-containing natural fiber blends with added strength for woven and nonwoven textile applications.

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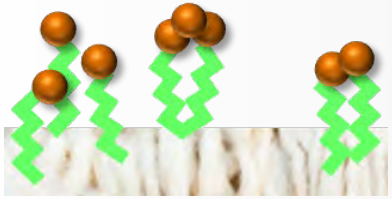
We reframe cotton Fiber as a TOOL for New Technology

SUBJECT to be treated

• Coating

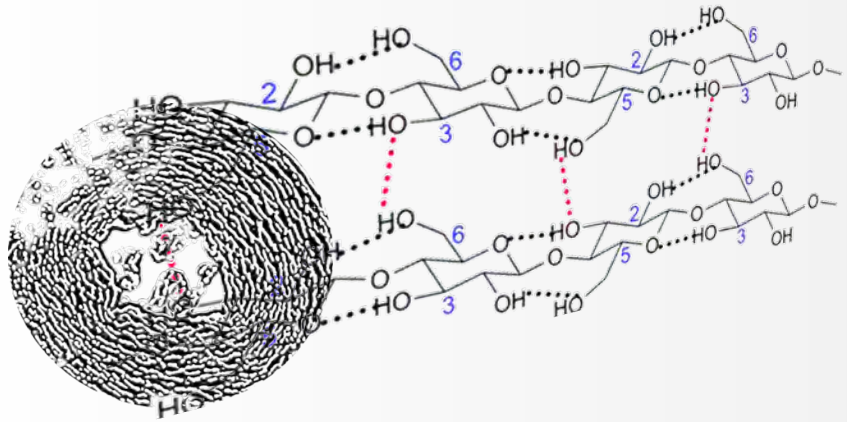
• Treat a binder



• Chemical binding

- Use of chemical agents
- Leaching, migration
- Health & environmental issues

- **BIO-FACTORY** for producing nanoparticles



- Chemical agent-free
- No leaching - Durable
- Safe & sustainable

Materials Post Processing
Fiber functionality and utility

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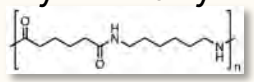
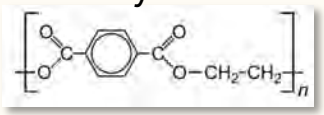
Synthetic Polymers

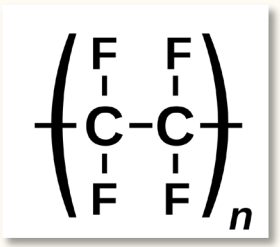
Polyamide/Nylon



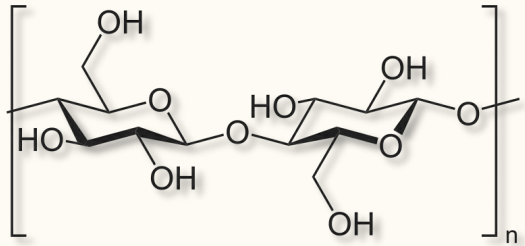
Polyester



expanded Polytetrafluoroethylene
(ePTFE, Gore-Tex)



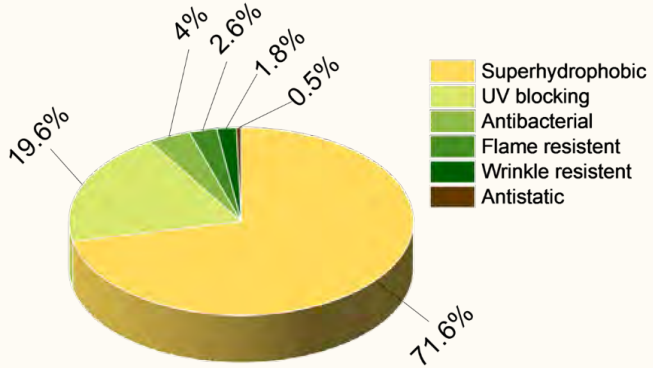
Plant-based fibers



Cellulosic Sources: Plant-based

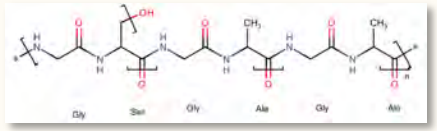
- Cotton
- Hemp
- Flax
- Jute
- Coconut
- Banana
- Kenaf

Current research trends

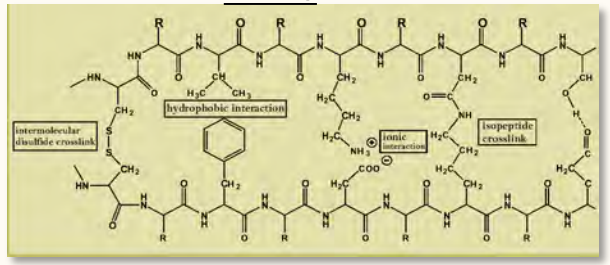


Animal-based fibers

Silk



Wool/hair



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Patent application I:

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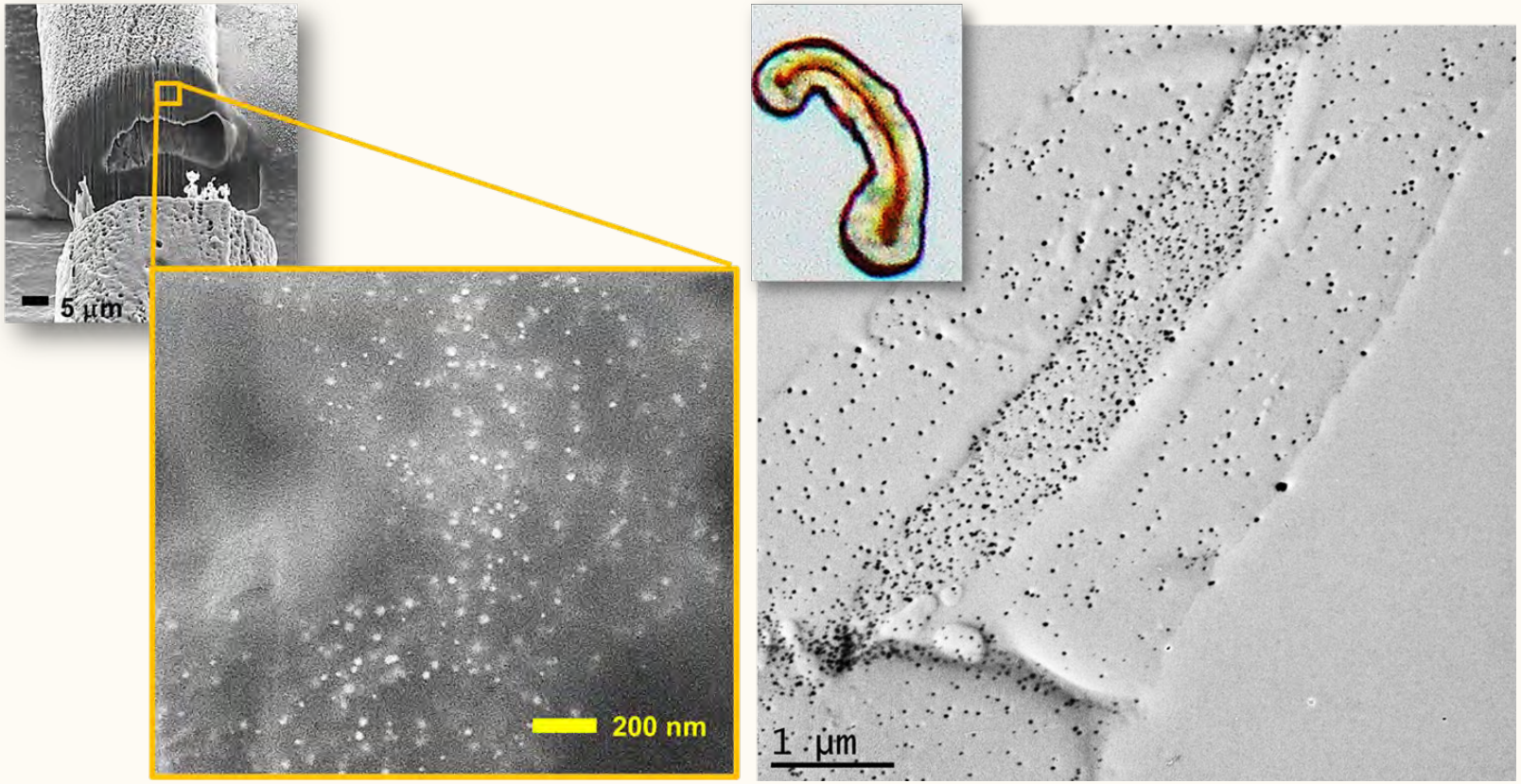
- Cellulosic Fibers Comprising Embedded Silver Nanoparticles and Uses Thereof. Nam, S., Condon, B.D., and Hillyer, M.B. Application No. 16/804,535.
- Awarded ARS Innovation Fund round 8.



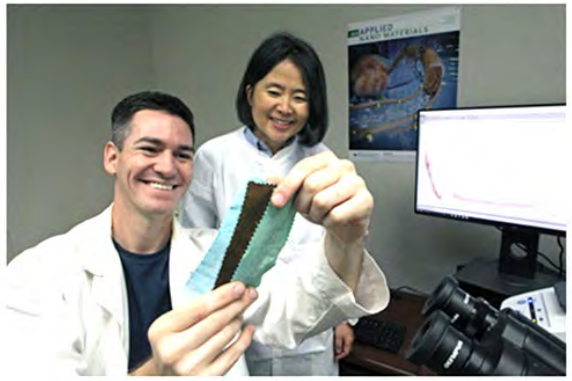
Washable antimicrobial cotton wipes

K. pneumoniae	*S. aureus*
>99.9	>99.9

Nanotech Super-Fabrics: Killing Germs, Saving Money, Reducing Waste

1 This article was informative 0 This article was not informative

ARS *Tellus*



Cotton web containing the copper oxide nanoflowers produced in the Cotton Textile Mill pilot plant using a mini-carding system. It can be used as is, or further processed to create durable nonwoven fabrics. (Photo courtesy of Matthew Hillyer)

USDA Researchers Develop Natural, Washable Cotton Antimicrobial Cleaning Wipes

By Cotton Grower Staff | April 14, 2023

TEXTILE INNOVATION / WIPES

Cotton as Antimicrobial Agent

TMS bioscience

CRADA (58-6054-4-035)

UNIVERSITY OF GEORGIA

MTRA (58-6054-4-034)

TruCotton™

BAST FIBRE TECH

Materials Post Processing

Patent application II:

Matthew Hillyer, Ph.D.
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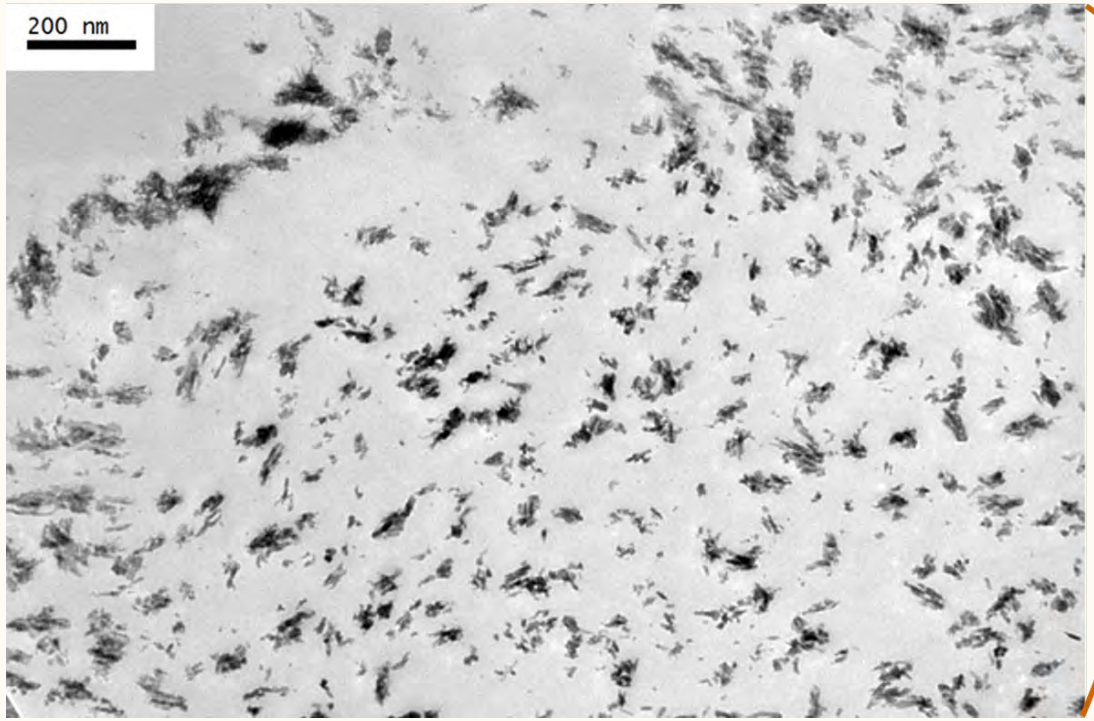
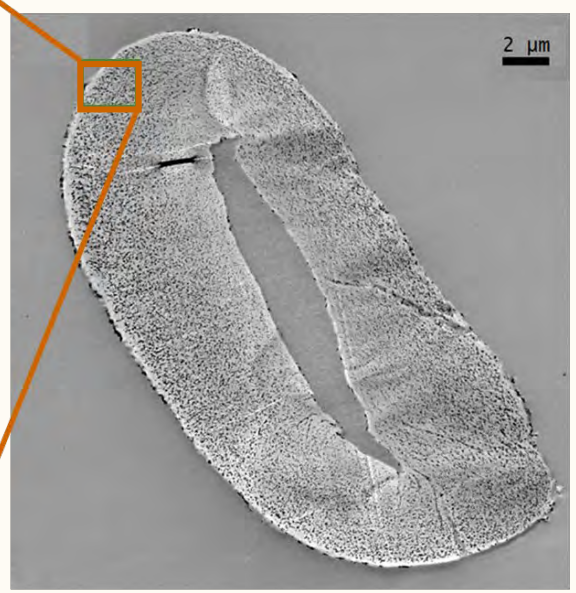
- Cellulosic Fibers Comprising Internally Dispersed Cuprous Oxide Nanoparticles. Hillyer, M.B., Nam, S., Condon, B.D. Application No. 17/371,906.
- Awarded ARS Innovation Fund round 11.



Cross-section of cotton fiber



AMTEX

Folia

Materials Post Processing
Fiber functionality and utility

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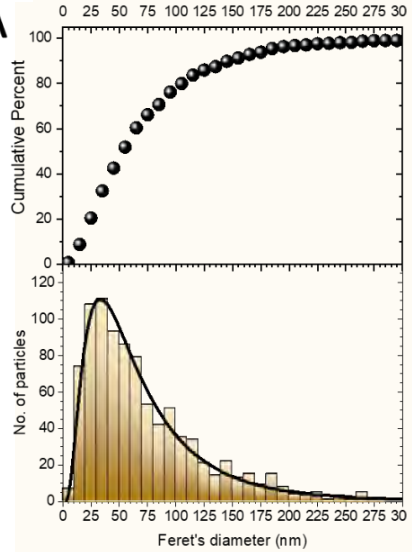
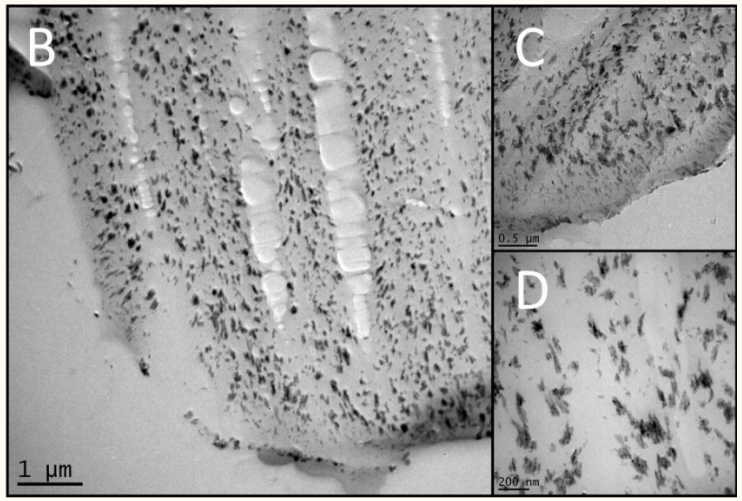
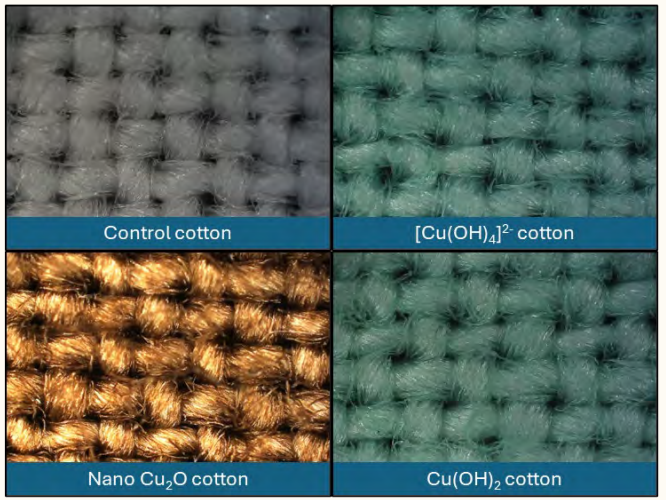
Nano Cu_2O cotton fiber cross section

A



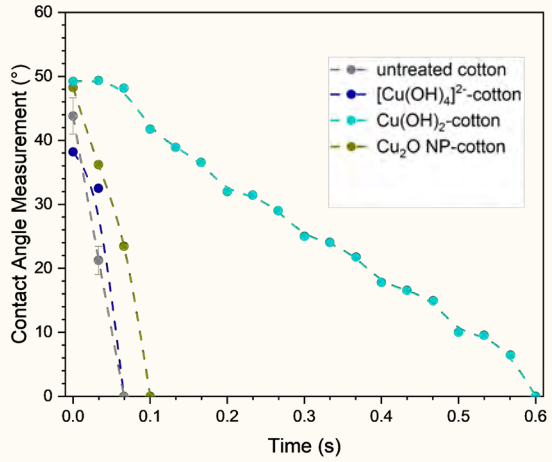


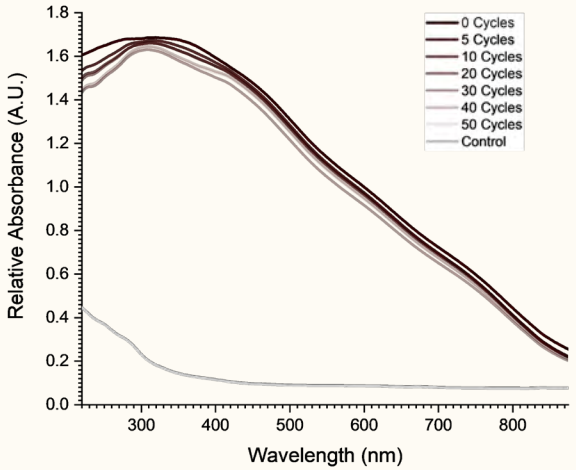
Optical microscopy images

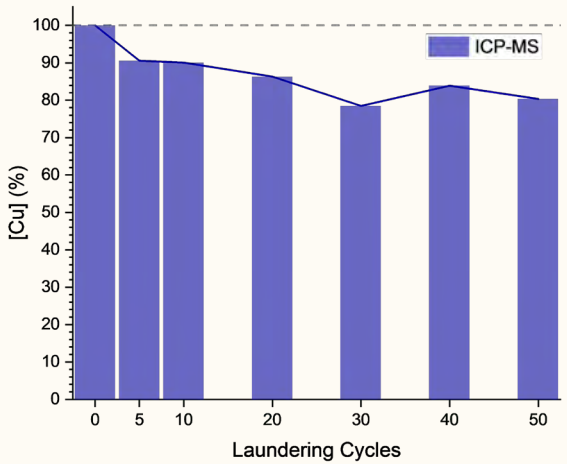


Laundering durability

Hydrophilicity/phobicity modulation







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Fiber functionality and utility

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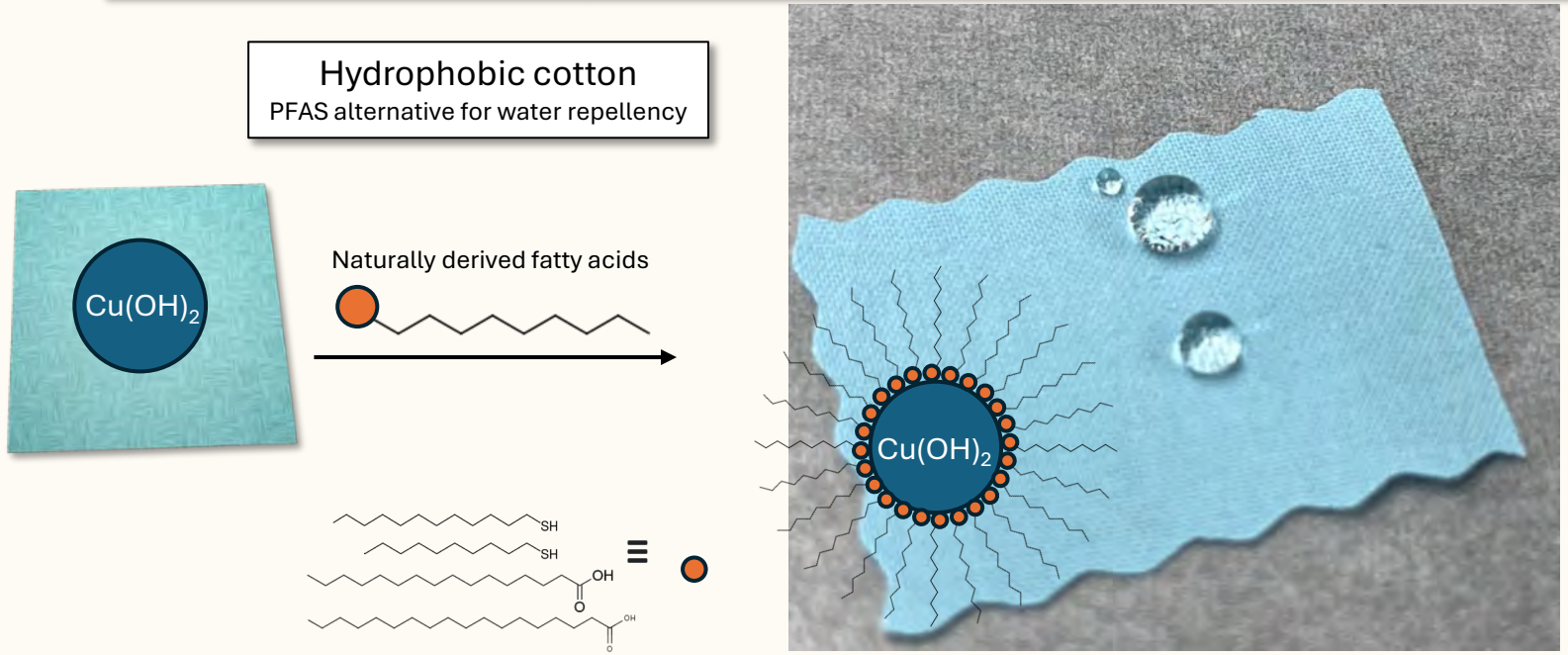
Percent inhibition of Cu2O NF-cotton fabric against various pathogens.

Pathogen	Classification	Percent inhibition by Cu_2O NP-cotton	Test Method
Klebsiella pneumoniae (4352)	Gram-negative bacterium	99.99994%	AATCC100
Escherichia coli (8739)	Gram-negative bacterium	99.9998%	AATCC 100
Staphylococcus aureus (6538)	Gram-positive bacterium	99.995%	AATCC 100
Aspergillus niger (6275)	Fungus	100%	AATCC 30 (Test III)
Human coronavirus (229E strain)	Enveloped RNA virus	≥90%	AATCC 100 for viruses



USDA Agricultural Research Service

Materials Post Processing
Patent application III:

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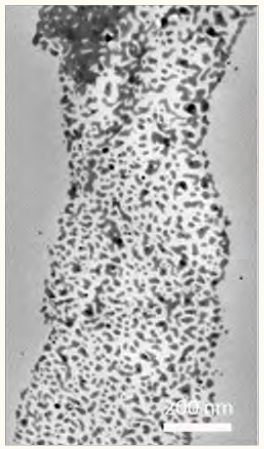
- Self-Embedding Silver Nanoparticle Biomass Waste Compositions.
  Nam, S., Easson, M.W., Jordan, J.H., and He, Z. Application No. 63/571,101.
- Awarded ARS Innovation Fund round 17.

Cotton gin trash (CGT)



Nanosilver-infused CGT nanofiber

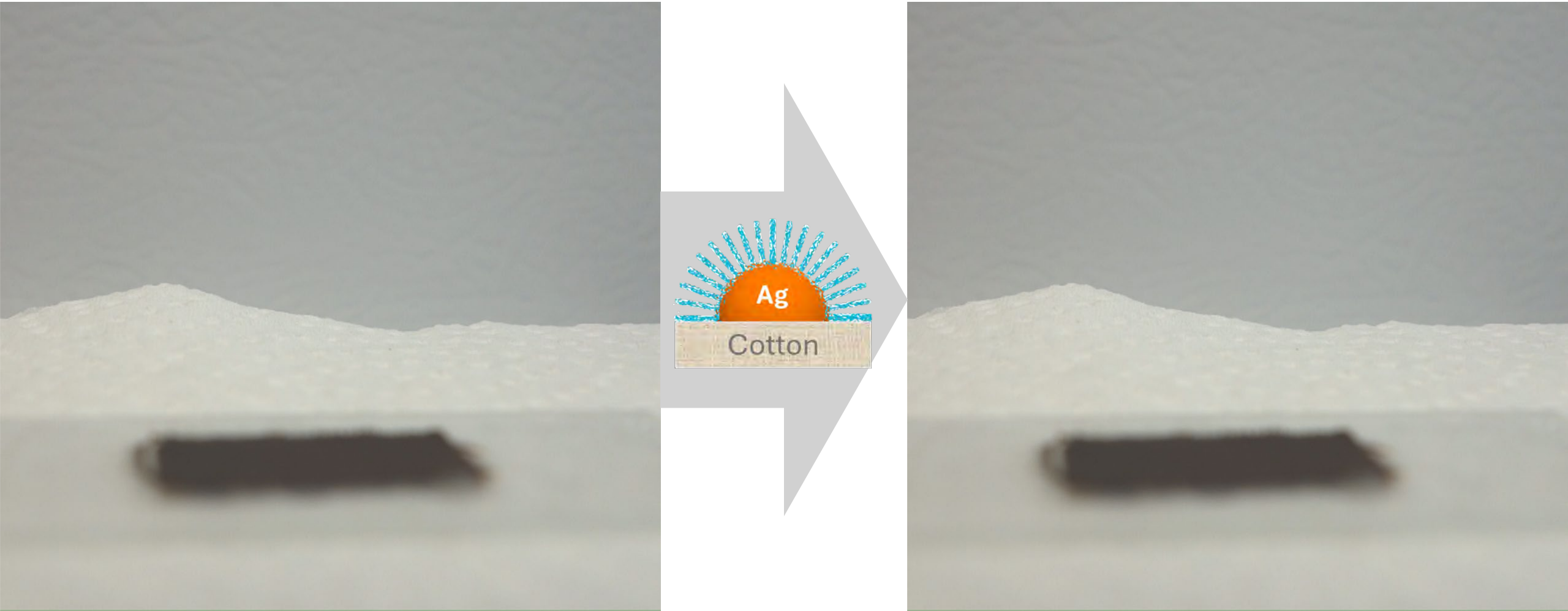
Ultralight nanosilver-infused aerogel resting on a cotton flower's stamen

Nano and Other Emerging Chemical Technologies Blog

April 12, 2024

ARS Researchers Discover Ability of Cotton Gin Waste to Transform Silver Ions into Silver Nanoparticles

Preliminary study: Surface modification of nanoparticles



Materials Post Processing
Naturally Flame Resistant Cotton Lines

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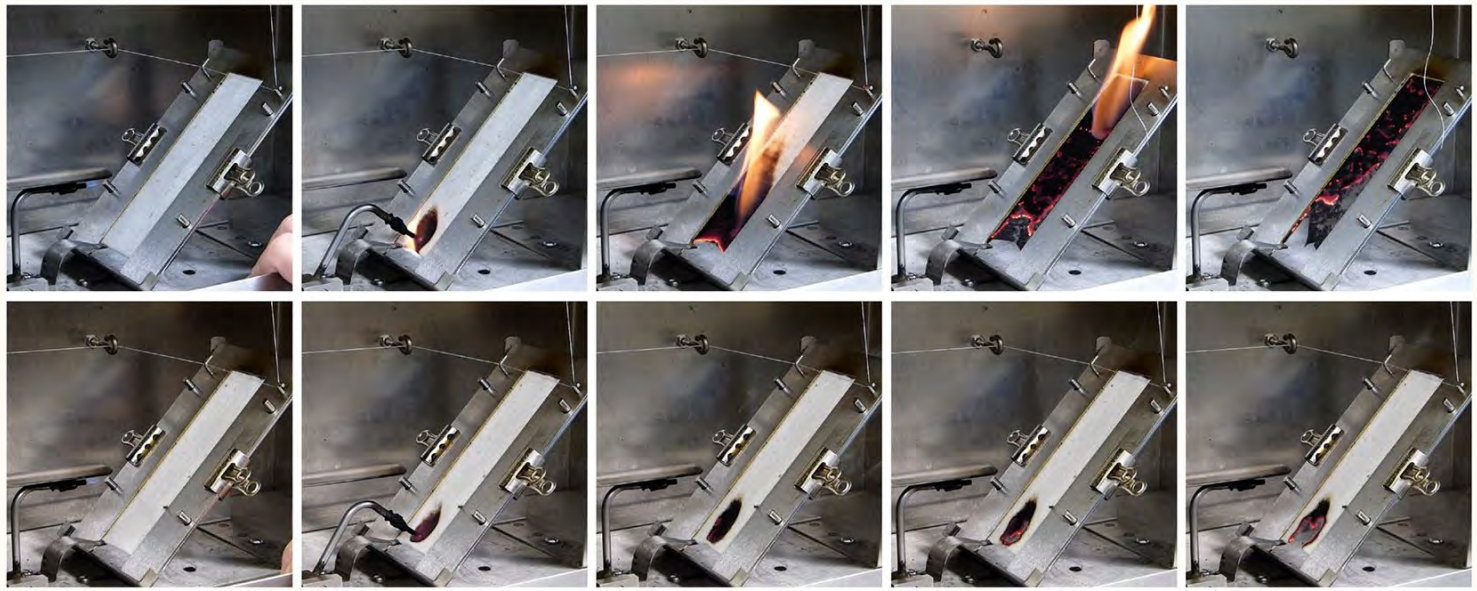
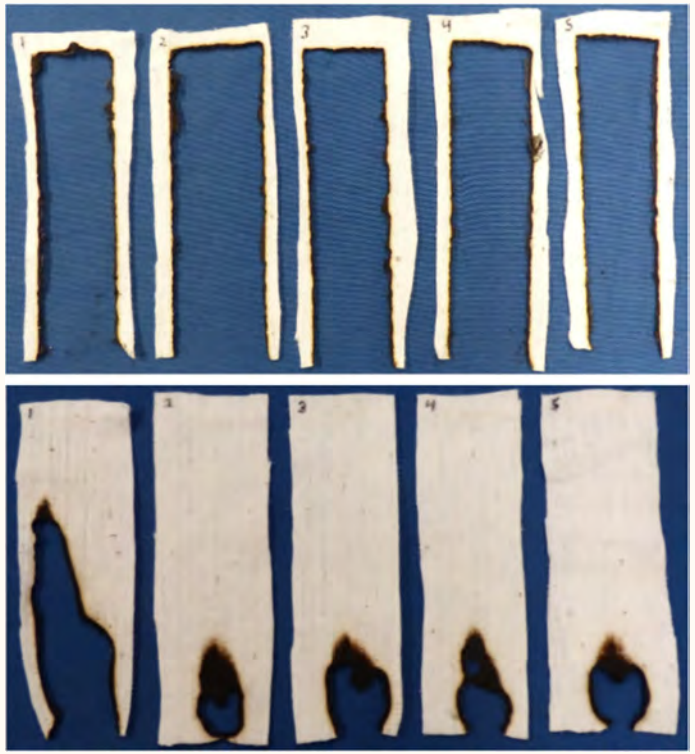
Multi-Parent Advanced Generation Intercross (MAGIC) population

Inferior heat release capacity recombinant inbred line (RIL)



Superior heat release capacity recombinant inbred line (RIL)



G.N. Thyssen, *et al*. *PLoS One*. **2023**, *18*(1). 10.1371/journal.pone.0278696

USDA Agricultural Research Service

Materials Post Processing
Ongoing Research

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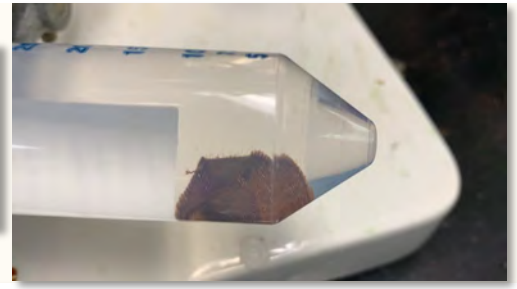
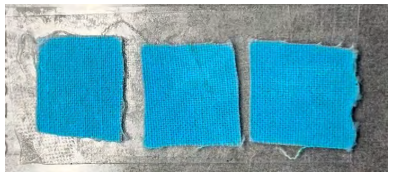
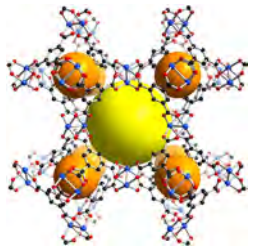
EMF shielding/UV protection
- **Ferromagnetic fabrics**
  - Fe_3O_4 nanoparticles



Metal Organic Frameworks (MOF)

- Thermoresponsive
- Gas separation
- Energy storage
- Drug retention/delivery
- Sensing/detection





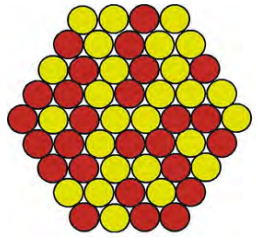
➢ Metallic nanofibers as clean and reusable insect breeding environments
- Kristin Duffield, Ph.D., and José Ramirez, Ph.D.
- Crop Bioprotection Research
- National Center for Agricultural Utilization Research, Peoria, IL

➢ Animal hair as a nanoreactor: towards nanofunctionalized wools and silks (Elk & buffalo hairs)
  - Ellie Putz, Ph.D.
  - National Animal Disease Center, Ames, IA

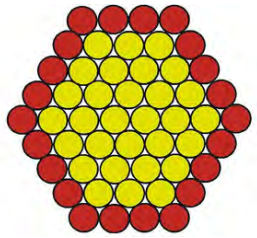
Expanding scope of nanomaterials

Substrates for water purification
- ARSX 2022 Top 8 proposal
- Drs. Nam, Hillyer, Reba

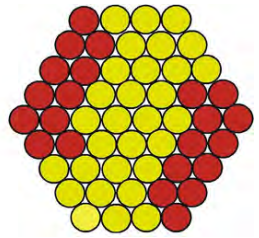
Bi/multi-metallic nanoparticles
- Increased antimicrobial activity
- Better attuned SERS materials
- Enhanced reactivity/catalysis



Alloy



Core-shell



Cluster

USDA Agricultural Research Service

Materials Post Processing

Priority needs/gaps in PFAS-free food packaging/textile research

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1. **Safety**: Explore alternative chemicals/systems that are safe.
2. **Effectiveness**: Provide advanced functional properties, e.g., water repellency, stain resistance, flame retardance, comparable to those of PFAS.
3. **Durability**: Leach resistance and permanent performance.
4. **Cost-effective**: Economically viable for manufacturers.
5. **Collaborative efforts**: Seek collaboration with researchers and industry stakeholders to share knowledge, resources, and best practices.

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Upcoming opportunities

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Oct 1-2, 2024

James B. Hunt, Jr. Library

North Carolina State University, Raleigh, North Carolina

Top experts share strategies for PFAS replacement and rPET production—exclusively at RISE.

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