National Institute of Food and Agriculture
www.nifa.usda.gov

Nanotechnology for Food and Agriculture Industry

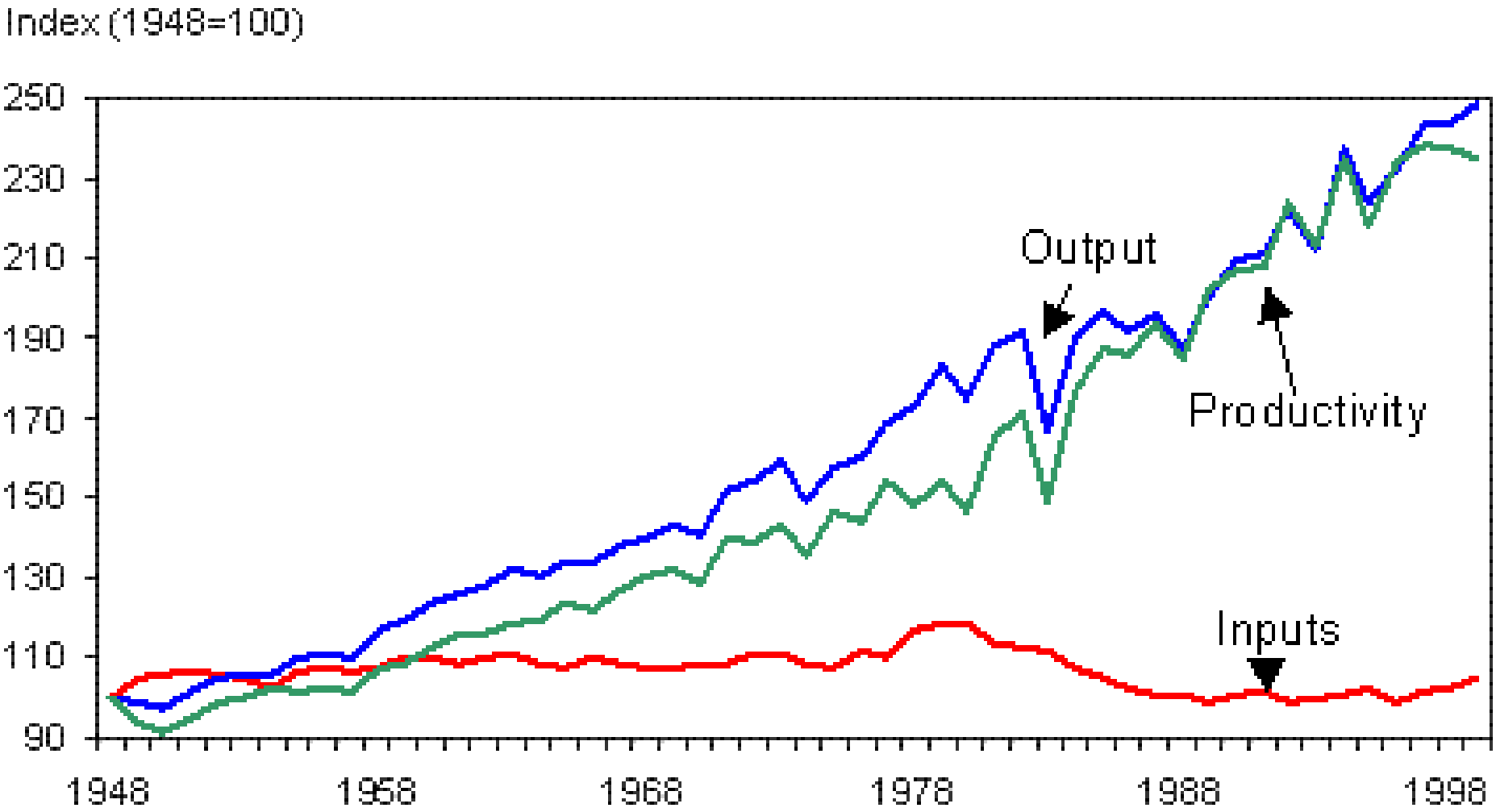
Hongda Chen, Ph.D.
National Program Leader
National Institute of Food and Agriculture (NIFA)
US Department of Agriculture (USDA)

2009 NSF Nanoscale Science and Engineering Grantees Conference
December 7-9, 2009
The Westin Arlington Gateway - Arlington, VA

The foundation of past, present and future

"AGRICULTURE IS THE FOUNDATION OF MANUFACTURE AND COMMERCE."

Productivity continues to be the engine of growth in agriculture



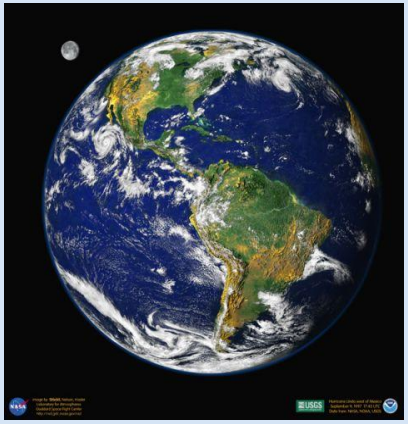
Final data year is 2002.

Source: Economic Research Service, USDA

21st Century Grand Challenges

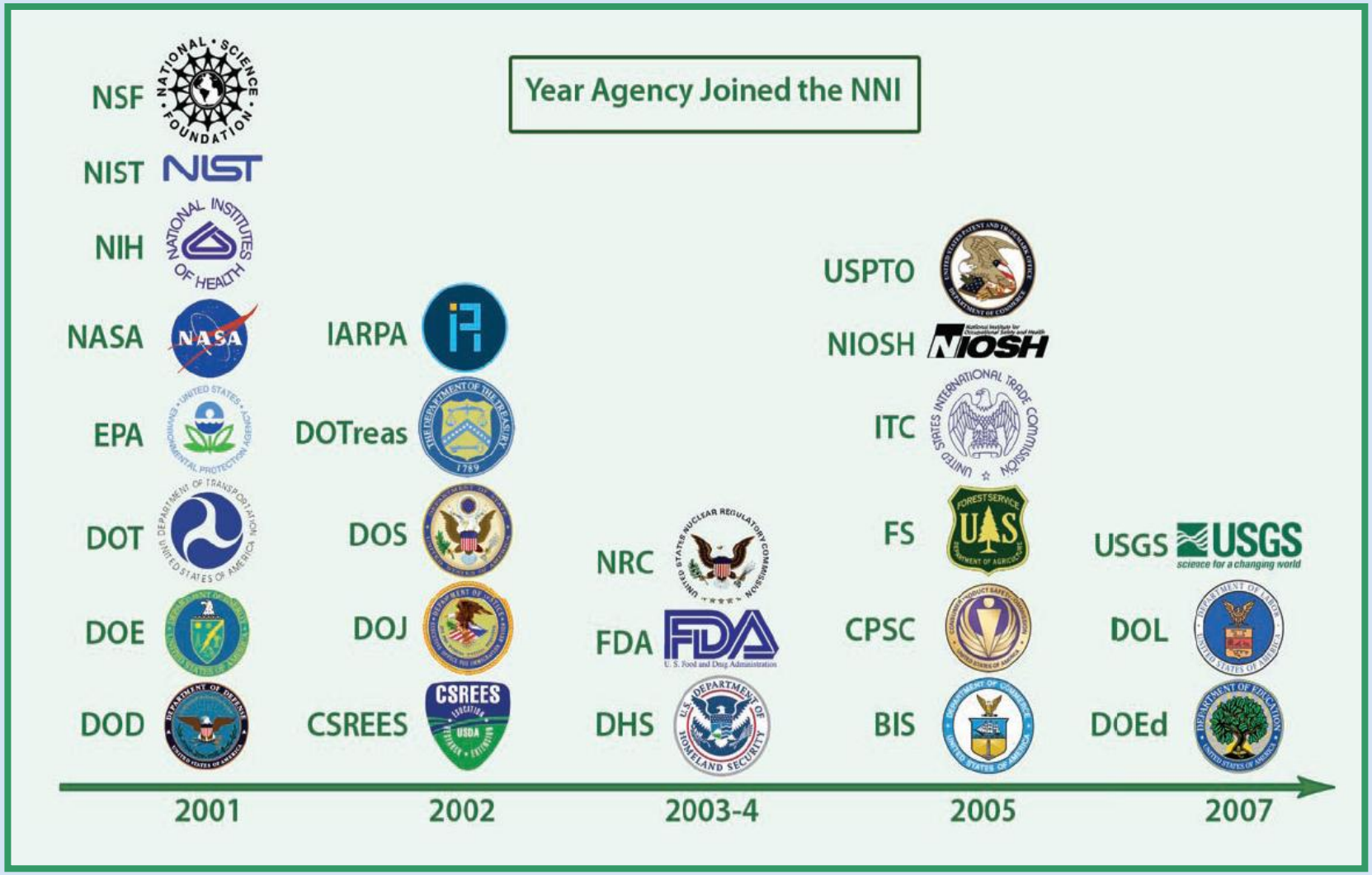
- The world faces grand societal challenges now and decades ahead – relevance to agriculture and food
  - Sustainability – resolving diminishing natural resources against increasing demands of growing world population
  - Vulnerability – food safety, biosecurity, and others
  - Human Health – food and nutrition related developmental and degenerative illness
  - Happy living – improved working condition, advanced education and learning, better environment, etc.
- Agriculture and food sector is a part of these challenges, and also could and should be a part of the solutions, provided we continue seeking appropriate research strategies.

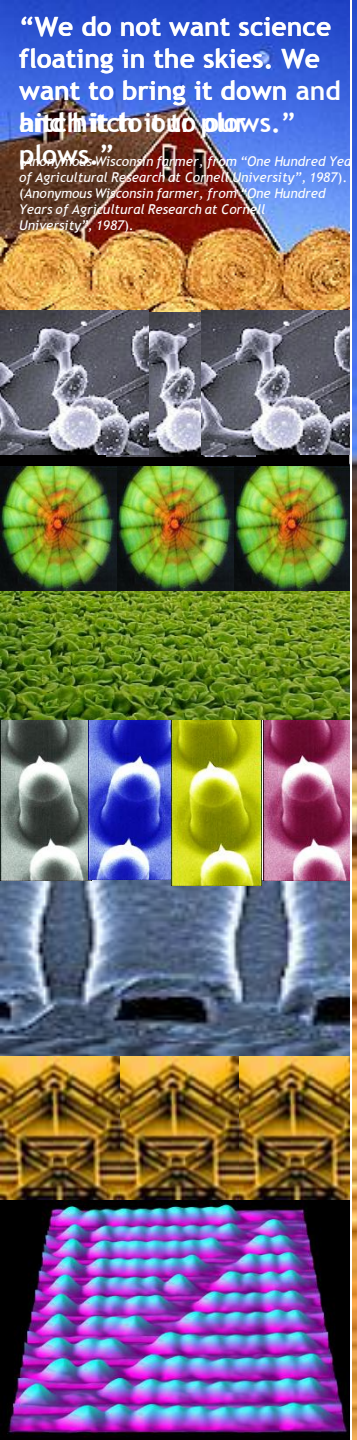
World Population:
2003 6.3B
2005 9-10B



Credit: *R. Stockli, A. Nelson, F. Hasler, 4/26/2003*

NNI Participating Agencies





"We do not want science floating in the skies. We want to bring it down and hitch it to our plows."

(Anonymous Wisconsin farmer, from "One Hundred Years of Agricultural Research at Cornell University", 1987).

CSREES-National Stakeholder Strategic Planning Workshop
November 18-19, 2002
USDA, Waterfront Center
Washington, DC

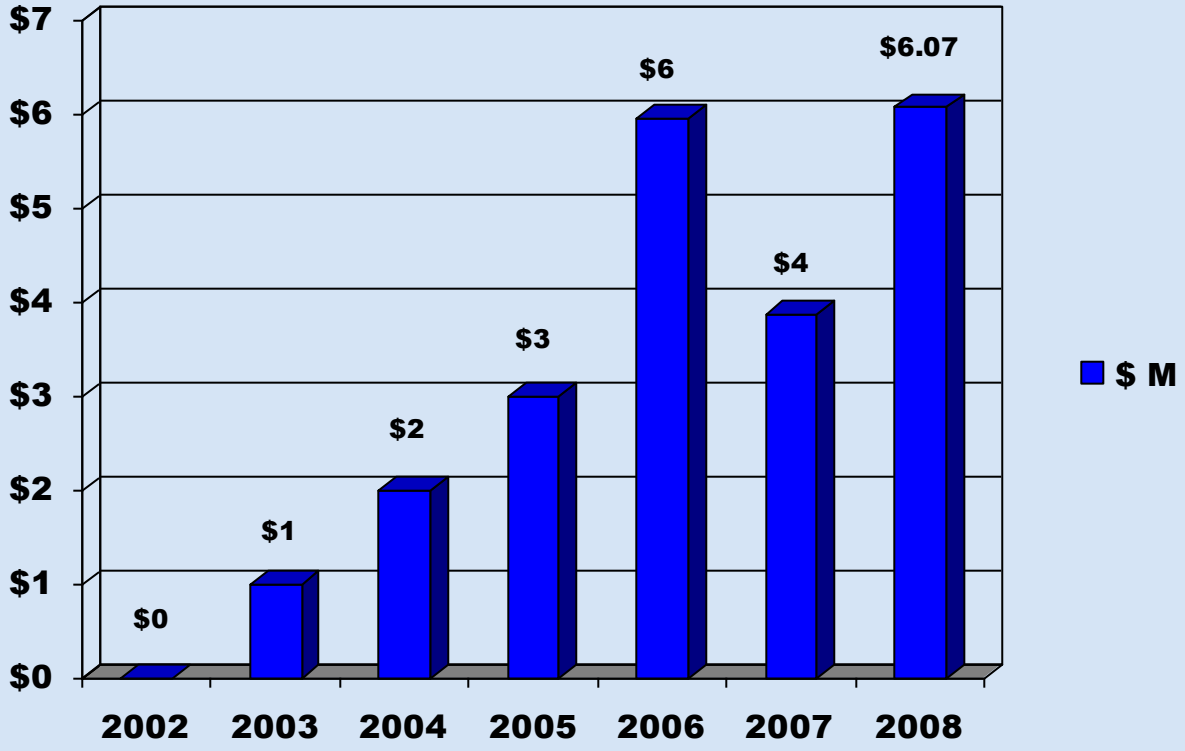
Dr. Norman R Scott
Biological & Environmental Engineering
Cornell University
&
Dr. Hongda Chen
USDA/CSREES

www.nseafs.cornell.edu

USDA Mission Oriented Nanotechnology Activities

- Plant productions
- Animal productions
- Food safety and agro-biosecurity
- Enhance food quality and nutritional value – improve human health
- Novel renewable energy
- Minimize environmental footprints
- Natural resources
- Higher education for future workforce
- Extension and outreach
- SBIR, and more

CSREES Budget for Nanotechnology R&D, Education and Extension



Funding Mechanisms

- Competitive grants programs
  - Agriculture and Food Research Initiative (previously NRI)
    - **Nanoscale Science and Engineering for Agriculture and Food Systems**
    - Plant biology – nanoscale cell wall structure
    - Bioenergy and biobased products – nano-cellulose-reinforced PLA for polyolefin replacement, cross-linked bio-nano composite packaging film
    - Soil process – Across from nano to micro scale spatial distribution of organic matters in mineral assemblages
    - Food Safety – Nano – aerosolization for sanitizing fresh produces
    - Plant Biosecurity
    - Improving Food Quality and Value
  - Integrated Research, Education and Extension Programs
  - High Education Challenge Grants
  - Food and Agricultural Sciences National Needs Graduate and Postgraduate Fellowship Grants Program
  - 1890 Capacity Building Grants
  - SBIR
    - Sensor for ammonia emission from animal manure (to control air quality)
    - Precise control of water and fertilizer for an environmentally friendly golf green (surface modification of natural zeolites with nano Fe-oxides for better nutrients retention and release)
    - Nano biocides for treating wood construction materials

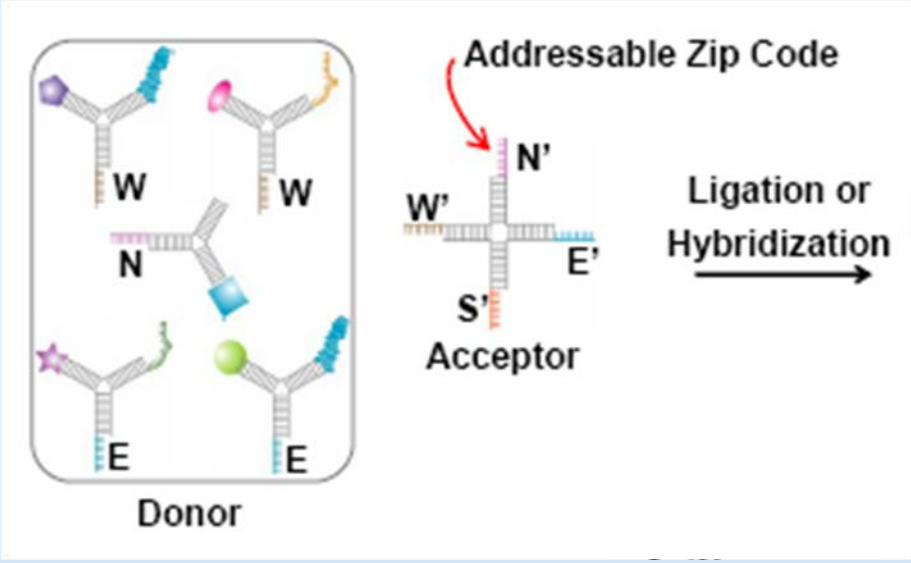
Funding Mechanisms

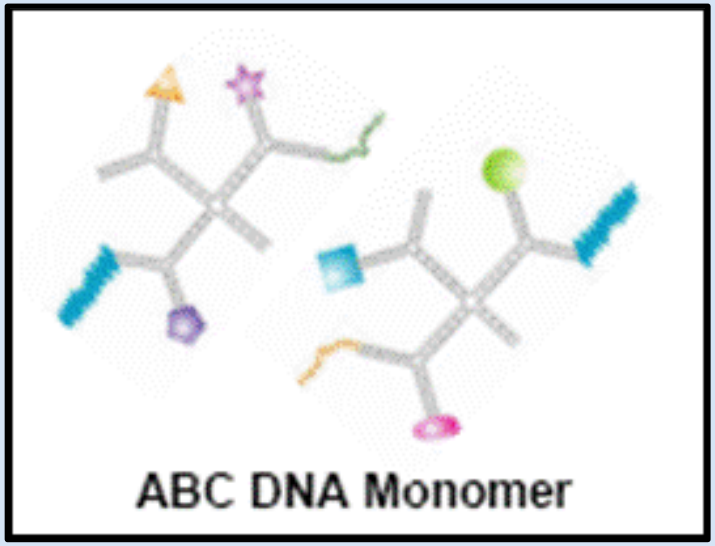
- Formula funds
  - Hatch Act grants (Research)
    - Multi-State Research Committee – NC-1031
  - McIntire-Stennis Cooperative Forestry
  - Evans-Allen Program
  - Smith Lever (Extension)
  - ……
- Special research grants
  - Nano whiskers for reinforcement in polymer matrix nano composite
  - Integrated nanoelectonic devices and systems for rapid, low-cost, ultra-sensitive detection of bacterial pathogens in foods

AFRI: Nanoscale Science and Engineering

- Current Priorities – Anticipated $5M for FY 2010 cycle
  - Nanoscale recognition, reception, and transmission mechanisms and novel materials for developing nano-based sensors specifically for targets important to food safety and agriculture biosecurity.
  - Novel nanoscale processes, materials, and systems with improved delivery efficacy, controlled release, modification of sensory attributes, and protection of micronutrients and functional ingredients suitable for food matrices.
  - Understanding nanoscale phenomena and processes to support the development of nano-based technologies for food and agricultural product quality monitoring, identity tracking, and preservation.
  - NEW: Assessment and analysis of perceptions and acceptance of nanotechnology and nano-based products by the general public, agriculture, and food stakeholders using appropriate social science tools.

Anisotropic, Branched, and Crosslinkable (ABC) Monomer for Pathogen-driven polymer





(Dan Luo, Cornell University)

Food Safety in USA

- USA proudly claims the safest food supply in the world, yet food borne illness remains a significant public health challenge.
  - CDC estimates: 76 million people get sick, more than 300,000 are hospitalized, and 5,000 Americans die each year from food borne illness, and cost $$$ millions.
  - Food-borne illnesses in the U.S. have plateaued in the recent years.
- Food borne illness outbreaks
  - The latest one linked to *E. coli* O157:H7 in ground beef causing at least 2 death and 16 hospitalization in New England, 11/ 2/ 09
  - Produce-related illnesses are on the rise as more Americans consume fresh vegetables and fruits. 1% in the 1970s; 6% in the 1990s. (*E. coli* O157:H7 in spinach; Salmonella in Serrano peppers)
- CDC Warnings in 2009: Raw alfalfa sprouts, pistachio, peanut butter
- Products recalls: 214 in 2006, 247 in 2007, and 310 in 2008

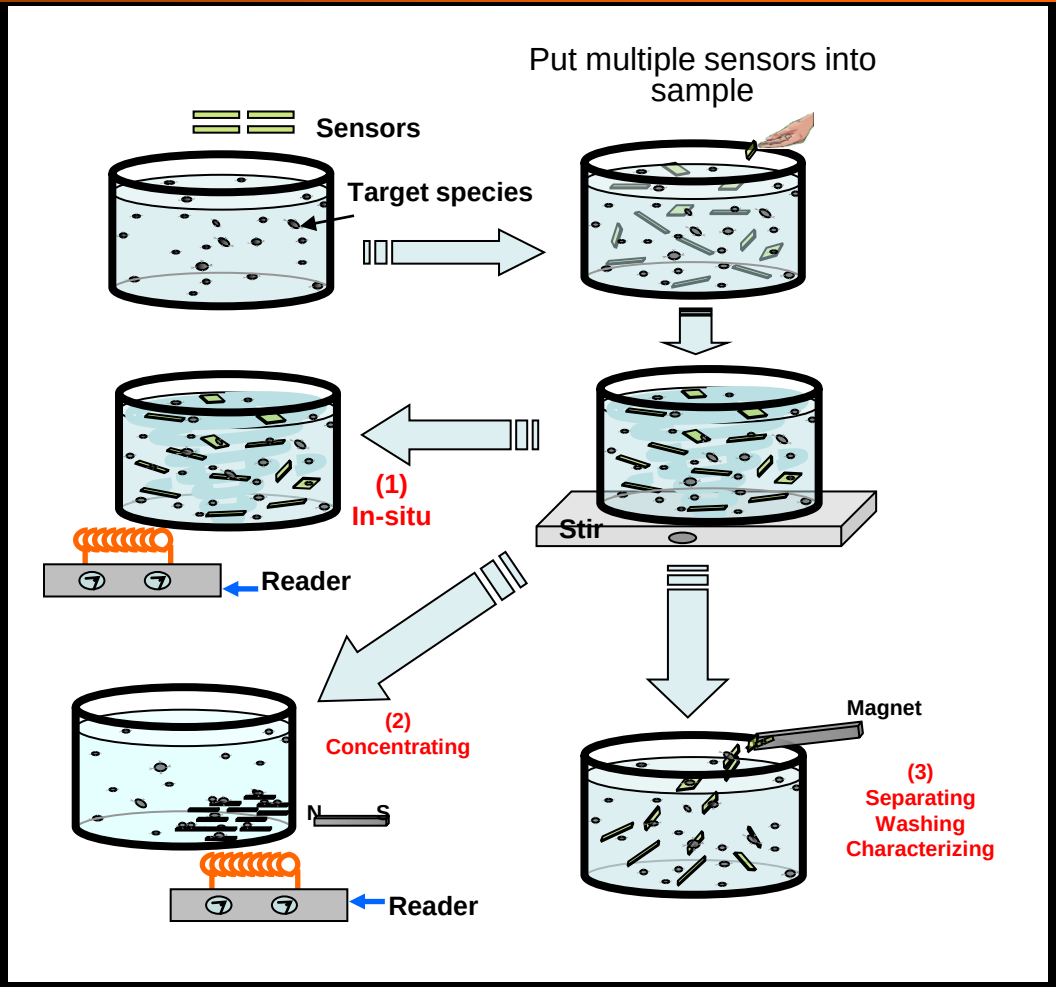
Technical Challenges of Nanosensors

- Specificity – Species, variants, viability – molecular recognition of biomarkers
- Sensitivity – lowest threat level - single molecule detection
- Sample – sensor interaction
- Simultaneous detection of multiple targets
- Rapid and Real time – online testing
- On-board intelligence, signal processing, communication
- Integral part of the products (packaging, foods, etc.)
- Low cost – affordable test and green fabrication
- Automation – portable, implantable, wearable – convenient to use for general operators

Multiple-sensor Approach

MSP provides a way to bring sensors to target !

➔ Truly free-standing

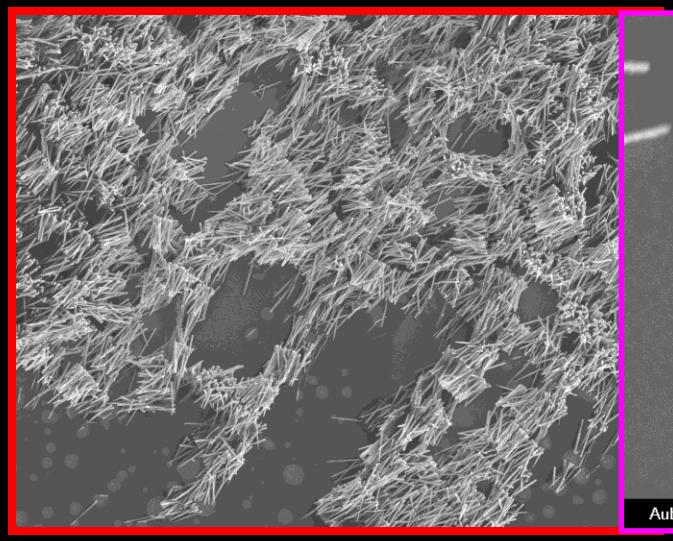


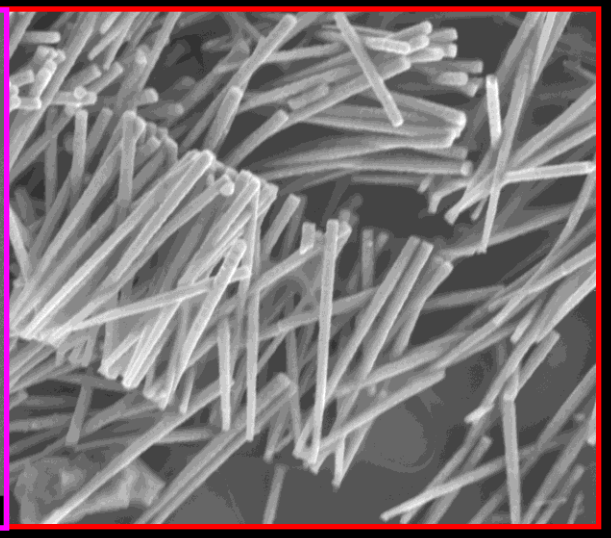
Significantly increase the ability to detect target species in liquid samples with very low concentration

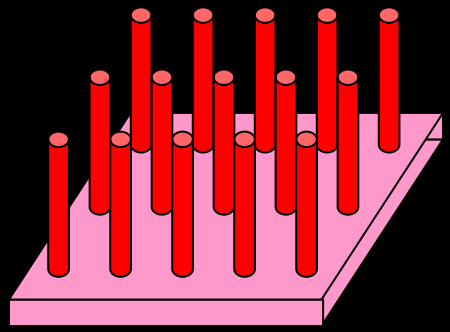
Auburn University Samuel Ginn College of Engineering

Auburn University DFS Detection and Food Safety Center

Fabrication of Fe-B Nanobars





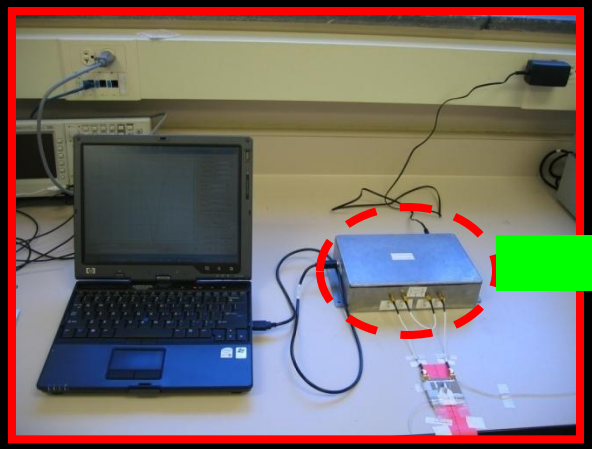


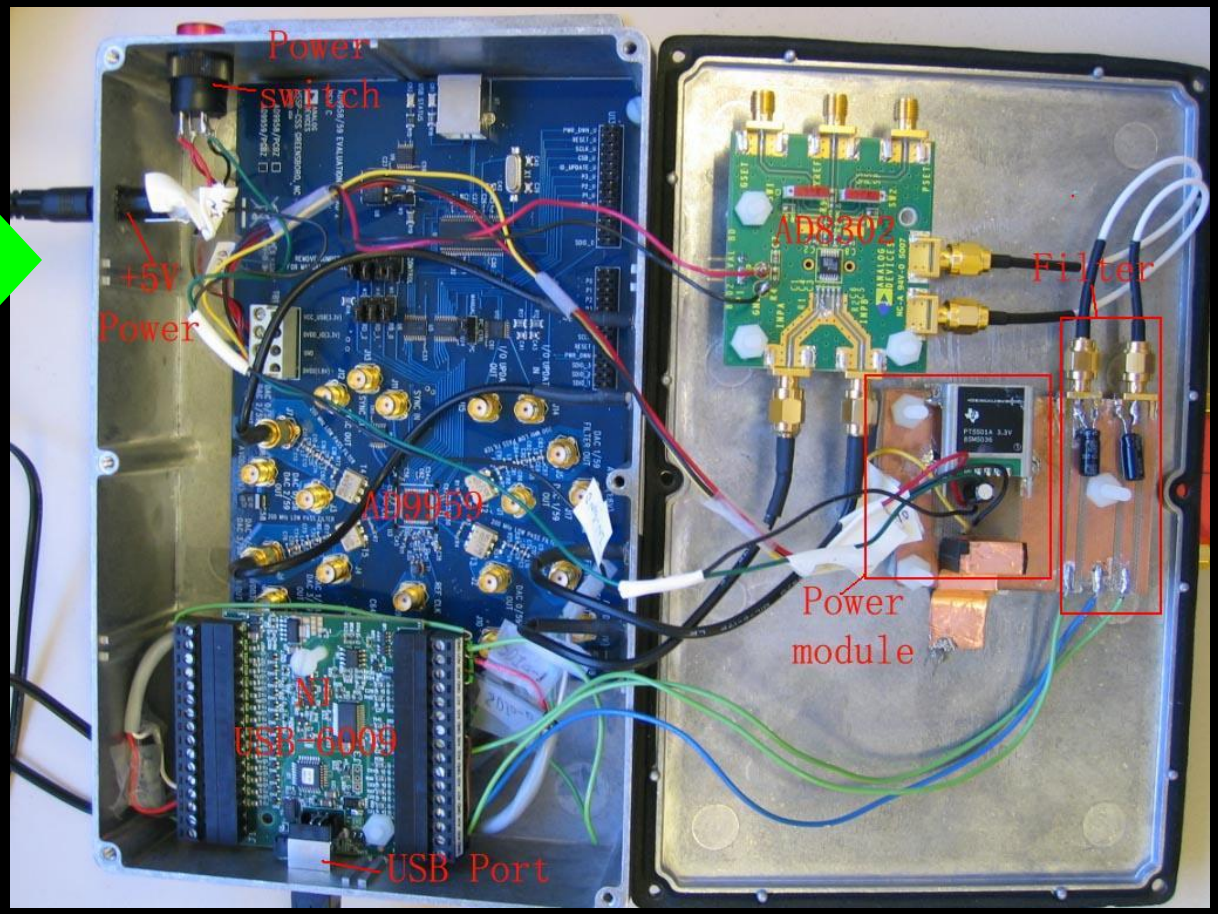
- Freestanding magnetostrictive nanobars
- Individual nanosensor platform
- Nanosensor array

Auburn University Samuel Ginn College of Engineering

Auburn University DFS Detection and Food Safety Center

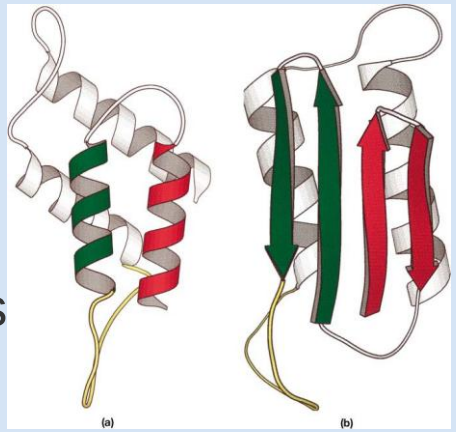
Interrogation System/Device





Frequency domain technology

- Examples of protein "conformational diseases"
  - Alzheimer's & Parkinson's
  - Cataracts
  - α1-antitrypsin deficiency
  - Transmissible Spongiform Encephalopathies (TSEs
    - Creutzfeldt-Jakob Disease (CJD)
    - Bovine spongiform encephalopathy (BSE)
    - Scrapie
    - Chronic wasting disease



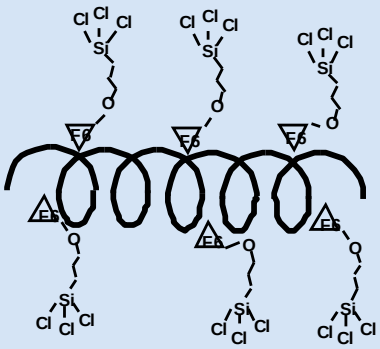
- A common trait of conformational disease causing proteins is "β-strand promiscuity", where protein *α–helical* content decreases (~from 42% to 30%) and *β–sheet* structure dramatically increases (~from 3% to 43%), resulting in assembly to form insoluble, protease resistant amyloid fibers.

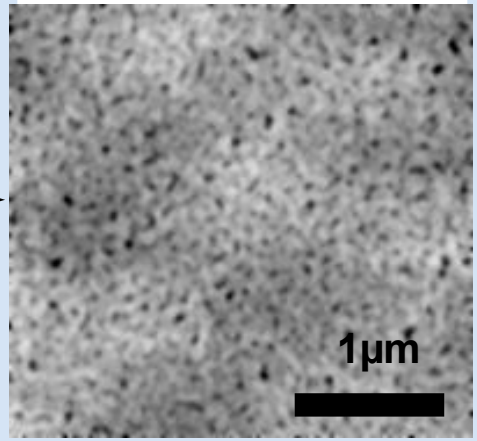
(Britt, Utah State University, 2004-04447)

•Carrel and Lomas, 1997, *Lancet*
•Pan, Baldwin, et al. 1993, *PNAS*

Zoonotics – protein conformation

Extending fluoro-alcohol stabilized conformations in bulk solution to protein imprinting (at surfaces and as 3-D network polymers) using silanes to form a matrix containing binding pockets that are complementary to the protein size, shape, conformation, chemistry.





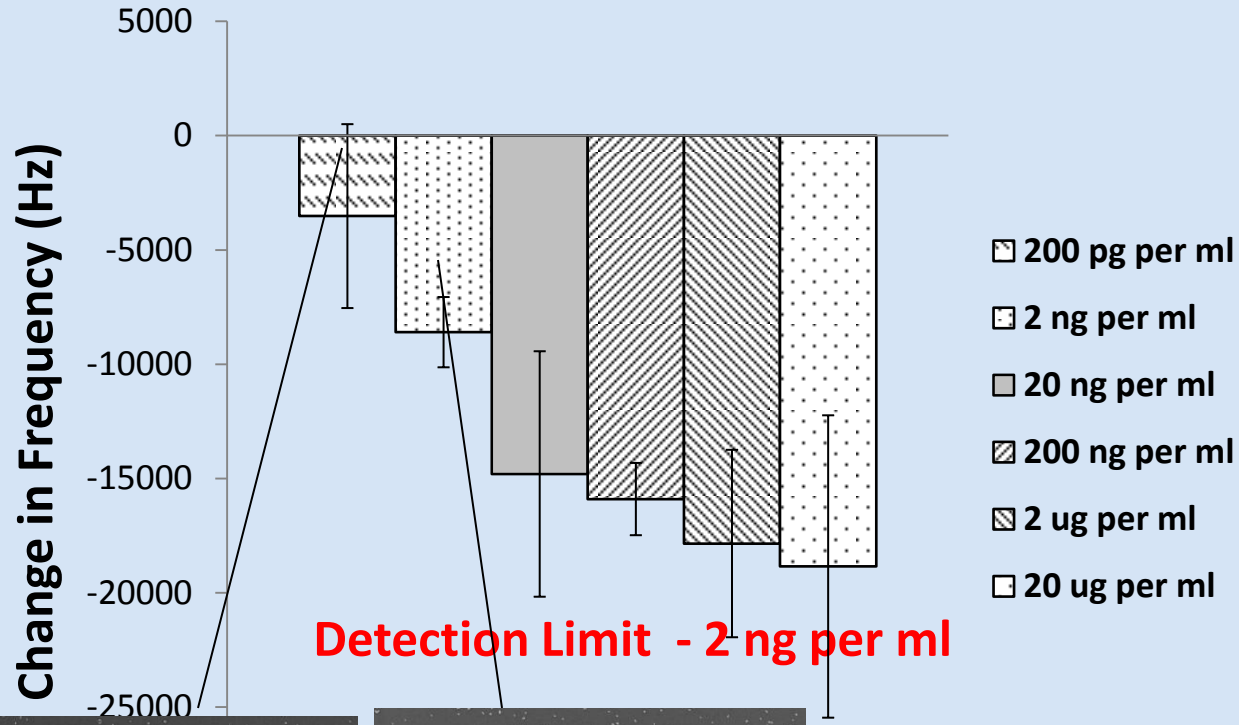
α-helix stabilization

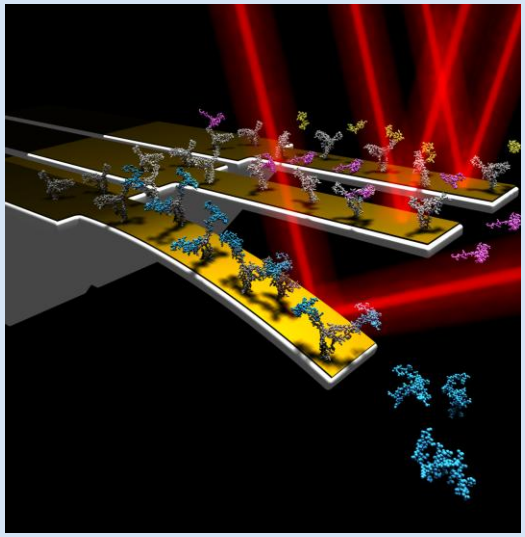
polymerization
(3-D network
or on a surface)

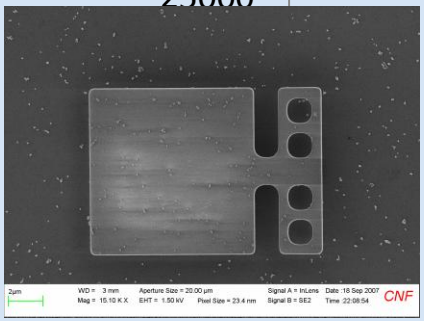
protein elution &
imprint pocket
generation

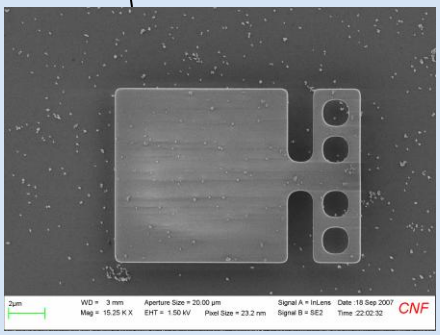
(Britt, Utah State University, 2004-04447)

Dose Response with Nanoparticles Labeling









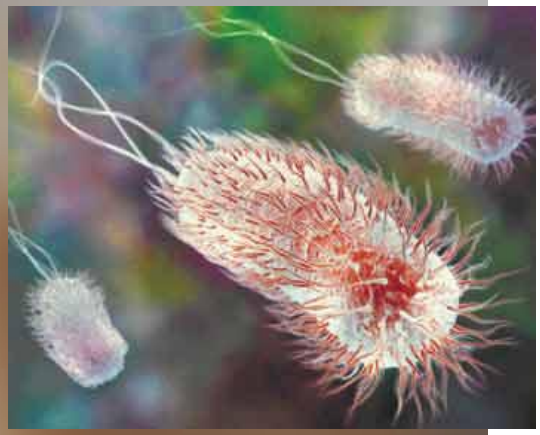
Antimicrobial Nanoscale Delivery Design

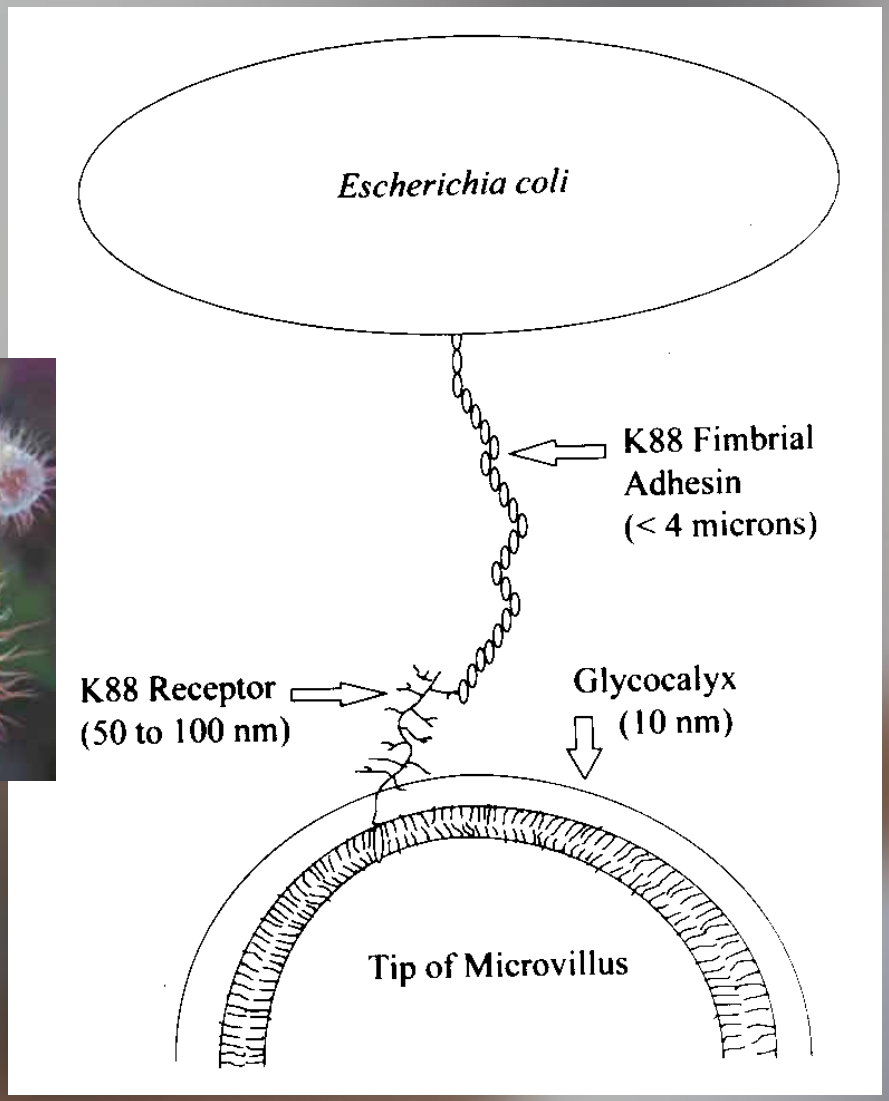
- Designing preservation systems with food antimicrobials has extremely broad horizon.
- Nano- and Microencapsulation can be a potential means to control the physical properties of antimicrobials
  - **Improved stability**
  - **Improved activity**
- Engineering of surface properties (charge, composition and thickness of interface) is critical consideration.
- Still many open questions in terms of fundamental mechanism of antimicrobials in complex systems
- Interactions between multiple antimicrobials may be worth of investigations for enhanced efficiency.

Structure design as a valuable tool to not only improve antimicrobial activity but better understand bacterial growth in complex foods. - Jochen Weiss, University of Hohenheim

Food Safety Intervention

- ***ADHESIN-SPECIFIC NANOPARTICLES FOR REMOVAL OF PATHOGENIC BACTERIA FROM POULTRY***
  - Latour, R. A., etc., Clemson Univ. 2000-05336

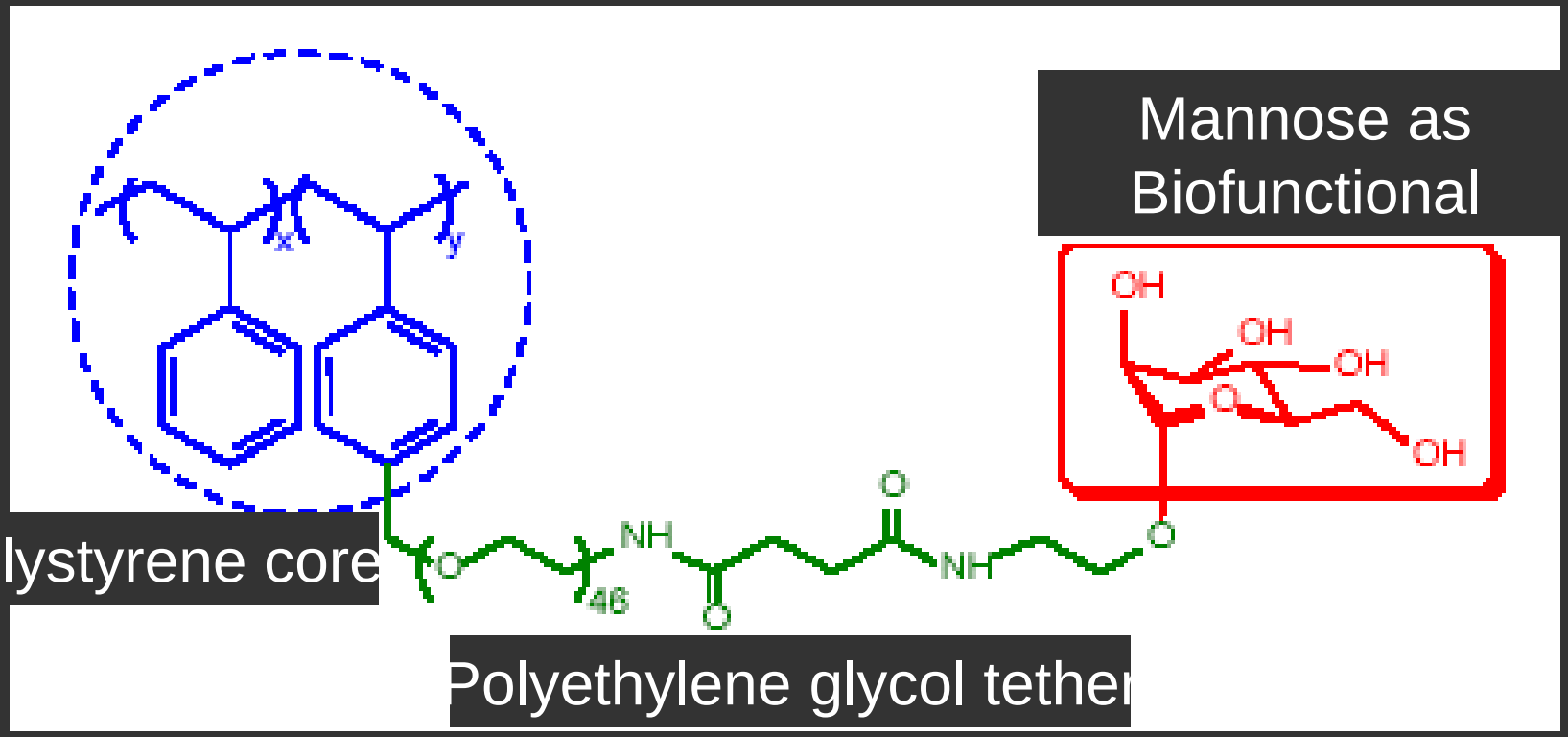




Bacterial Binding to Host is Mediated by Adhesins

(Latour, etc. Clemson University)

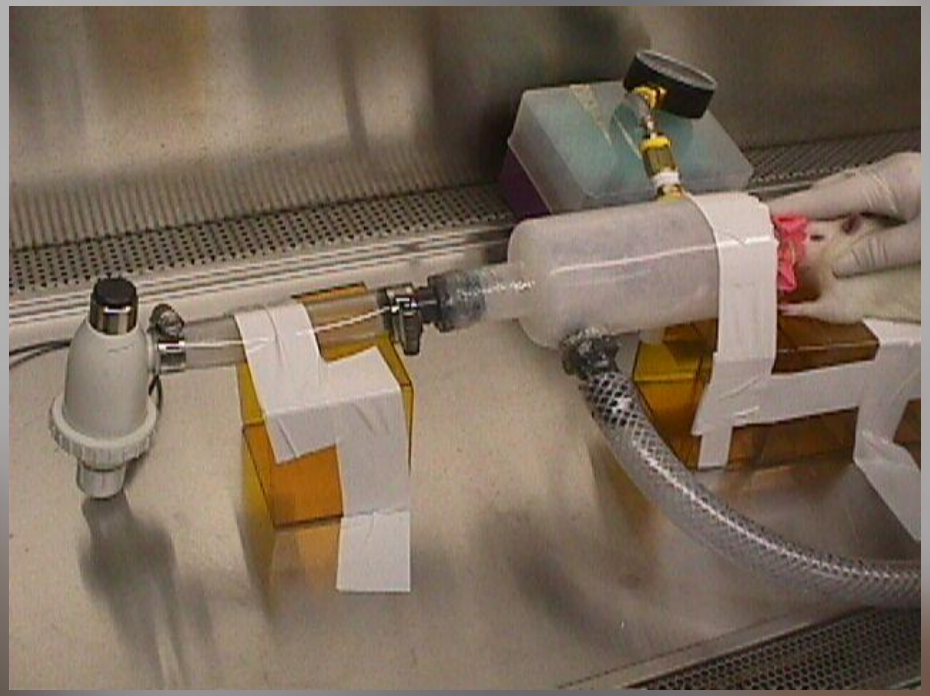
Nanoparticle Chemical Structure: Mannose Functionalization



(Latour, etc. Clemson University)

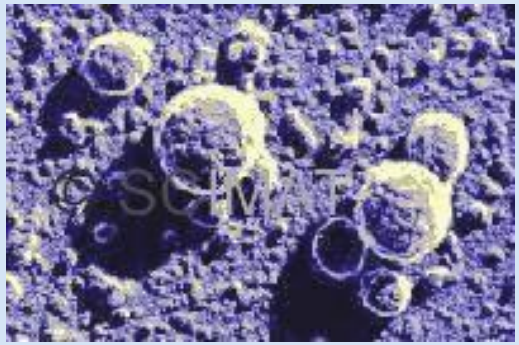
Nanoparticles Exposure Sensitivity Studies

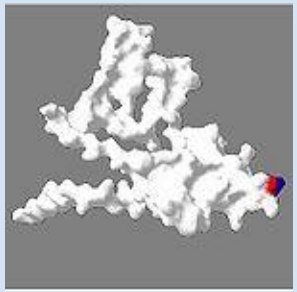
- In vitro studies
  - cell toxicity studies
- In vivo studies for worker handling safety
  - Skin (rabbit)
  - Ocular (rabbit)
  - Inhalation (rat)
  - Ingestion (rat)
- In vivo studies: end users



(Latour, etc. Clemson University)

Cheese making – Ancient Nanotechnology



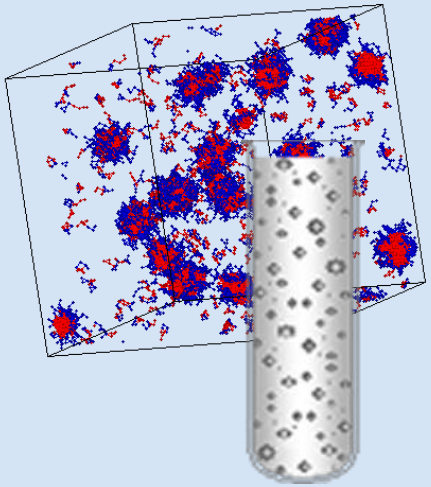


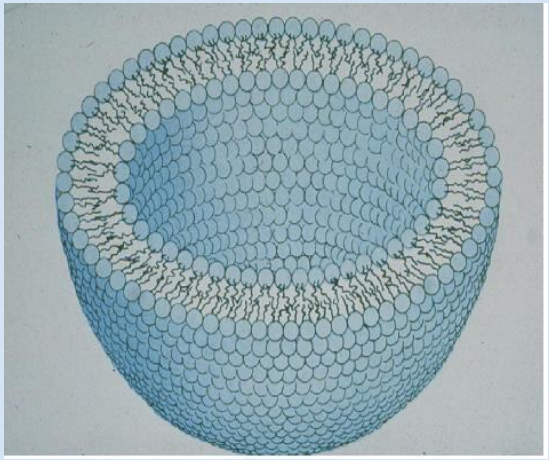
New: Increasing Scientific Data on the Fate, Transport and Behavior of Engineered Nanomaterials in Selected Environmental and Biological Matrices (EPA, NSF, and USDA)

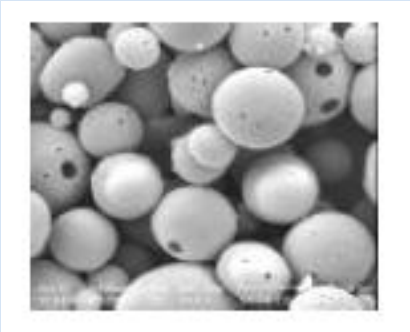
- ***Area 1:*** *Evaluation of potential exposures to engineered nanomaterials including an exploration of environmental and biological fate, transport, and transformation of these materials throughout their lifetimes.*
- ***Area 2:*** *Improve the scientific understanding of engineered nanoscale additives and ingredients that may be intentionally introduced into food for delivery of important micronutrients and modification of sensory attributes.*

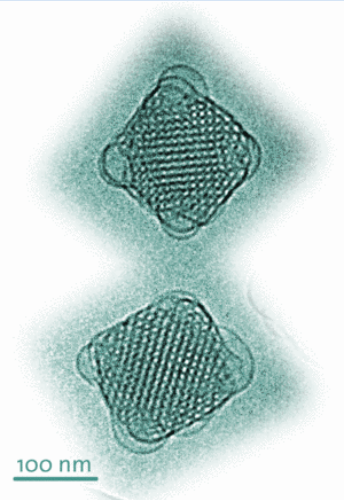
Nanoscale Systems for Delivery

- Micelles
- Emulsions
- Liposome
- Nanoparticles
- Dendrimers
- Block copolymers
- Bicontinuous fluids







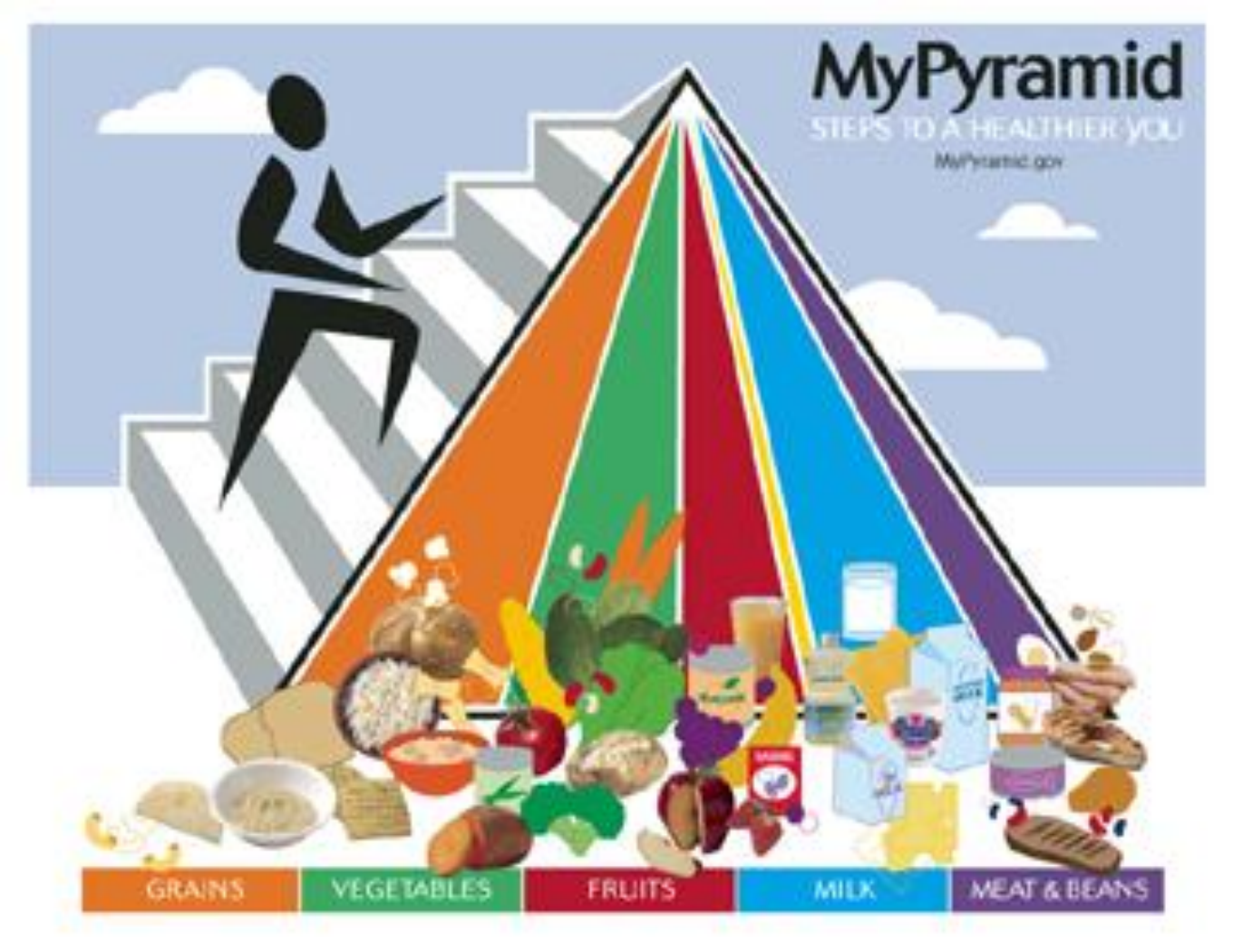


Improving Delivery of Micronutrients and Bioactives

- Delivery of nutritional functions (micronutrients and bioactive compounds) through food matrix
- Protect nutritional stability in the environment
- Controlled bio-availability of molecules
- in-situ texture, flavor & color formation
- Flavor release (sensory interaction and perception)
- Intrinsic physical preservation
- Smart delivery systems
- Food quality sensors
- Nanotags (traceability)

Chen, Weiss, and Shahidi, *Food Tech*. April 2006

Nanoparticles naturally in foods



Nanocomposite Polymers Improved Packaging

- **Improvements in oxygen and water vapor transmission barrier properties**
- **Improvements in mechanical properties**
  - **Young's modulus and tensile strength**
- **Improvements in thermal stability (100°C)**
- **TEM and X-ray showed high degree of intercalation/exfoliation in 7.5% clay**
- **LDPE/Clay (7.5%) Nanocomposites showed better modulus and oxygen barrier than existing meal bag**
- **Smart Packaging: Using conjugated/conductive polymer nanosensor to detect amines - food spoilage and diseases (breath)**

Layer-by-Layer Technology

- Substrate -> polycation -> polyanion …
- Embedded ethylene oxidation enzyme
- Materials from natural resources and safe for food contact, and biodegradable
- Remove ethylene -> control over ripening during storage and home use

Video: The Science of Small

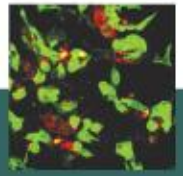
- http://www.csrees.usda.gov/newsroom/partners/21/nanotechnology.html
- http://nano.gov/

NSF Center Proposal Industry-University Cooperative Research Center (I-UCRC)

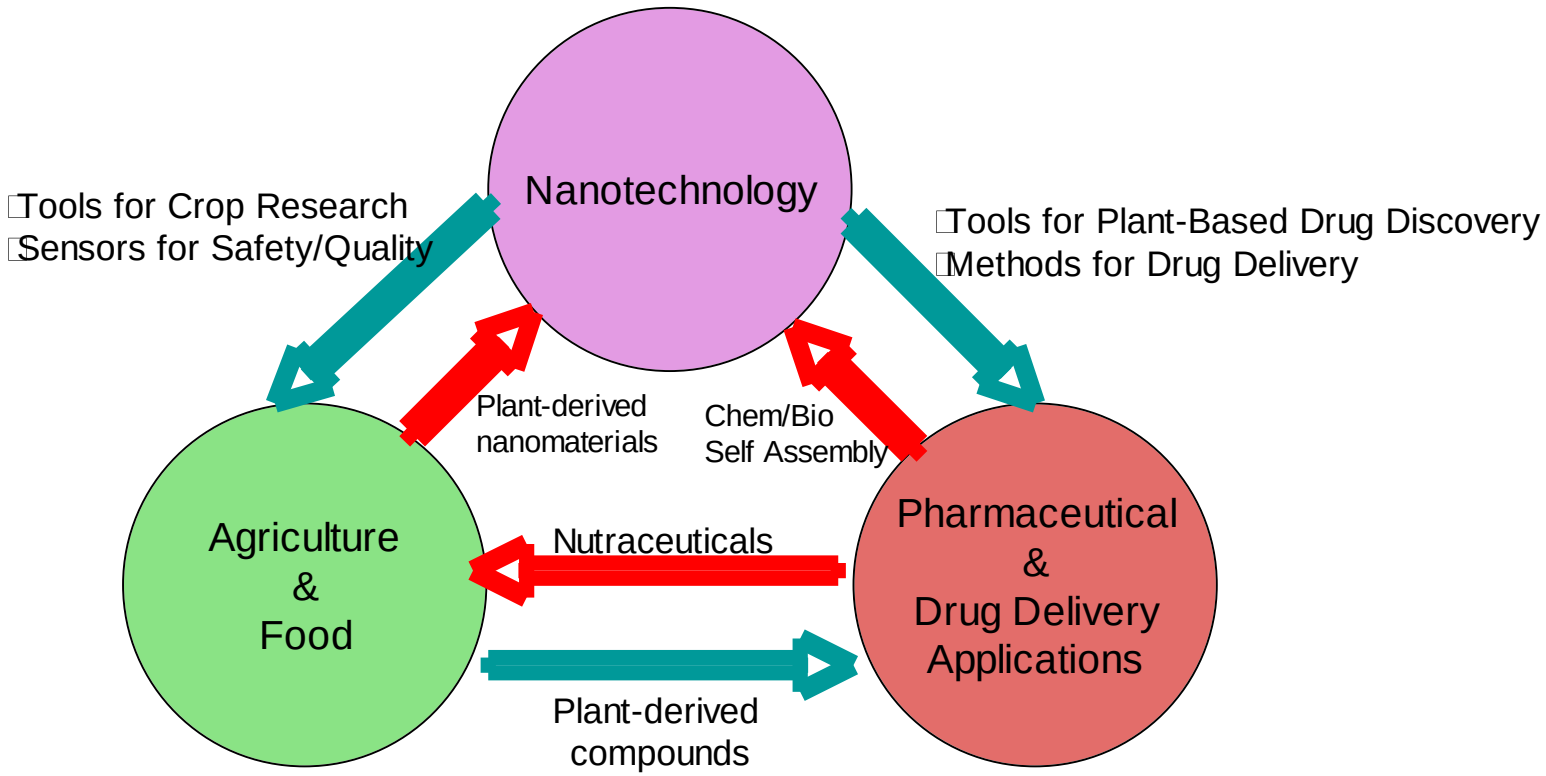
Brian Cunningham, PI, Illinois
Richard Linton, Co-PI, Purdue
Irfan Ahmad, Industry Liaison

December 7, 2009





Center for Agricultural and Pharmaceutical Nanotechnology (CAPN)



Conferences and International Cooperation

- Annual International Food Nanoscale Science Conference, started 2006
- International Union of Food Science and Technology (IUFoST), food nanotechnology symposia, Nantes, France, 2006; Shanghai, China, 2008
- Nano4Food, the Netherlands, 2005, Atlanta, GA 2006
- International Conference of Food Applications of Nanoscale Science (ICOFANS) series, 2010, Japan (in planning)
- Many other symposia at professional conferences
- International dialogue and communications: the Netherlands, Canada, Japan, Germany, UK, France, Portugal, Brazil, *Taiwan*, Korea, China, New Zealand, and many others

NRI Grantees Conferences

- 2005, @ Cornell University
  - Keynotes from and tours at NNIN and Nanobiotechnology Center
  - With NC-1031: Nanotechnology and Biosensors
- 2006, @ IFT Annual Meeting, Orlando, FL
  - Initiated an international food nanotechnology annual conference series (2007, Chicago; 2008, New Orleans; 2009, Anaheim)
- 2007, @ UC Davis
  - Toured the Molecular Foundry, Lawrence-Berkeley National Laboratory
- 2009, @ Santa Fe, NM
  - AFMNet, and Conjunction with CINT User Facility Conference

USDA Agricultural Research Service Nanotechnology Activities

- Paper coatings containing nanocomposites of silica and pectin enhance the flame-retardancy of paper;
- blending just 10% cellulose nanofibrils (10-20 nm in diameter) leads to a 5-fold increase in the tensile strength of starch-based plastics;
- polyaniline and cellulose-nano-fibril composites that provide 10-50 times greater conductivity than carbon black and used to produce anti-static paints and coatings.
- surface enhanced raman spectroscopy (SERS) isused to rapidly and accurately identify *E. coli* and *L. monocytogenes* on silver colloidal nanoparticles;
- 30 percent sugar beet pulp with pectin nanofibrils blended into poly-lactic acid (PLA) creates a PLA alloy with improved functional properties;
- nano-rod based biosensors to rapidly, accurately and selectively identify Salmonella;
- nano-cantilever to detect toxin molecules with high sensitivity;
- electrospun protein and PLA nanofibers with potential applications in filtration, biomedical materials, biosensors and control-release agents; and
- nanoemulsions, nanoparticles, and microfibrils have been incorporated into edible films to develop food products with improved barrier and mechanical properties, greater nutritional value, and improved taste.

USDA Food Safety Inspection Service (FSIS)

- The Food Safety and Inspection Service (FSIS) protects the Nation's food supply ensuring that meat, poultry, and egg products are safe, wholesome, and accurately labeled. Its statutory authority resides in three acts: Federal Meat Inspection Act (FMIA), Poultry Products Inspection Act (PPIA), and Egg Products Inspection Act (EPIA). Among the many provisions of these acts, an underlying principle outlined in each act that may be relevant to nanotechnology issues in food safety indicates that FSIS is authorized to prevent products from entering commerce that are adulterated or misbranded. Key provisions that address this principle can be found for instance in FMIA Section 601(m) and (n), PPIA Section 453(g) and (h), and EPIA Section 1033(a) and (l).

USDA Office of Risk Assessment and Cost-Benefit Analysis (ORACBA)

- Under the Office of the Chief Economist
- Established by statute to ensure that all major regulations promulgated by USDA that affect human health, human safety or the environment have a regulatory analysis that includes a risk assessment and cost-benefit analysis. (See the Federal Crop Insurance Reform Act of 1994)
- Provides risk assessment guidance to USDA agencies.
- **Nanotechnology Activities**
  - Developing capacity to conduct risk assessments and provide guidance on risk assessments concerning the use of nanotechnology in the environment, agricultural production, processing or food products.
  - NanoRisk Analysis: Advancing the Science for Nanomaterial Risk Analysis in September 2008.
  - Participates in the Society for Risk Analysis Emerging Nanoscale Materials Specialty Group (EMNMS).

USDA Economic Research Service (ERS)

ERS
ECONOMIC RESEARCH SERVICE

- Study nanotechnology for food applications (i.e., food, nutrients, and food contact materials, such as food packaging) with a focus on potential food safety issues
- Preparing reports of issues on potential economic impacts of nanotechnology applications to food industry and consumers

Other USDA Agencies with Interests in Nanotechnology

- Animal and Plant Health Inspection Service (APHIS)
- Foreign Agriculture Service (FAS)
- Food and Nutrition Service (FNS)

Priority areas that agriculture must address:

1. Climate Change
2. Bioenergy
3. Food safety
4. Nutrition
5. International food security

Thank You!

http://www.nifa.usda.gov
hchen@nifa.usda.gov