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

A Brief Overview of Nanoscale Science and Technology for Agriculture and Food Applications Suppoted by USDA/NIFA

Hongda Chen

at

National Nanotechnology at Ten

Nanotechnology Innovation Summit

December 8 to 10, 2010, National Harbor, Washington, DC

INVESTING IN SCIENCE | SECURING OUR FUTURE

Outline

- Why nanotechnology for Agriculture and Food systems?
- NIFA Priority Science Areas
- NIFA investment in nanotechnology
- Examples of activities in Nanotechnology Applications in Agriculture Production and Foods
- Closing thoughts

Humanity's top ten challenges before 2050

- **Energy**
- **Water**
- **Food**
- **Environment**
- **Poverty**
- **Terrorism & War**
- **Diseases**
- **Education**
- **Democracy**
- **Population**

2003	**6.3**	**Billion People**
2050	**9-10**	**Billion People**

Sustainability, Human Health, and Economic Growth

Source: Richard Smalley, 1996 Nobel Laureate in Chemistry

Credit: R. Stockli, A. Nelson, F. Hasler 2003 April 26

NIFA Priority Science Areas

- Global Food Security and Hunger
  - To boost agricultural production, improve global capacity to meet the growing food demand, and foster innovation in fighting hunger.
- Climate Change
  - To adapt to changing environments and sustain economic vitality; and to take advantage of emerging mitigation technologies.
- Sustainable Energy
  - To develop biomass (forestry and crops) used for biofuels, bioenergy production, and value-added bio-based products.
- Childhood Obesity
  - To ensure nutritious foods affordable and available; and to provide guidance for health and well-being decision making.
- Food Safety
  - To reduce the incidence of food-borne illness, provide a safer food supply and develop food processing technologies to ensure food safety.

National Nanotechnology Initiative

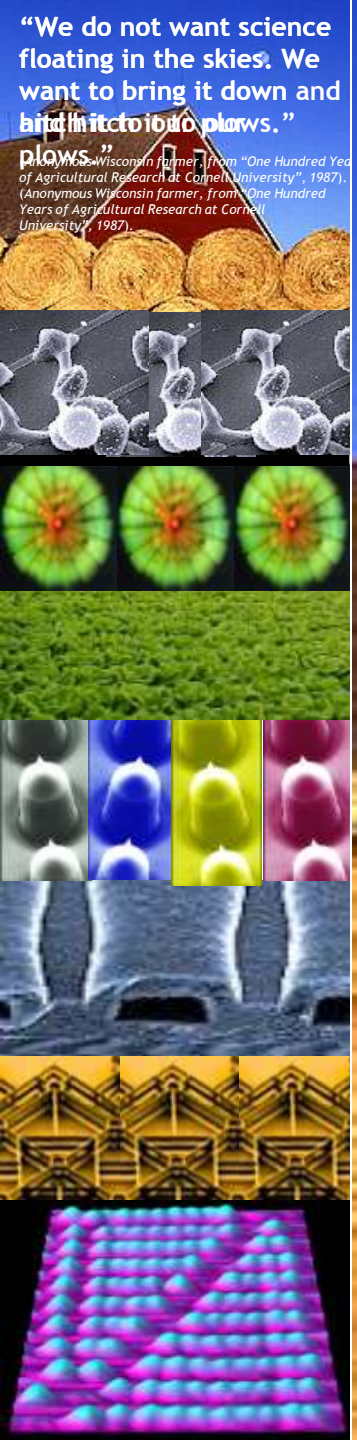
Collaborative, Multi-agency, Cross-cut Program Among 25 Federal agencies

Funds R&D to advance understanding and control of matter at nanoscale toward:

Improved quality of life

National economic benefit

OSTP
OMB
NIH
NSF
DOD
DOE
NIST
FDA
NASA
USDA/ NIFA
NIOSH
USDA FS
DOS
EPA
DOTr
NRC
DOT
USPTO
ITIC
USGS
DOL
DOJ
DOEd
DOC BIS
DHS
CPSC
ITC



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

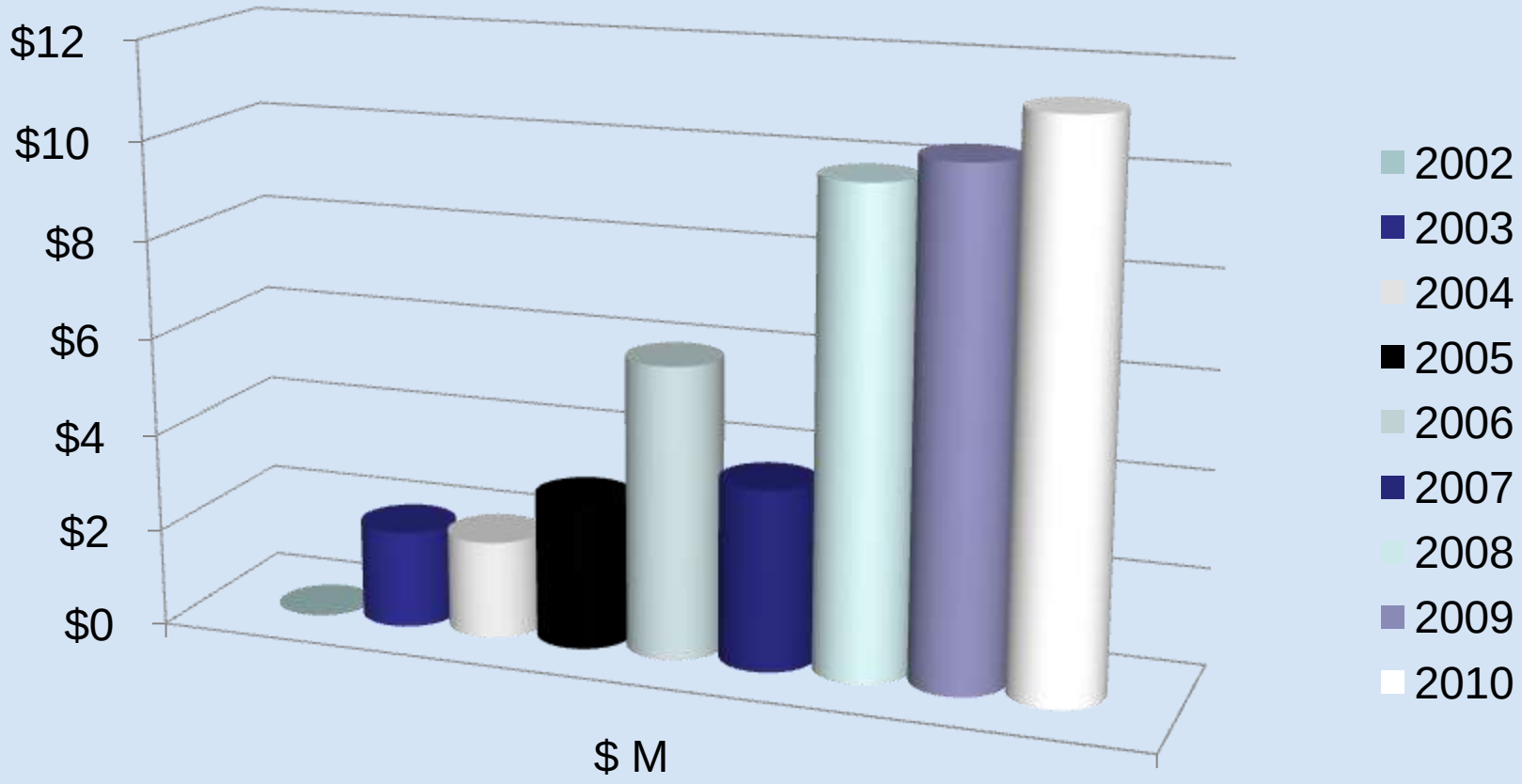
(Anonymous Wisconsin farmer, from "One Hundred Years of Agricultural Research at Cornell University", 1987).

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

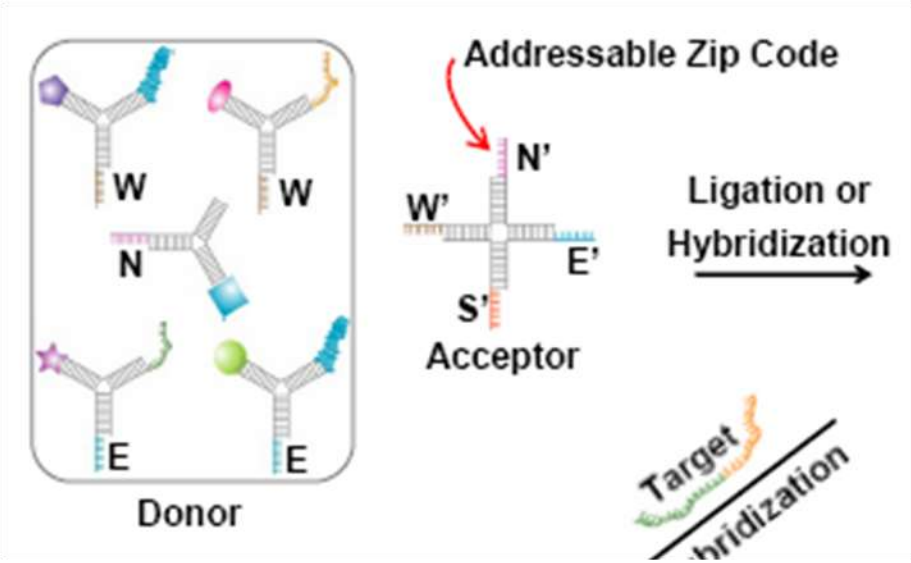
www.nseafs.cornell.edu

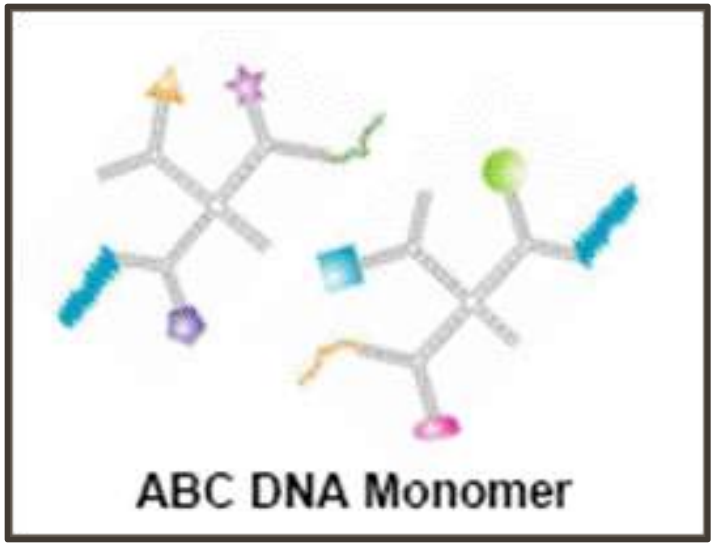
NIFA Expenditure in Nanotechnology



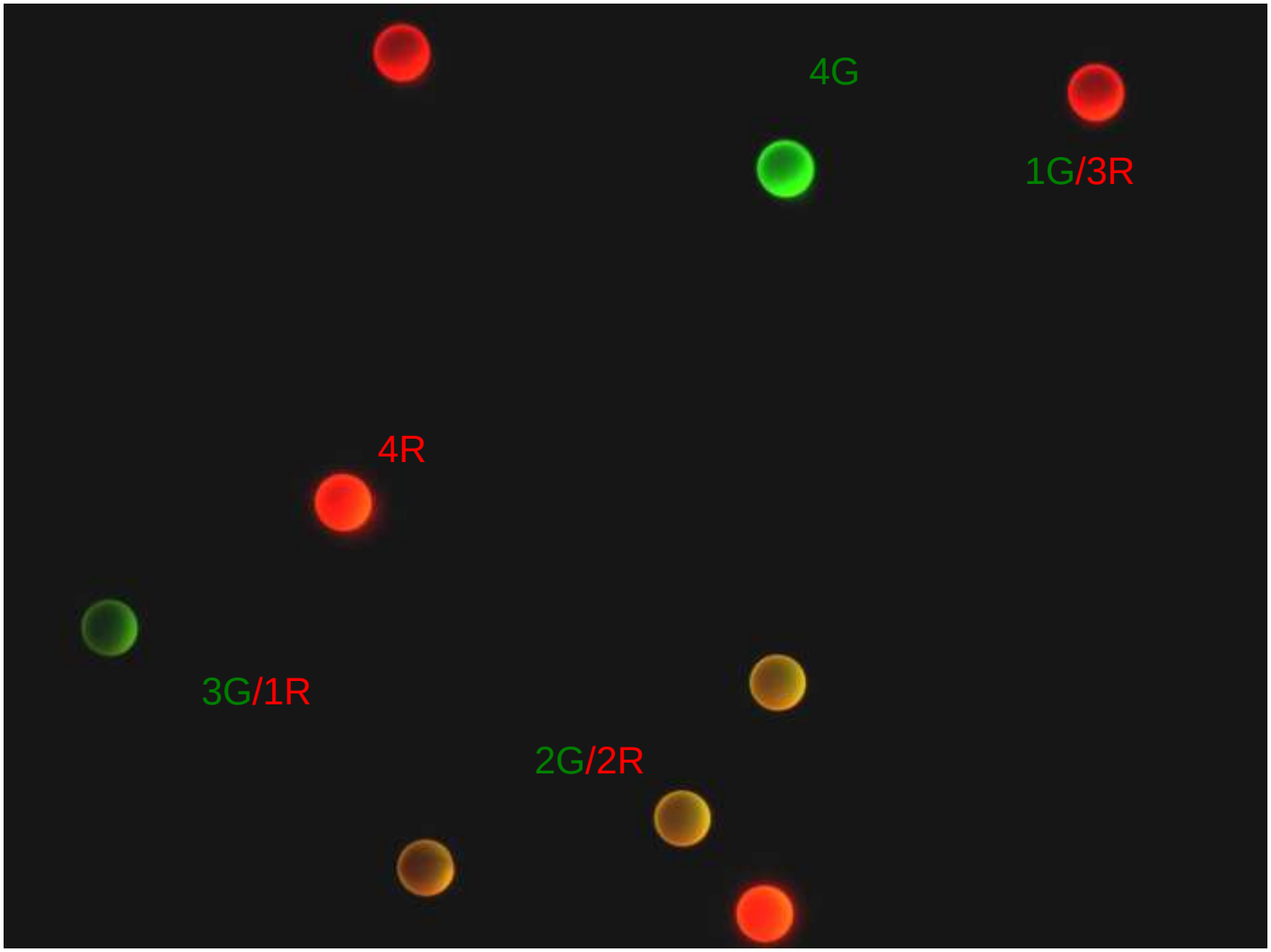
Anisotropic, Branched, and Crosslinkable (ABC) Monomer to Polymer

Luo, Cornell University

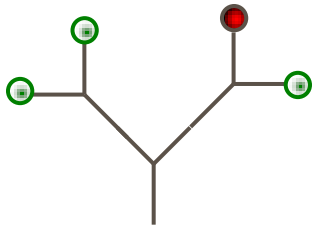




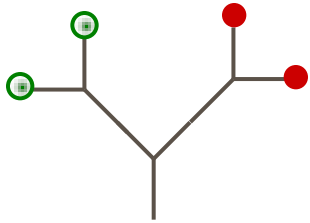
Barcode decoding via fluorescent microscopy



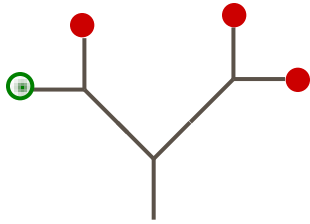
3G/1R



2G/2R



1G/3R



Y. Li, Y. Cu and D. Luo, *Nature Biotechnology*, **23**, 885-889, (2005)
Um. et. al. *Nature Protocols* **in press** (2006)

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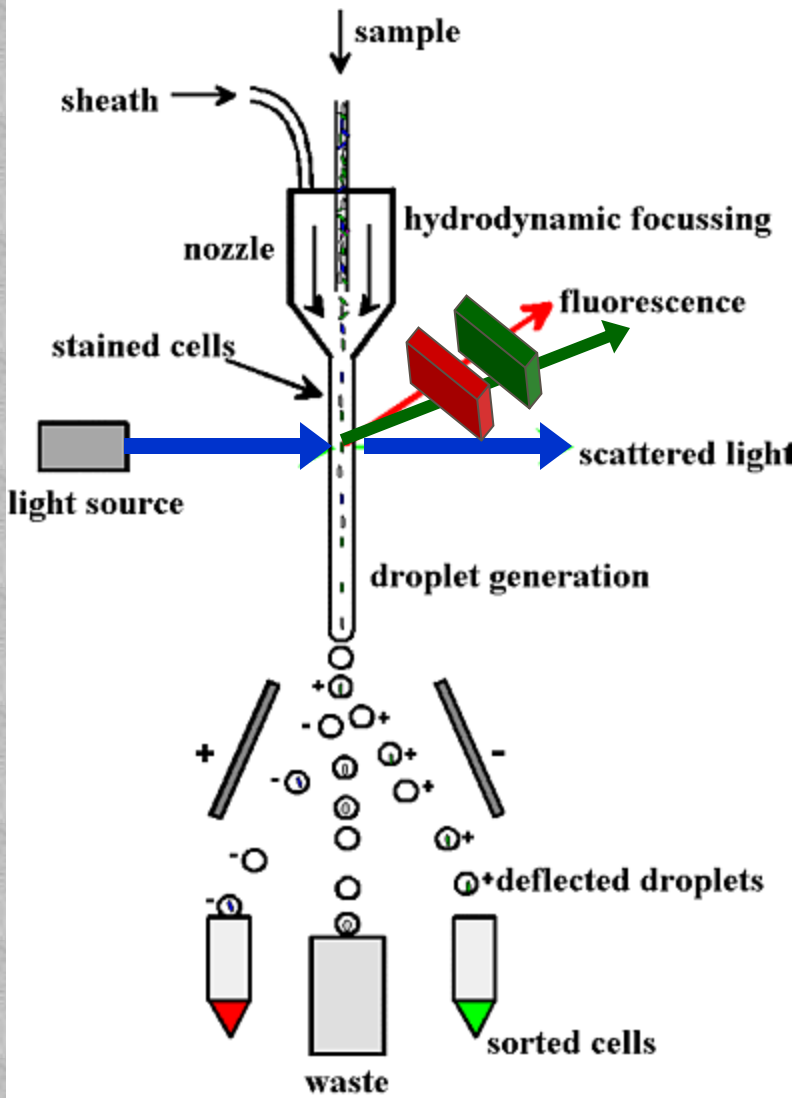
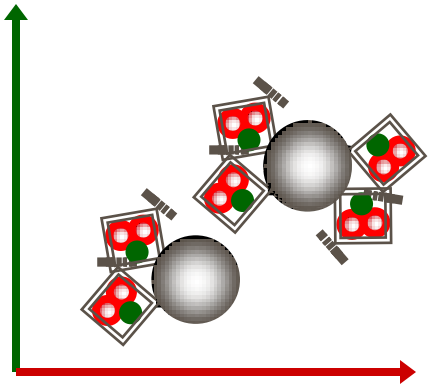
Product Traceability

- Five essential requirements:
  - Enough vocabulary
  - Not compromise the product
  - Same life as the product service life
  - Easy to read
  - Very inexpensive
    - *Stephen D. Nightingale, 2008 IFT International Food Nanoscience Conference*

Barcode decoding via flow cytometry

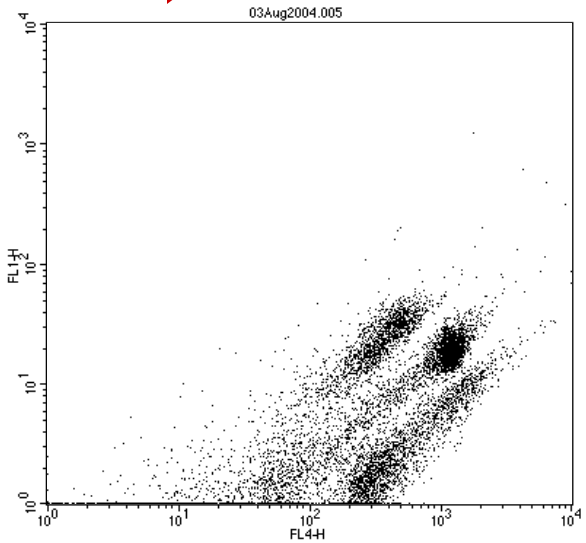




$$\frac{I_R}{I_B} = k_{barcode}$$

$$\ln(I_R) = \ln(I_B) + \ln(k_{barcode})$$

y=1.06x-5.0
y=0.99x-5.9
y=1.00x-3.3



Three different DNA species from **Anthrax, Ebola and SARS** were detected simultaneously with 3 DL-DNA-based nanobarcodes using commercial polystyrene microbeads. Detection limit: **10^{-18} mole (attomole).** Detection speed: **30 seconds.**

Y. Li, Y. Cu and **D. Luo,** *Nature Biotechnology,* **23,** 885-889, (2005)

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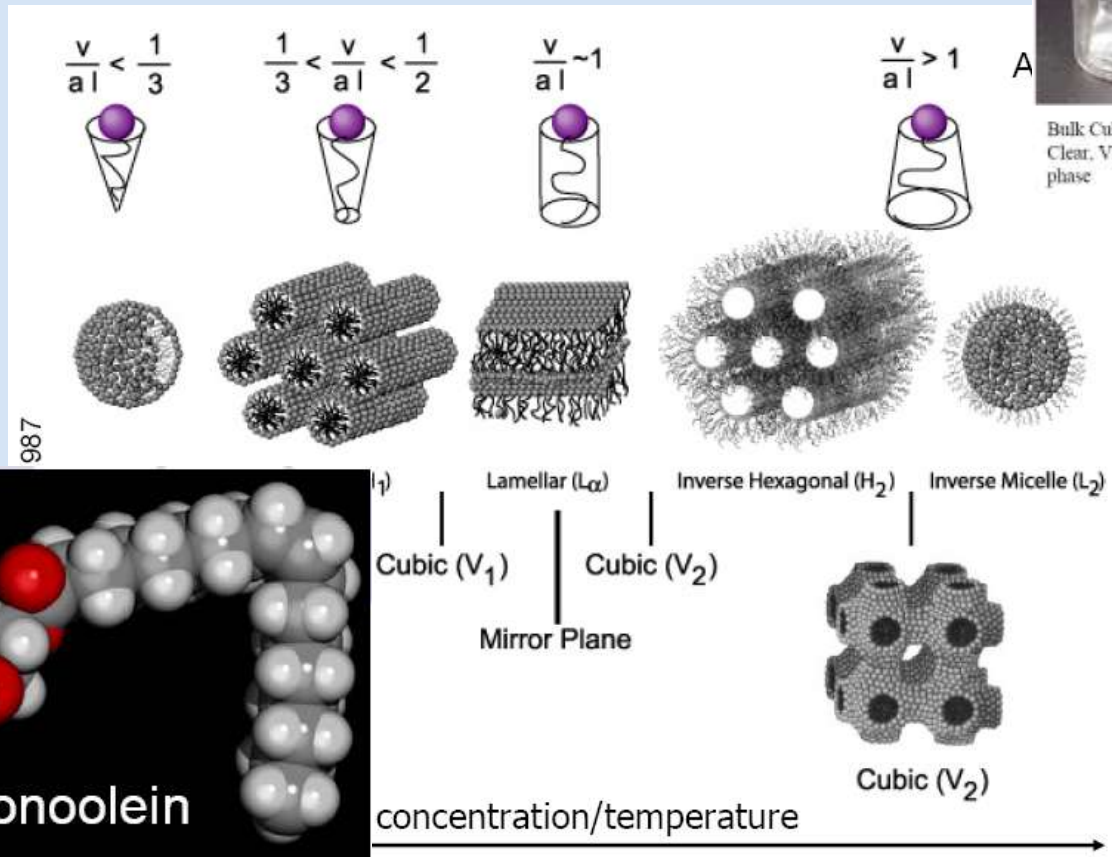
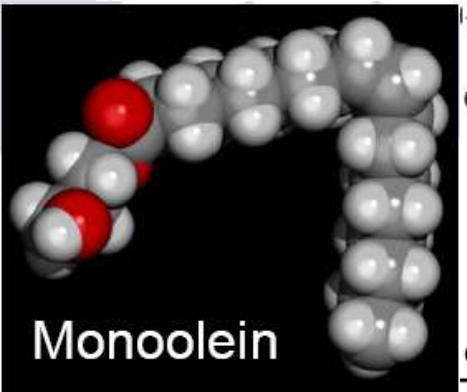
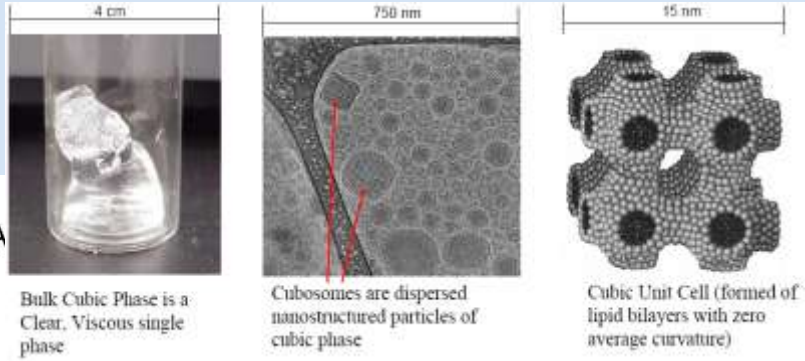
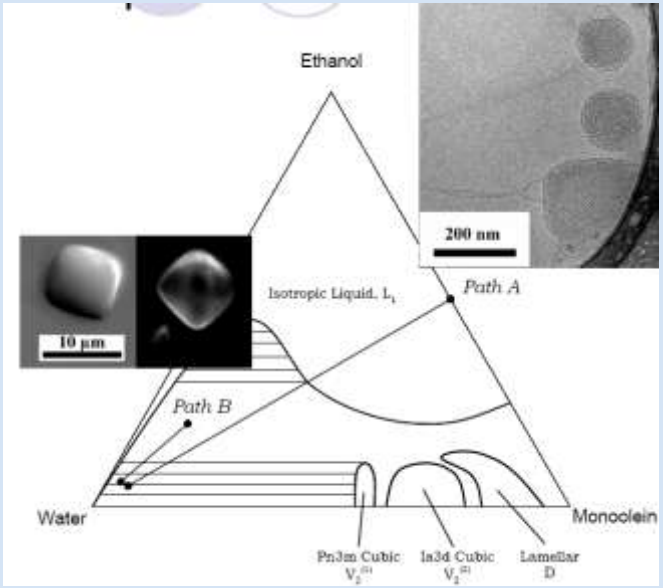
Nanostructured Delivery of Micronutrients and Drug

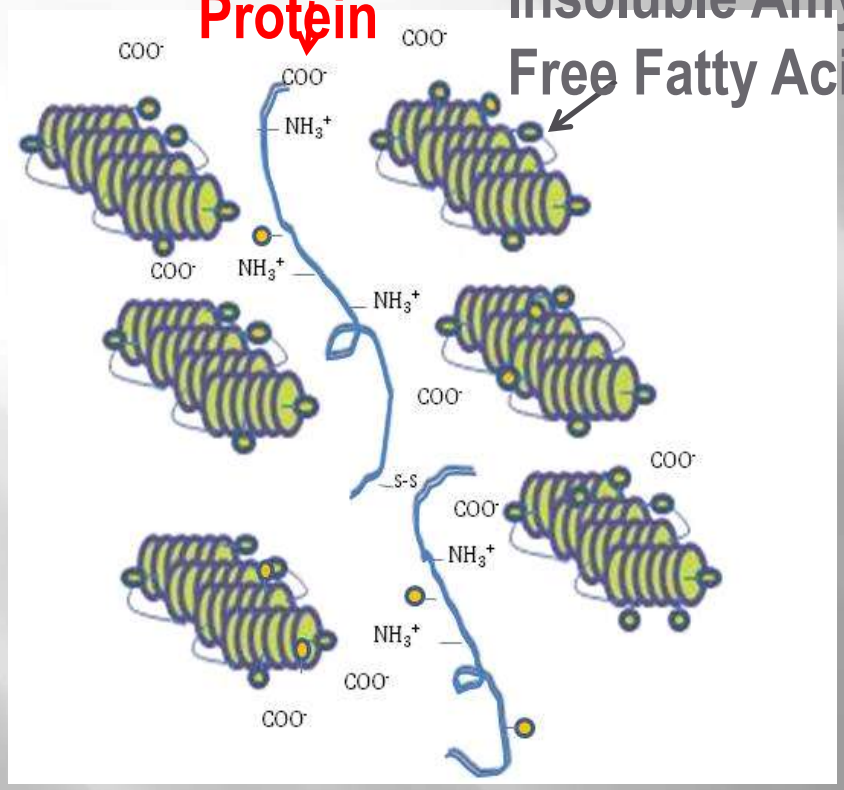








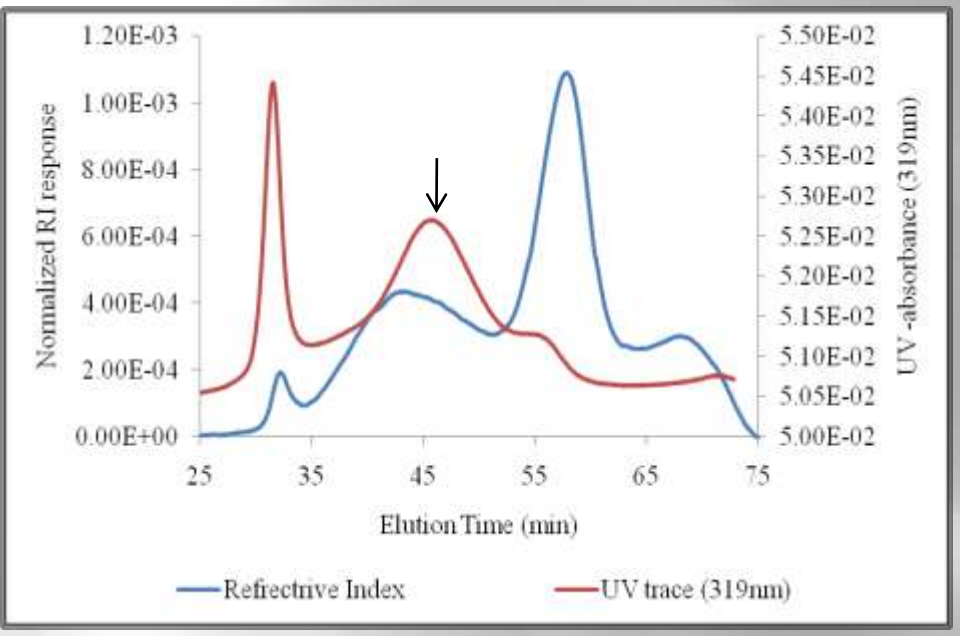
A soluble nano-scale self-assembling complex from starch, protein and lipid for healthy nutrient delivery – B. Hamaker/O.H. Campanella, Purdue University



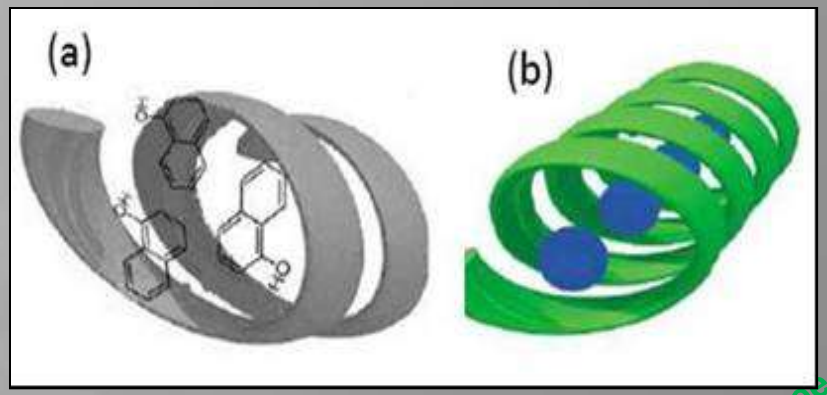
- **Self Assembly**: Components associate via electrostatic bonding between the well known hydrophobic interaction-driven amylose-FFA complex and certain disulfide-linked soluble proteins. Assembly kinetics are currently being investigated

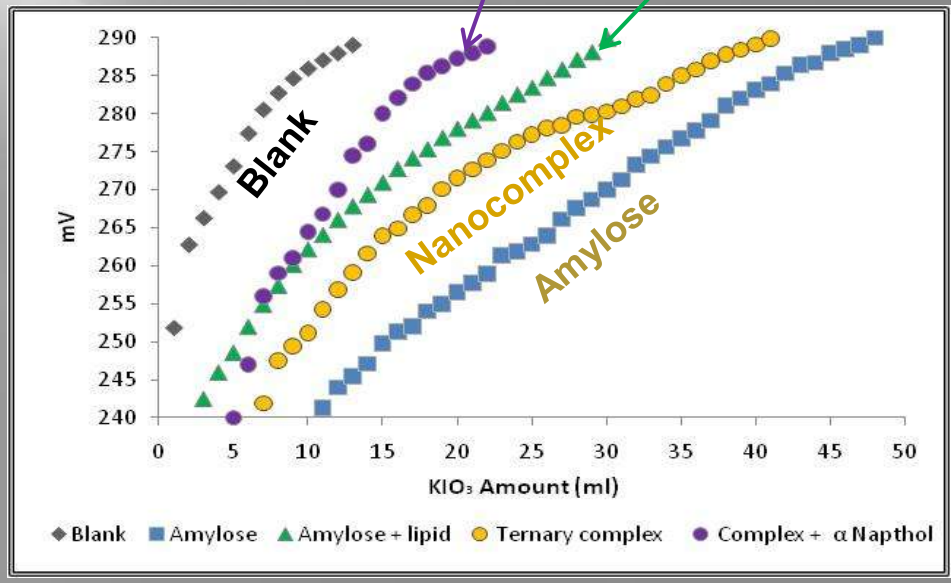
- **Physicochemical Methods** are used to characterize formation and functionality of the nanocomplex including small hydrophobic molecule carrying capacity

BINDING ABILITY OF THE NANOCOMPLEX



Chromatographic response of ternary nanocomplex containing the α-napthol





Iodine binding capacity of the measured by potentiometric titration

- Model compound α- napthol mostly insoluble in aqueous phase
- Solubilization of α-napthol through binding with ternary nanocomplex indicated by HPSEC

Avian Influenza Biosensor –

Y. Li, U. Arkansas

Novel concepts for the biosensor:

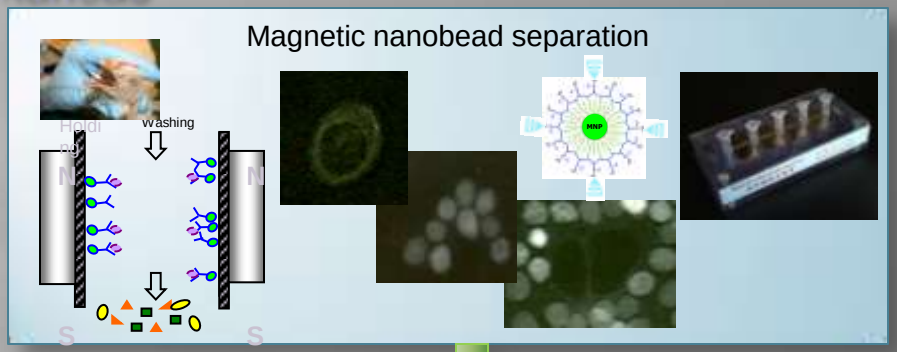
- Magnetic nanobeads (coated with anti-H5 antibody) based sample pretreatment for highly efficient capture and separation of target AI virus
- Micro/nanofluidic chips based sample control for high ratio of surface area/volume with accurate, small volume of sample
- Interdigitated micro/nanoelectrode (immobilized with anti-N1 antibody) based impedance measurement for sensitive, specific detection of AI virus

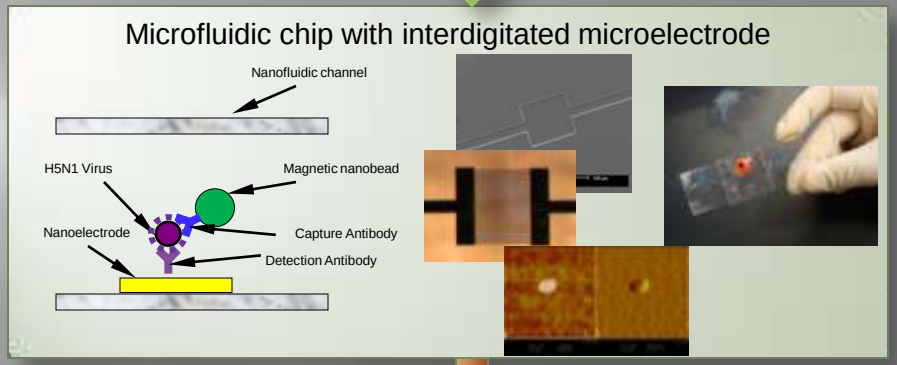
Design the biosensor prototype:

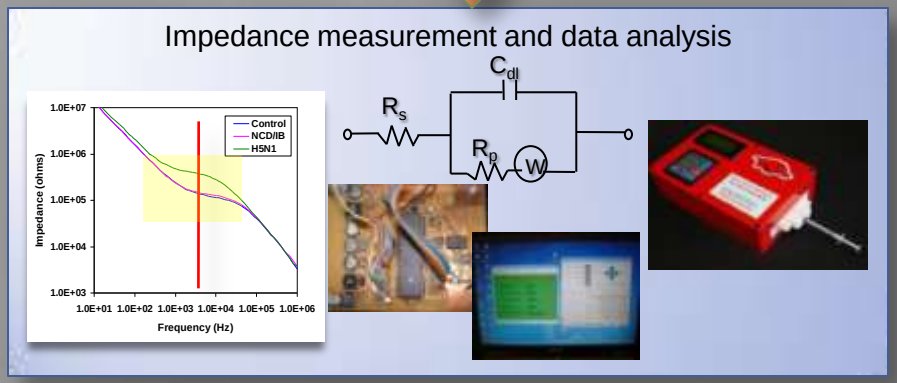
- The hardware: biosensor instrument can be either stand-along or connected to a laptop.
- The software: easy way to control the biosensor and to collect and analyze the data.

Advantages

- Rapid
- Portable
- Cost-effective
- Reusable
- Easy to operate
- Quantitative
- Multiple uses

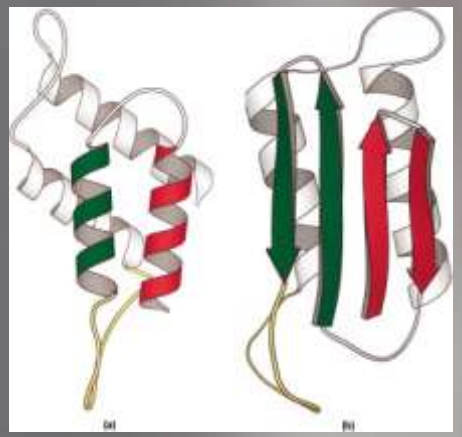






Protein Conformational Diseases

- 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.

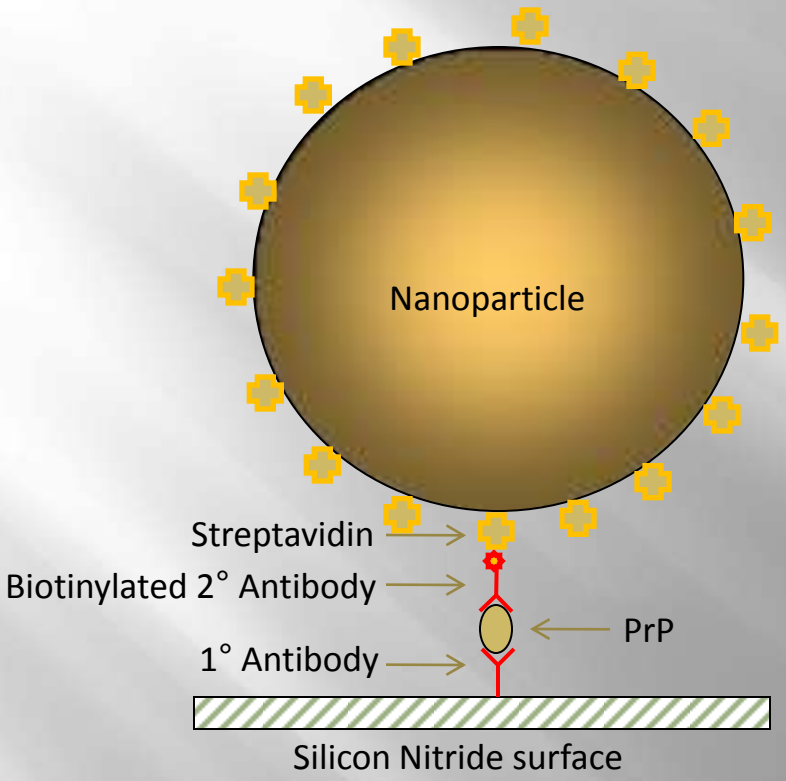
(Britt, Utah State University, 2004-04447)

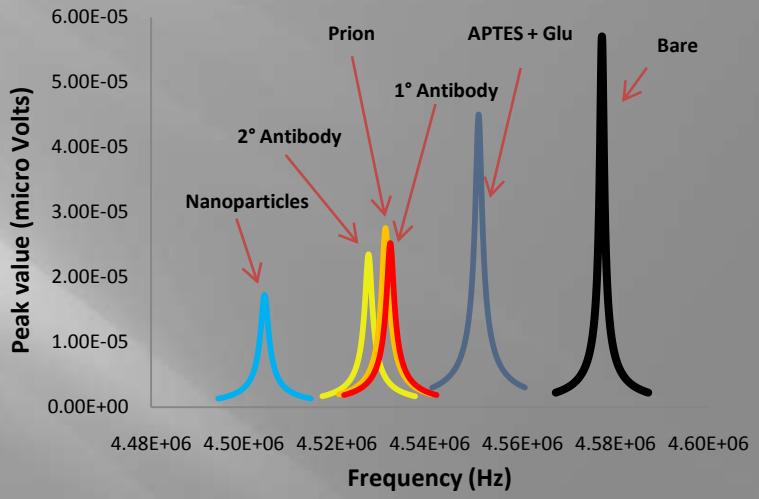
•Carrel and Lomas, 1997, *Lancet*
•Pan, Baldwin, et al. 1993, *PNAS*

Working Principle –

R.A. Montagna, H.G. Craighead, M. Varshney and P. Waggoner, Cornell University

$$f \alpha \frac{1}{m} \qquad \Delta f \alpha \Delta m$$





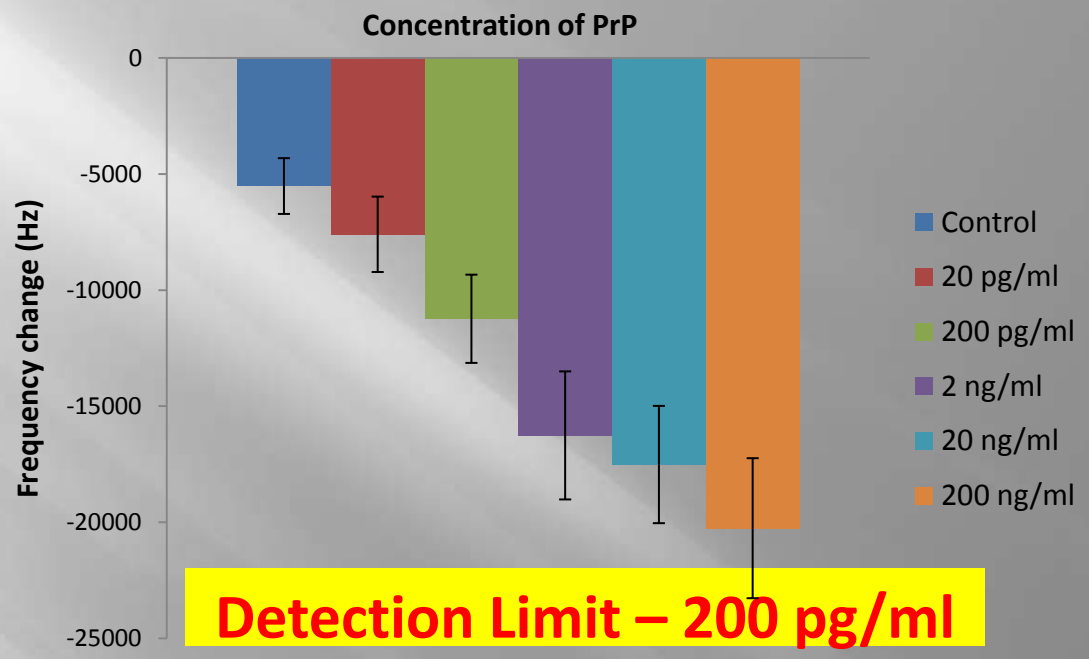
Frequency response for different steps

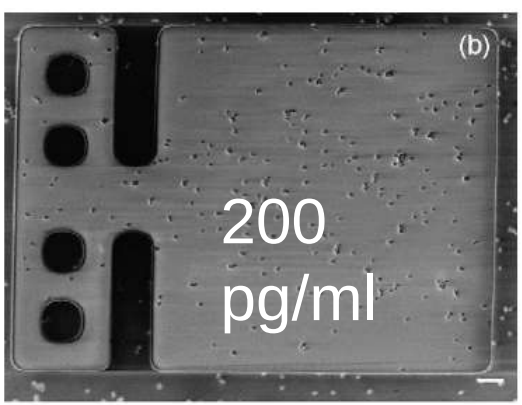
Enhanced Specificity – use of two antibodies

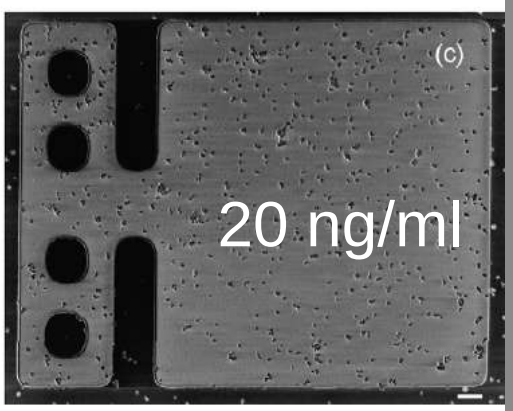
Magnetic nanoparticles can be used for the concentration and purification from blood samples

Prion detection in Blood Serum

R.A. Montagna, H.G. Craighead, M. Varshney and P. Waggoner, Cornell University



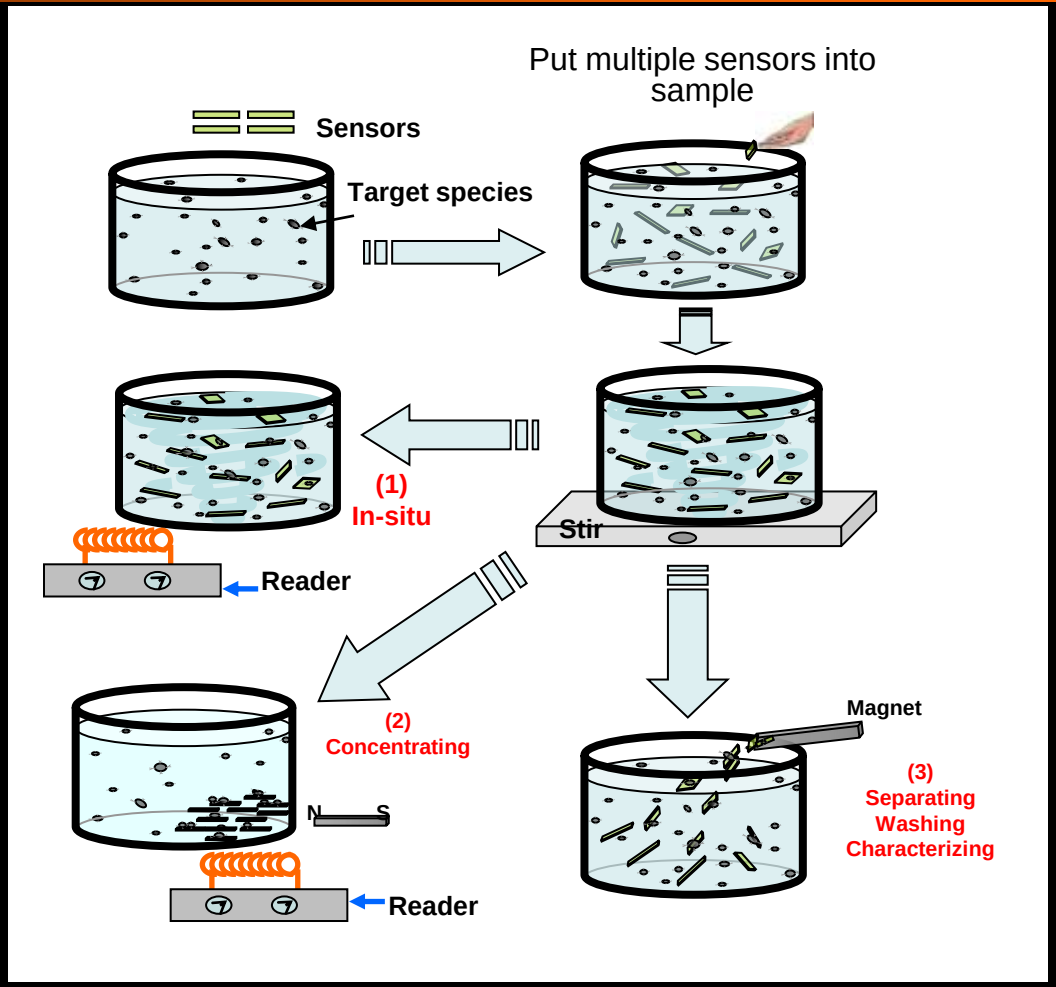




Multiple-sensor Approach

MSP provides a way to bring sensors to target !

➔ Truly free-standing



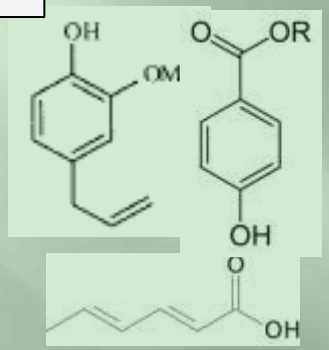
Significantly increase the ability to detect target species in liquid samples with very low concentration

Auburn University Samuel Ginn College of Engineering

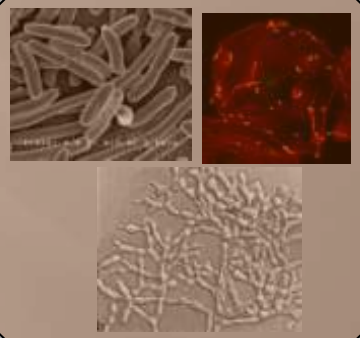
Auburn University DFS Detection and Food Safety Center

The Fundamental Issue !!

Antimicrobials



Pathogens



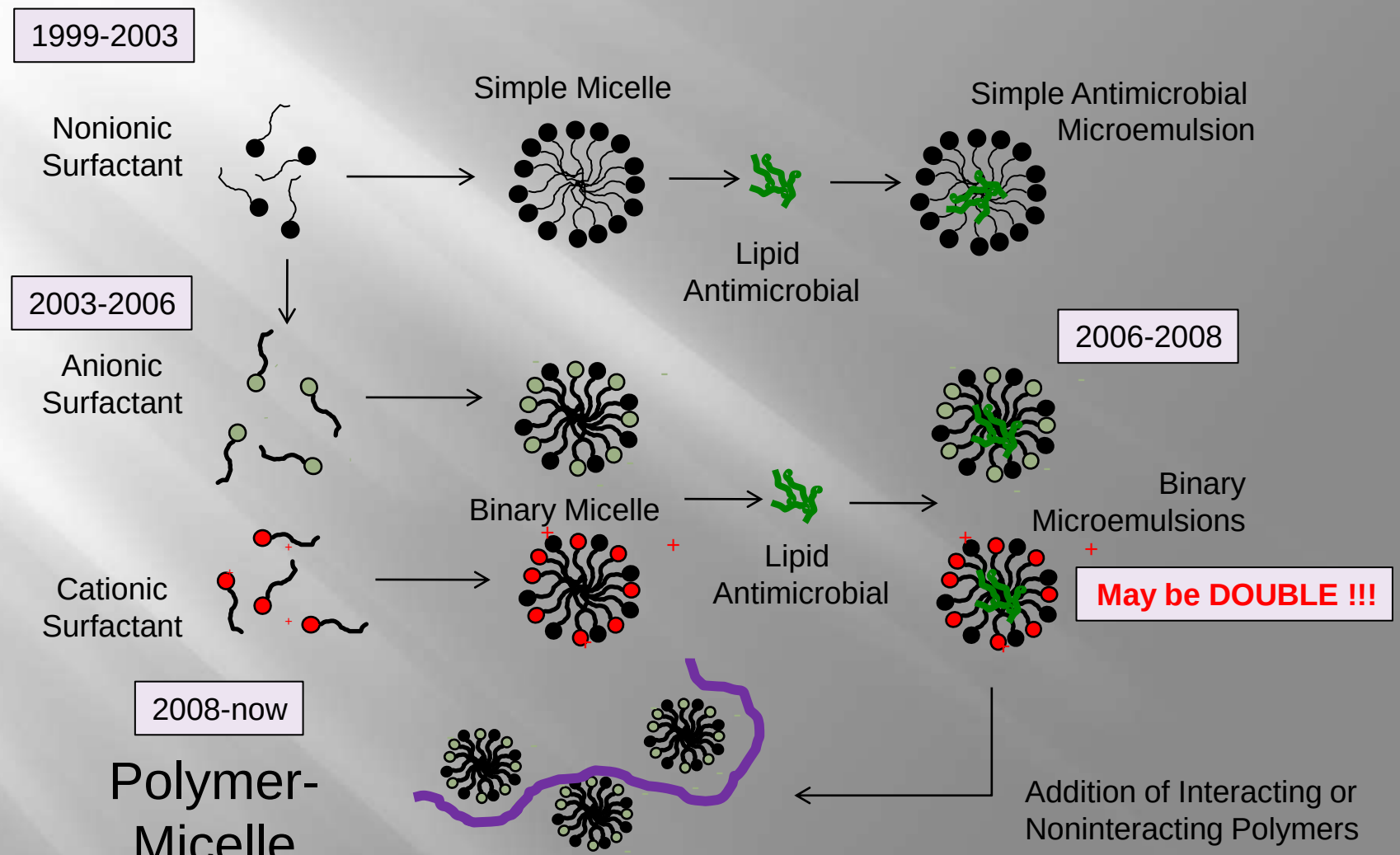
Model Micro-Systems

Foods

Ingredient Interactions!!!

Courtesy of J. Weiss

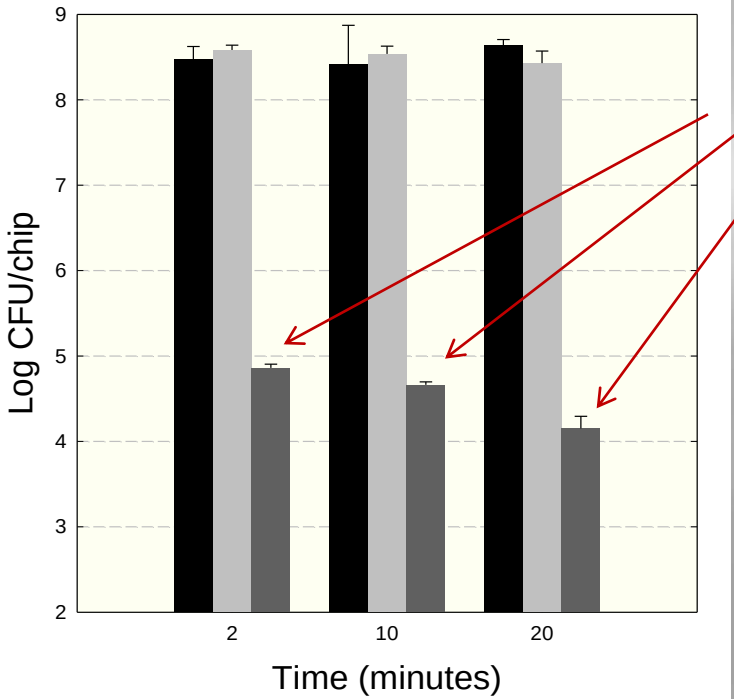
Micelles as Carriers of Hydrophobic or Amphiphilic Antimicrobials – Development History



Courtesy of J. Weiss

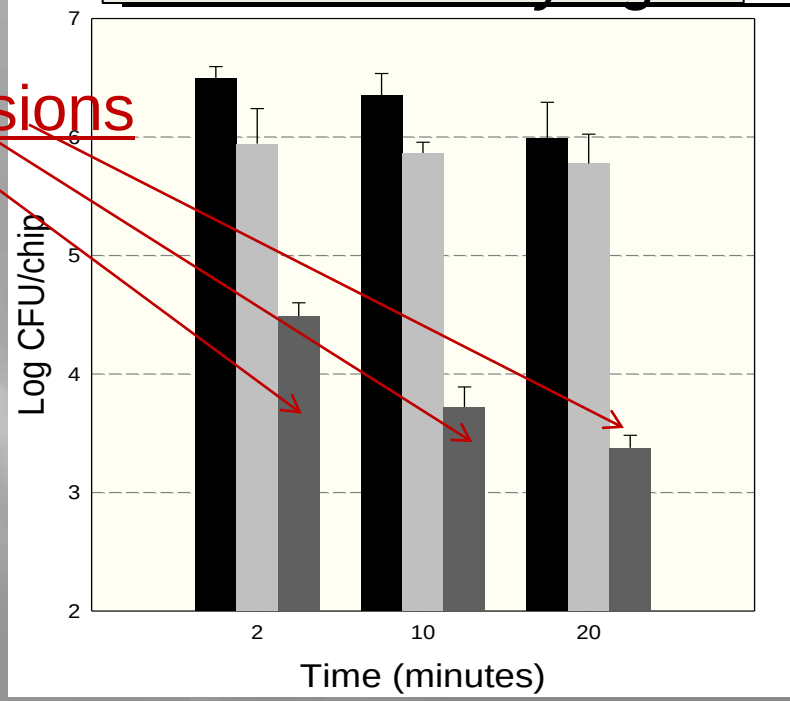
Inactivation of CDC Reactor Biofilms By Eugenol-Containing Microemulsions

Escherichia coli O157:H7 932



Microemulsions

Listeria monocytogenes

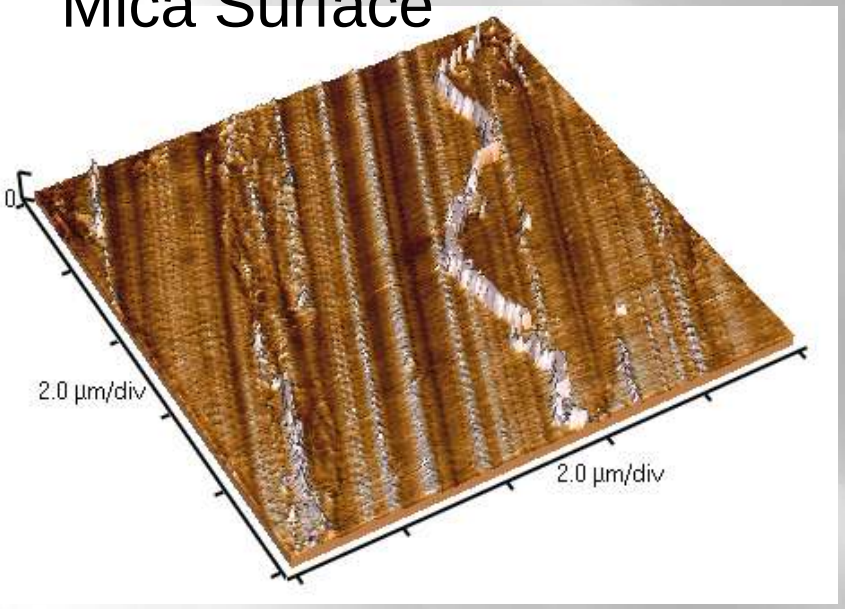


Cell numbers (log CFU/chip) of *Escherichia coli* O157:H7 (strain 932) and *Listeria monocytogenes* (strain 101) 48-h biofilms treated with distilled water (control), surfynol 5% and surfynol 5% + eugenol 0.9% for 2, 10 and 20 minutes. ■ Distilled water control, □ Surfynol 5% and ▩ Surfynol 5% + eugenol 0.9%.

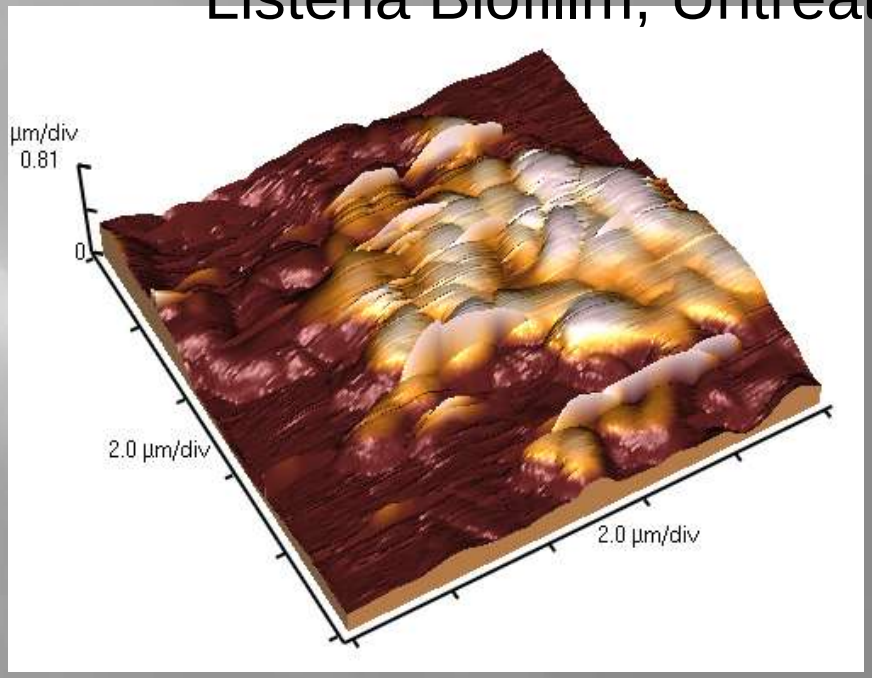
Micellar based systems also effective against "true" pathogenic biofilms
→ again direct addition does not show comparable effects

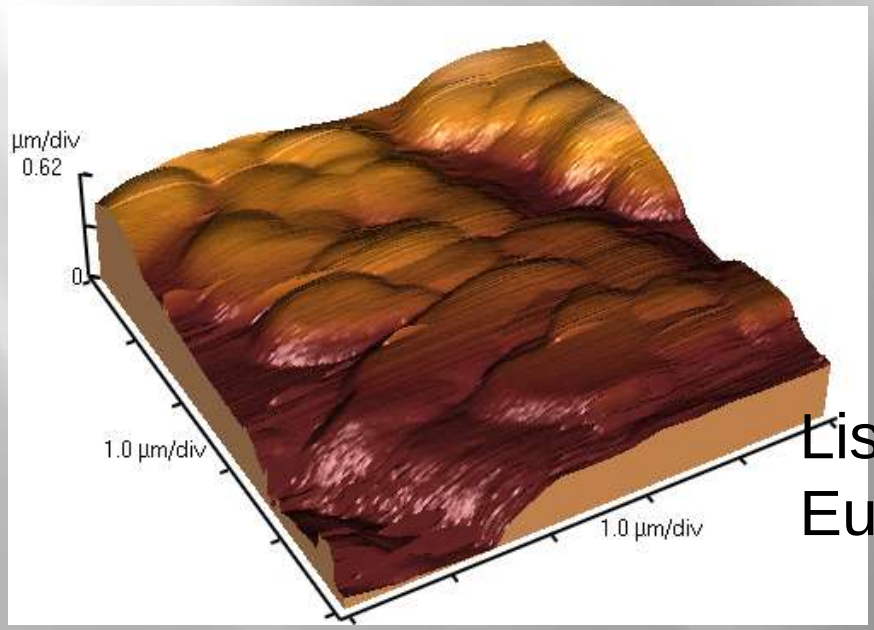
Atomic Force Microscopy of Treated Biofilms

Mica Surface



Listeria Biofillm, Untreated





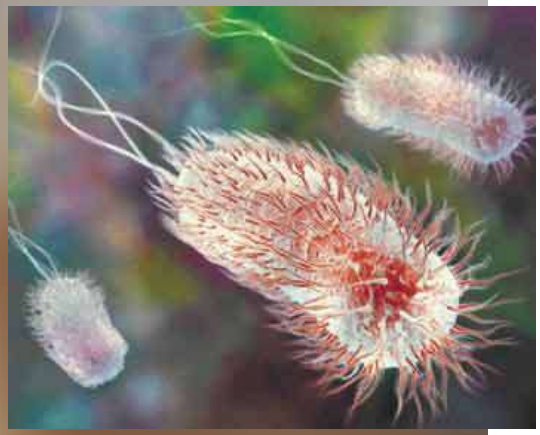
Listeria Biofilm, Treated With Eugenol Microemulsions

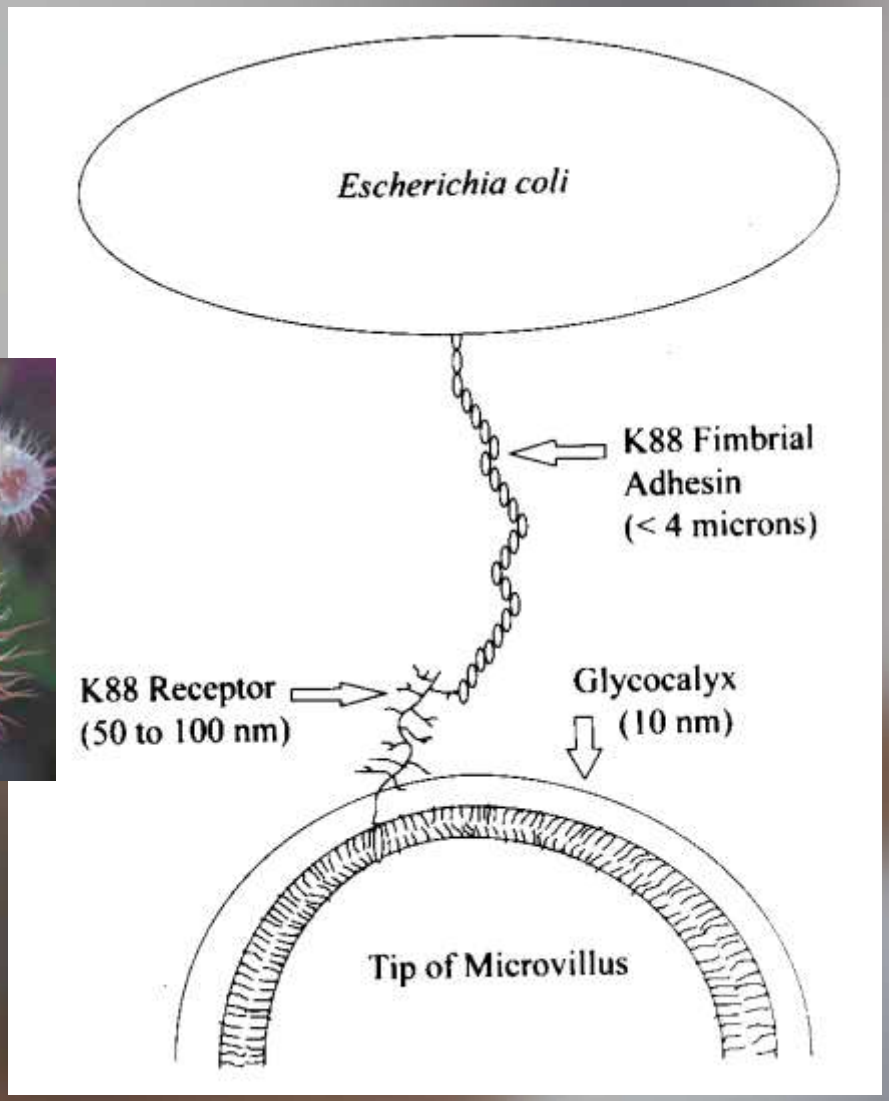
AFM Shows Evidence of Loss of Integrity of Biofilms….

Courtesy of J. Weiss

Food Safety Intervention

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

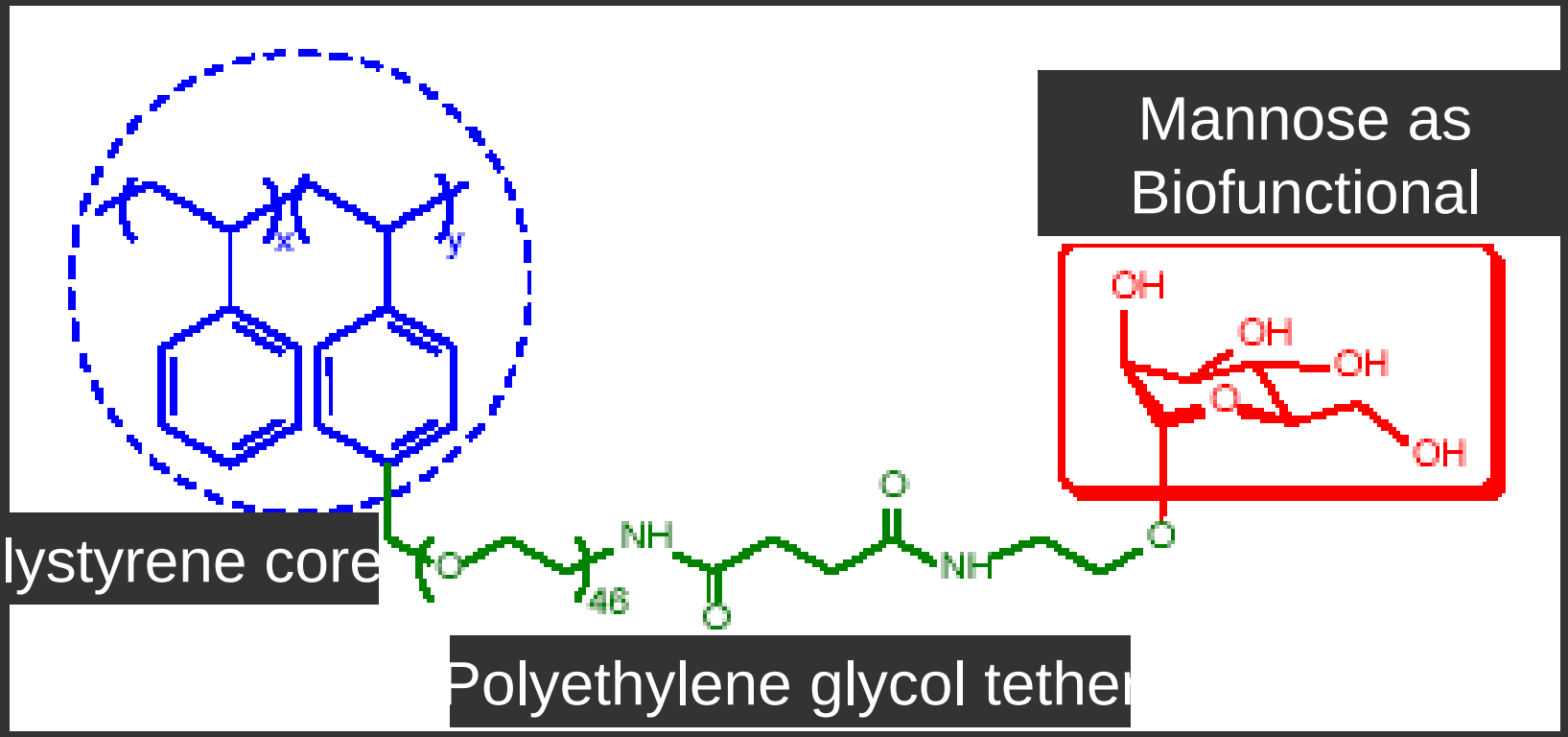




Bacterial Binding to Host is Mediated by Adhesins

(Latour, etc. Clemson University

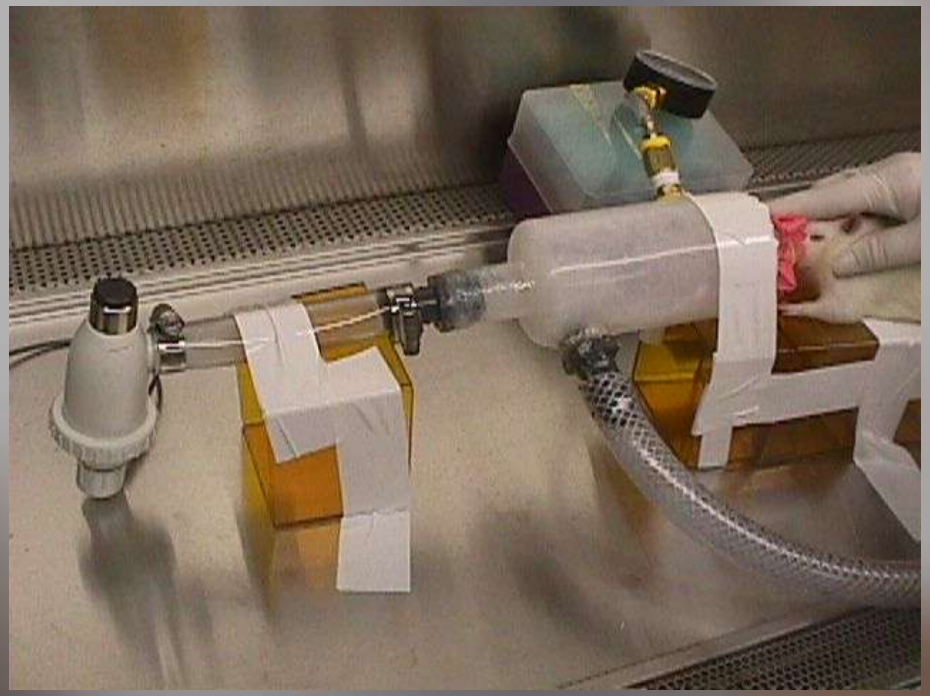
Nanoparticle Chemical Structure: Mannose Functionalization



(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)

Photocurrent Generation by a PSI-Modified Electrode

Photosystem I (PSI), a nanoscale protein complex from natural Photosynthesis, is extracted from spinach purchased at a local grocery store. When attached to an electrode surface, PSI can photo-catalyze electro-chemical reactions that drive an electric current through an external circuit, like a photo-activated battery.

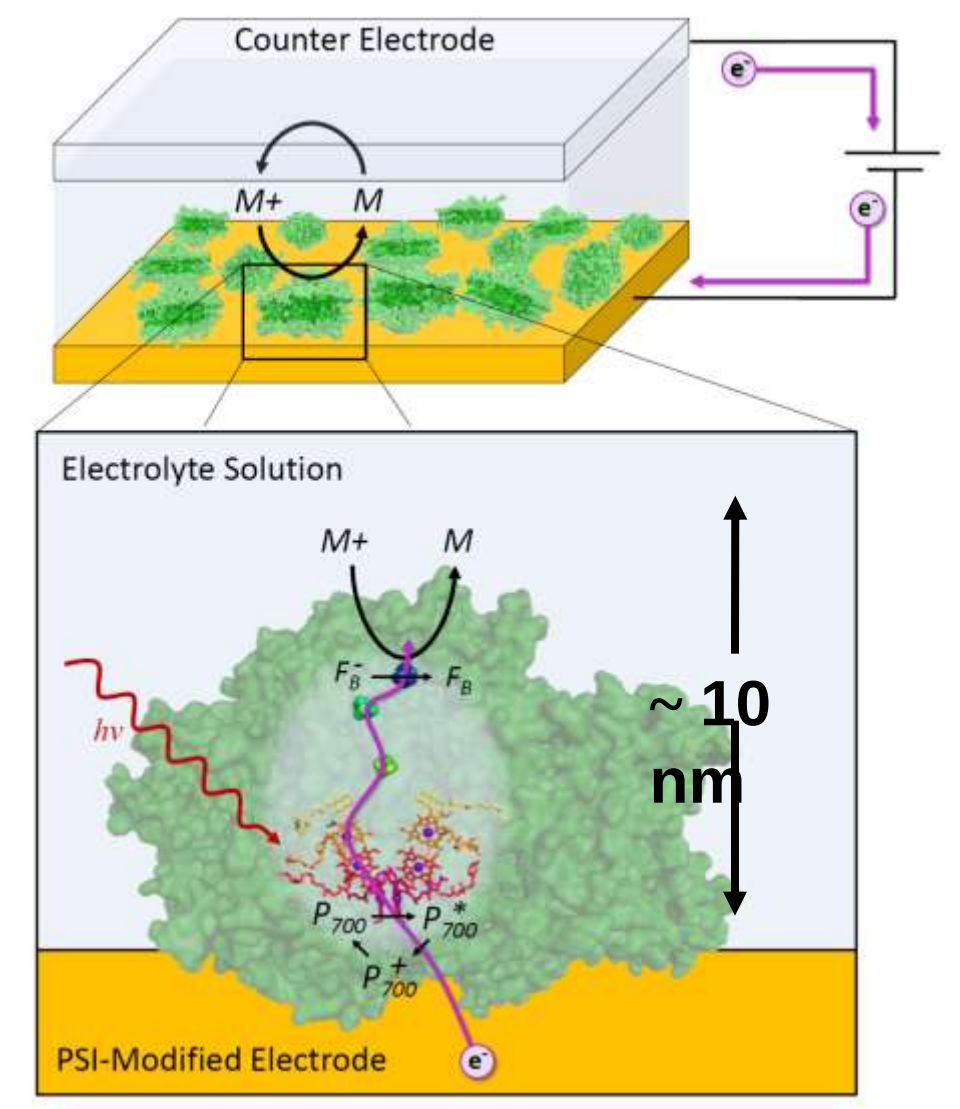
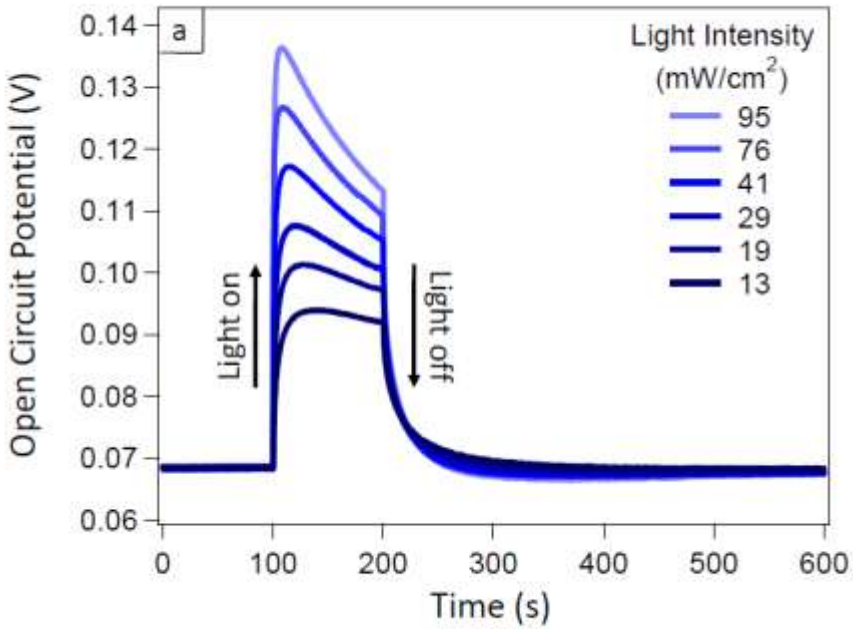
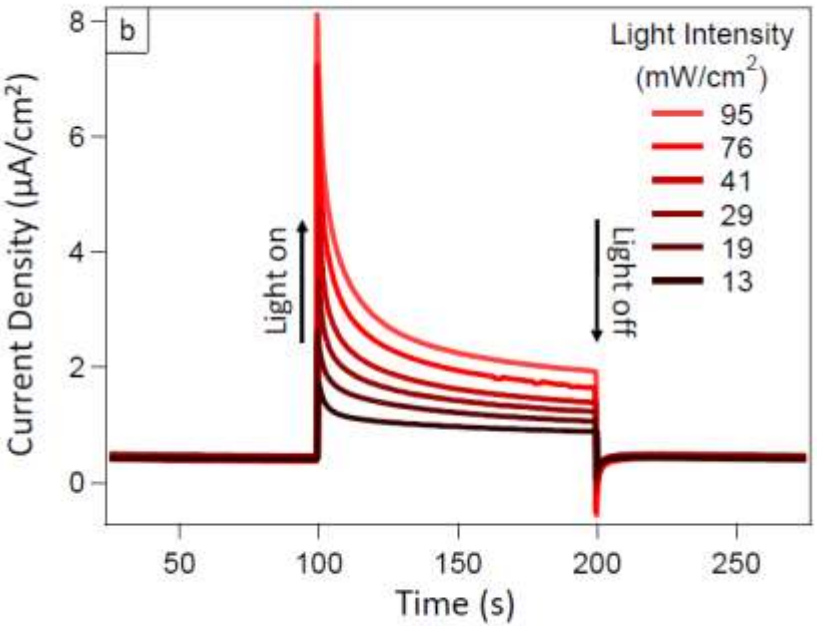


Figure courtesy of Peter Ciesielski





While still low compared to mature silicon photovoltaic technology, the photocurrent produced by this device represents an increase of 10,000 x in less than 3 years over previously reported photocurrents produced by PSI-modified electrodes.

Ciesielski, P. N.; Hijazi, F. M.; Scott, A. M.; Faulkner, C. J.; Beard, L.; Emmett, K.; Rosenthall, S. J.; **Cliffel, D. E.; Jennings, G. K.,** Photosystem I - Based biohybrid photoelectrochemical cells. *Bioresource Technology* ***2010, 101, (9), 3047-3053.***

PSI-Based Photoelectrochemical Cells (5) in Series

This device produces a voltage comparable to that of a AA battery. It's most expensive component is the glass microscope slide that serves as the cell base (~30 ¢), and these devices have remained functional for over 300 days and counting.

Ciesielski, P. N.; Hijazi, F. M.; Scott, A. M.; Faulkner, C. J.; Beard, L.; Emmett, K.; Rosenthall, S. J.; Cliffel, D. E.; Jennings, G. K., Photosystem I - Based biohybrid photoelectrochemical cells. *Bioresource Technology* ***2010, 101, (9), 3047-3053.***

AFRI 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; 2010, Chicago)
- 2007, @ UC Davis
  - Toured the Molecular Foundry, Lawrence-Berkeley National Laboratory
- 2009, @ Santa Fe, NM
  - AFMNet, and Conjunction with CINT User Facility Conference
  - http://www.nifa.usda.gov/nea/technology/pdfs/website_meeting_agenda.pdf

Relevant EHS Research

Increasing Scientific Data on the Fate, Transport and Behavior of Engineered Nanomaterials in Selected Environmental and Biological Matrices

- http://epa.gov/ncer/rfa/2010/2010_star_nano.html
- Due: February 2, 2010
- ***Research 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*
- ***Research 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.*

Effective in touch with people to improve perception – C. Batt, Cornell University

Food Nanotechnology: Understanding the Parameters of Consumer Acceptance

Understanding of acceptable characteristics and uses of nanomaterials in food

- Establish the baseline parameters of acceptability of nanotechnologies in food. (Qualitative interviews)
- Understand *who* may be most open to nanotech foods (National survey)
- Understand factors that influence acceptance (Food sensory experiment)

PD: William K. Hallman, Rutgers U.

Closing thoughts

- Nanoscale Science and Nanotechnology for agriculture and food applications is still in its infancy
  - Exciting potentials has been demonstrated in diverse applications, hence fertile ground for innovations
  - Seeking benefits for people and the society – collaborative efforts of industry, government and academia to identify significant targets and move cutting edge research to realization of its impact
  - Responsible development and deployment of technologies
  - Strengthen science education, outreach, public engagement, and societal dimensions.

Thank You!

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