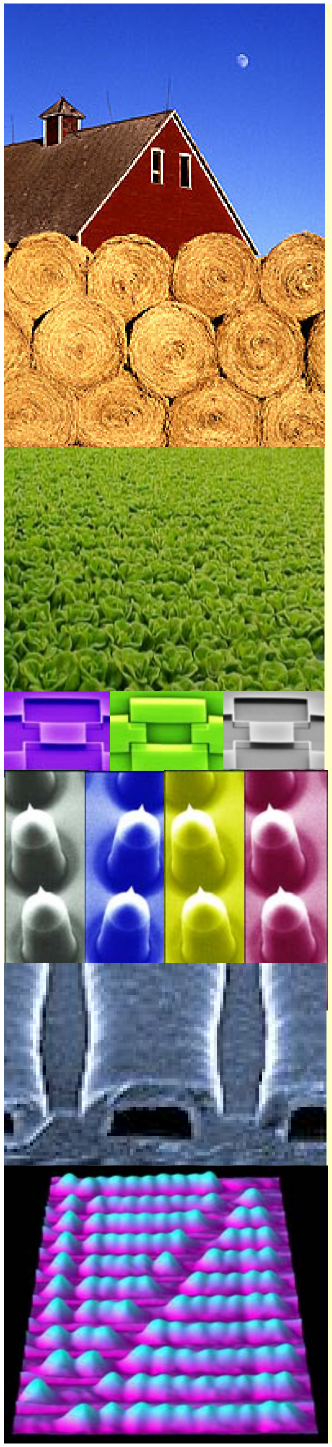


Nanotechnology Opportunities in Agriculture and Food Systems

Dr. Norman R Scott

Biological & Environmental Engineering

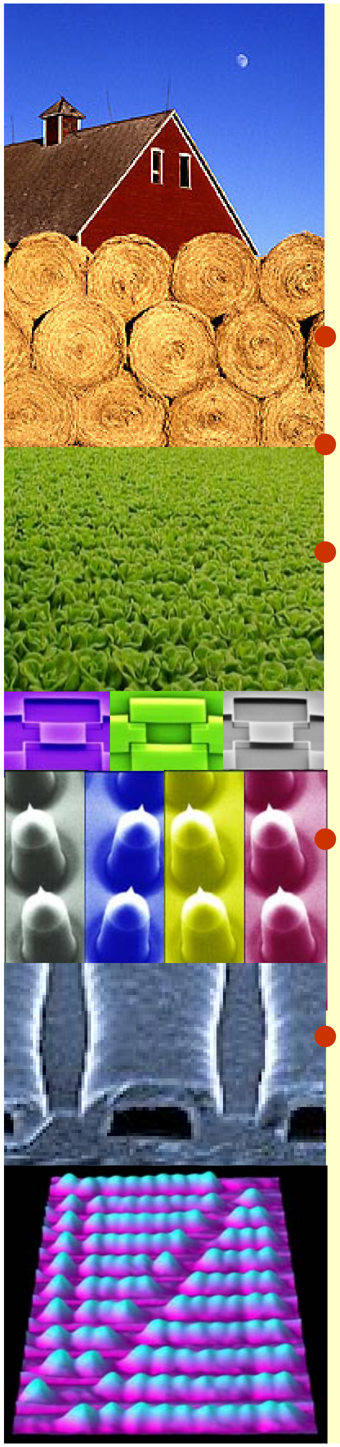
Cornell University

NSF Nanoscale Science & Engineering Grantees Conference

December 5, 2007

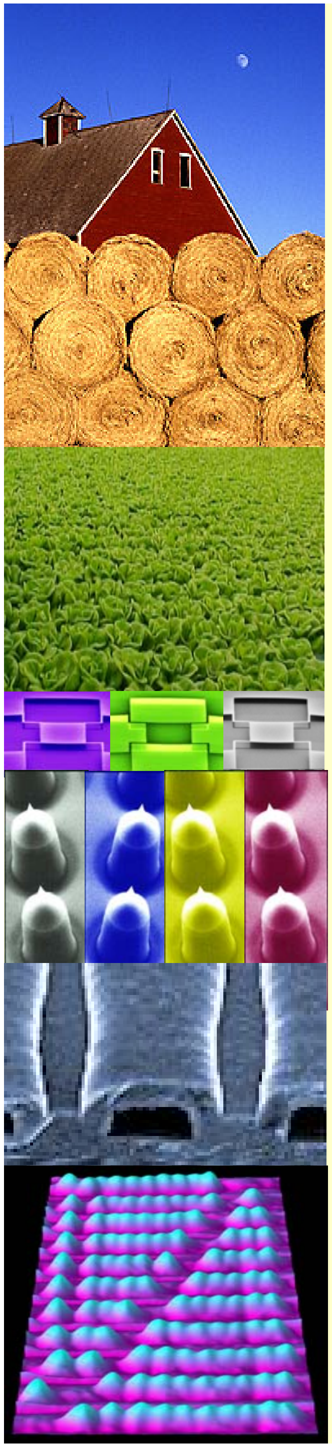
Arlington, VA

nrs5@cornell.edu



CONCLUSIONS/ASSERTIONS

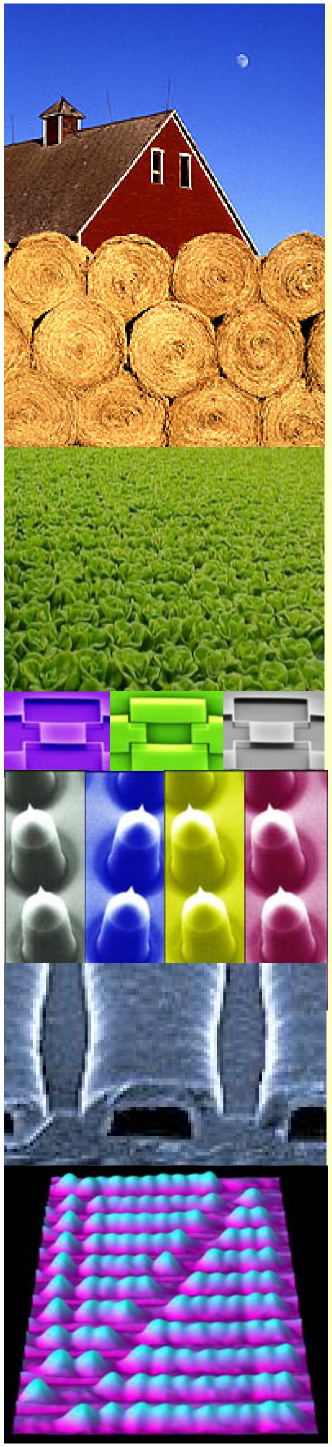
- An enabling technology
- Revolutionize agriculture and food systems
- Existing research demonstrates many examples of possibilities of nanotechnology
- Building blocks exist and can/will/are being integrated into commercial products
- Food safety/health, social and ethical issues can delay or derail advancements



US Population and labor force indicators (2001)

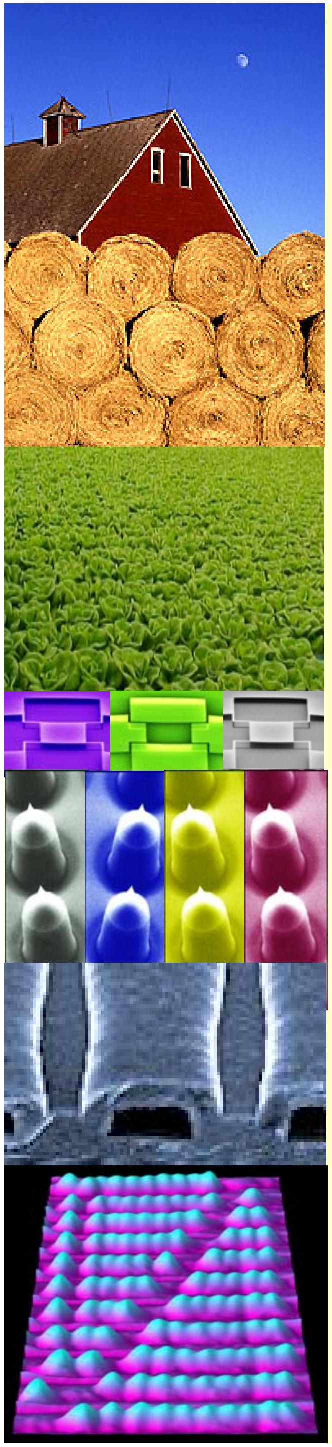
(FAO State of Food and Agriculture – 2003-2004)

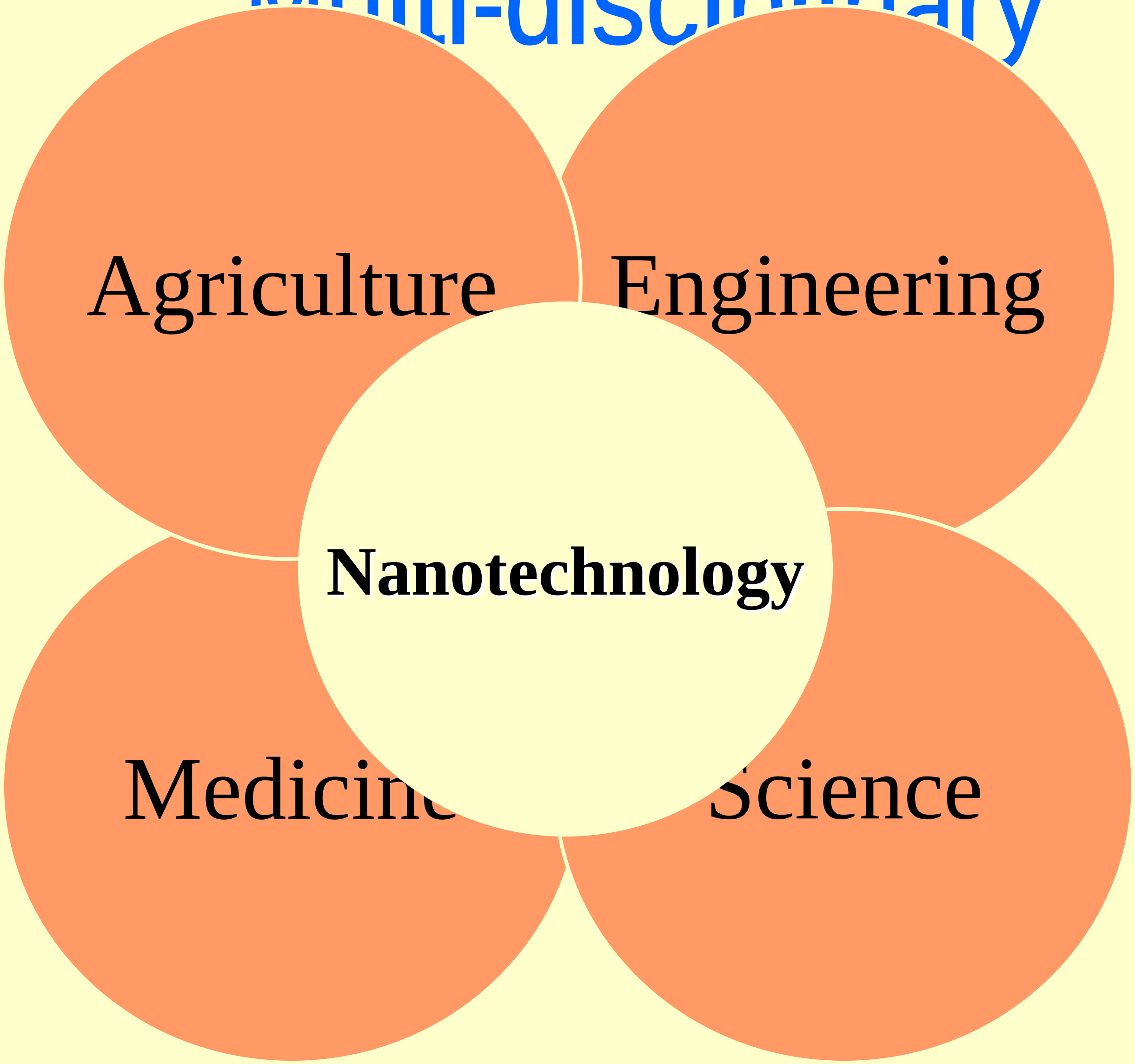
Total Population (thous.)	Rural Population (thous.)	Rural Population (%)	Agric. Population (thous.)	Agric. Population (%)	Economic Active Population (thous.)	Economic Active Population Agric. (thous.)	Economic Active Population Agric. (%)
285,926	**64,539**	**23**	**6,162**	**2**	**146,635**	**2,968**	**2**

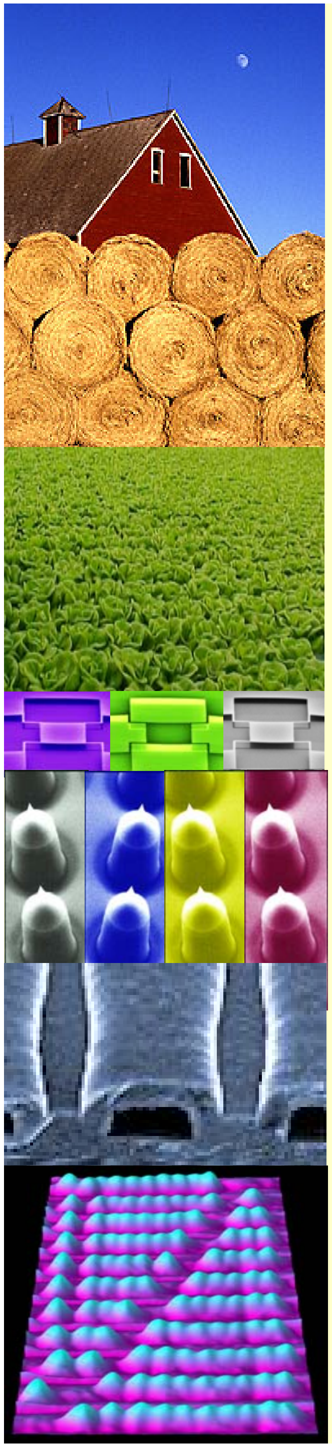


The total spent for all food consumed in the U.S. was $1,082.5 billion dollars in 2006, a 6.6 percent increase from $1,015.1 billion in 2005. The ERS/USDA indicates that spending on food away from home was 48.9% of the $1,082.5 billion in total food expenditures in 2006—spending for food at home was 51.1%. Families spent 9.9 percent of their disposable personal income on food—as disposable personal income continues to climb, the share spent on food declines.

Multi-disciplinary





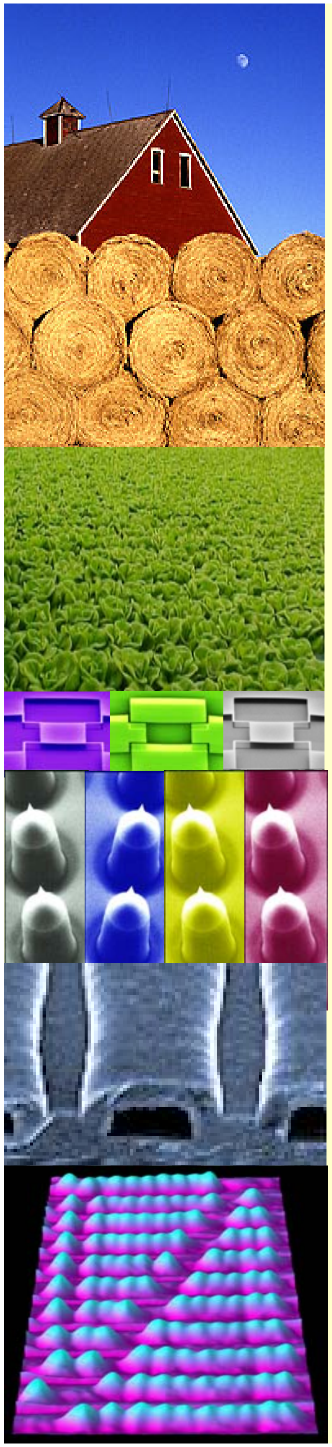


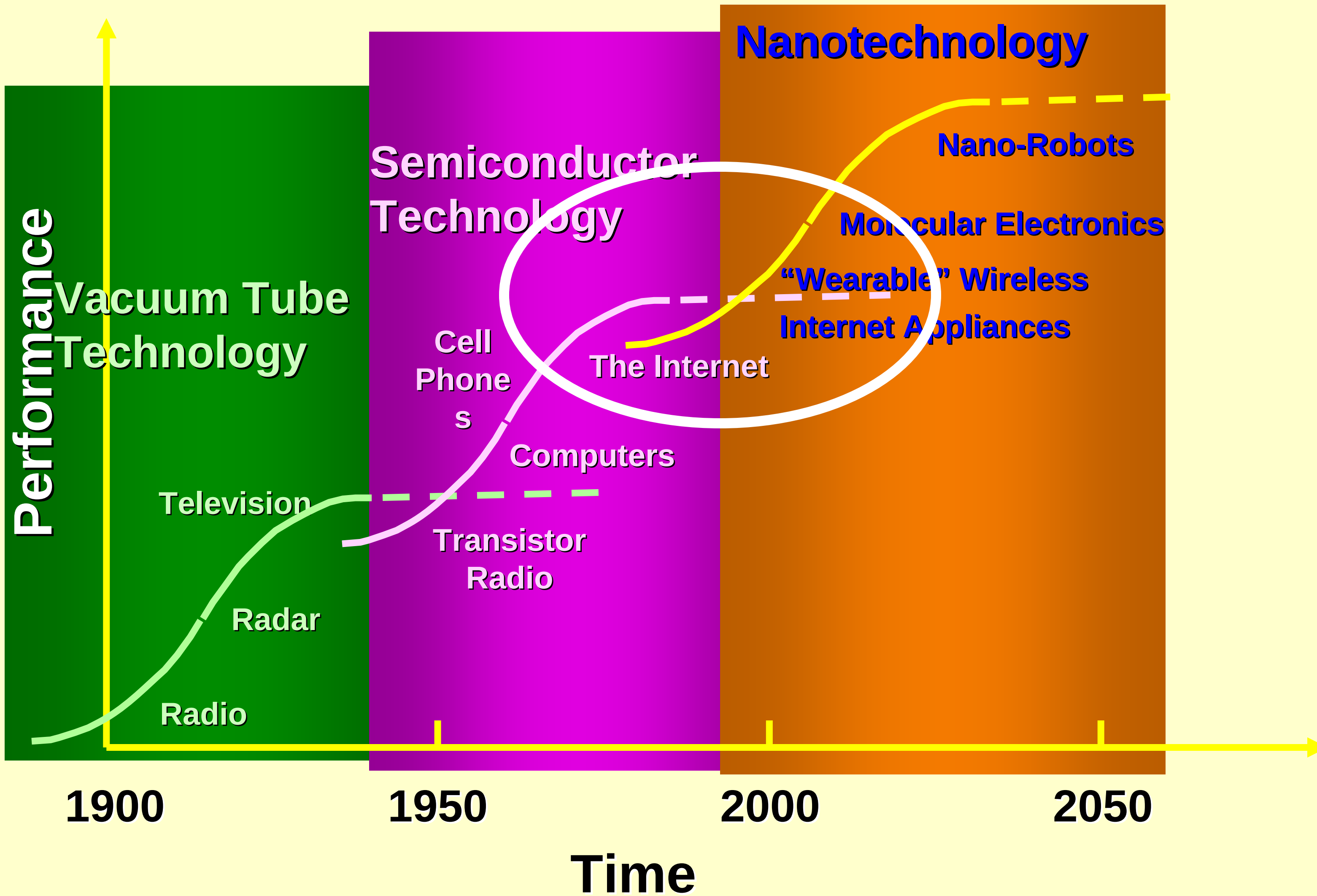
“Little” BANG Technologies

(convergence of nanotechnology, biotechnology, information technology and cognitive science- NBIC)

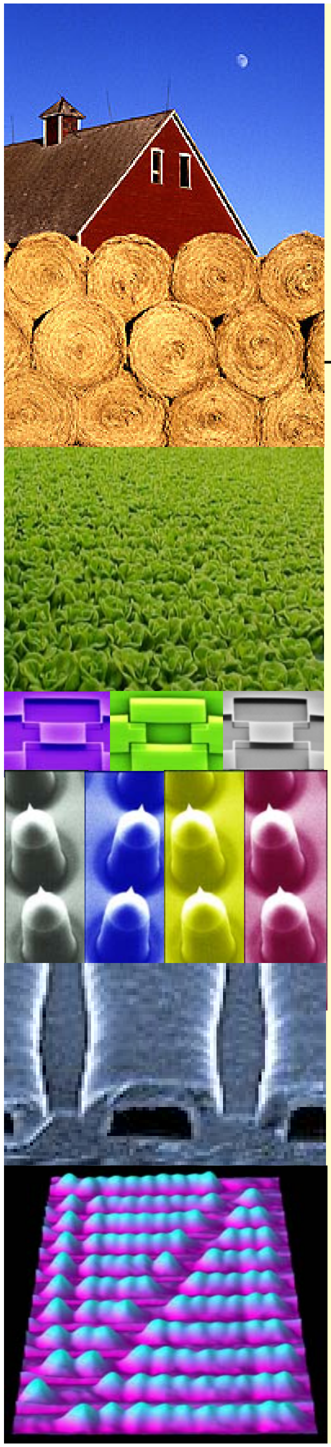
- **Bits- basic unit in information science**
- **Atoms- basic unit for nanotechnology**
- **Neurons- cognitive science deals with neurons**
- **Genes- biotechnology exploits the gene**

Evolution of Technologies





Cooper, 2001



A National Planning Workshop:

NANOSCALE SCIENCE AND ENGINEERING FOR AGRICULTURE AND FOOD SYSTEMS

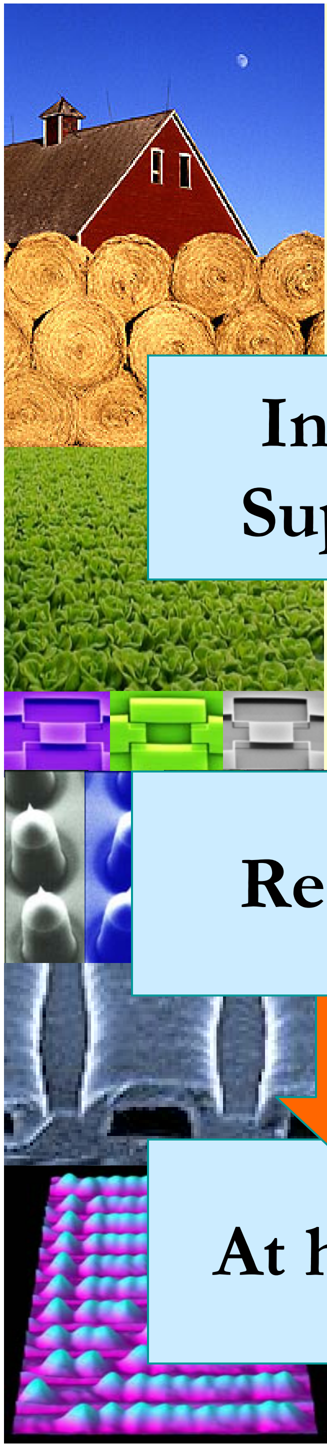
Workshop November 2002
Report September 2003

www.nseafs.cornell.edu

Norman R. Scott, Cornell University

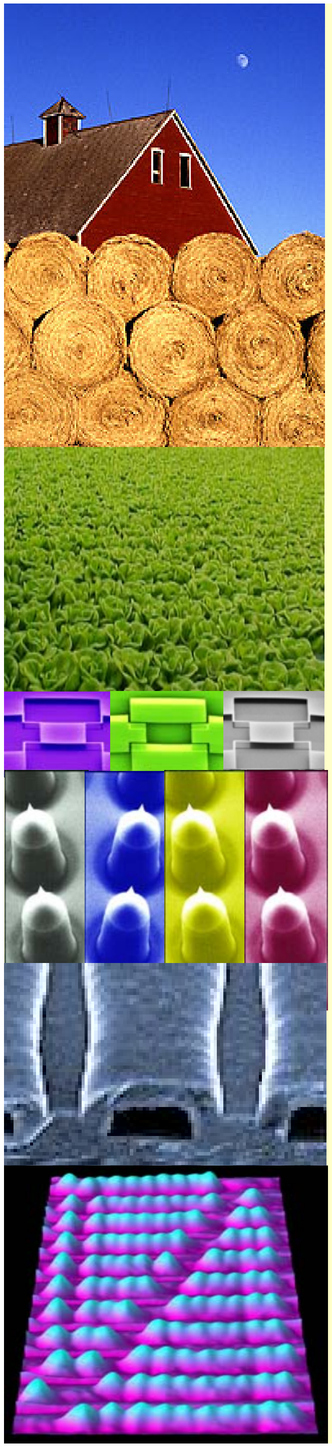
Hongda Chen, USDA

Organizing Principle: Agrifood Supply Chain



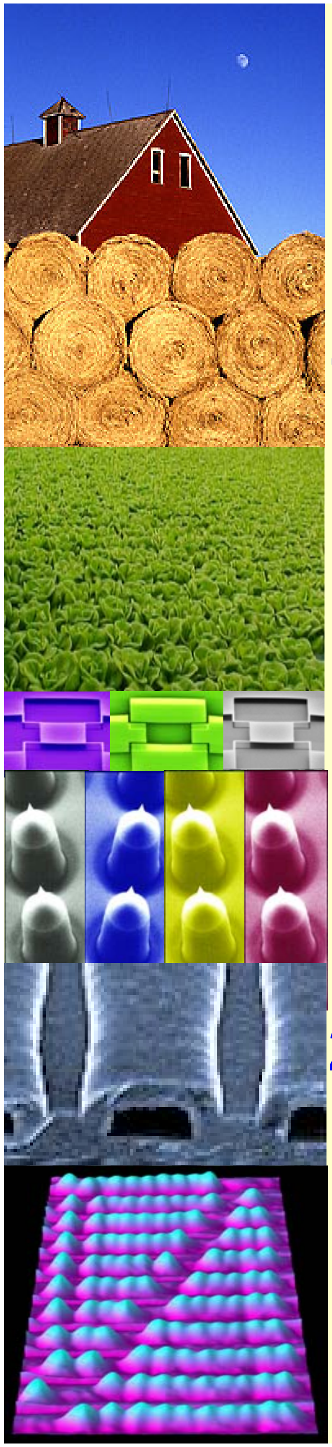
Input Supply → Farming/ Ranching → Processing → Transport → Wholesale → Retail → At home

Various types and combinations of nanotechnologies may be applied at any given point along supply chain.



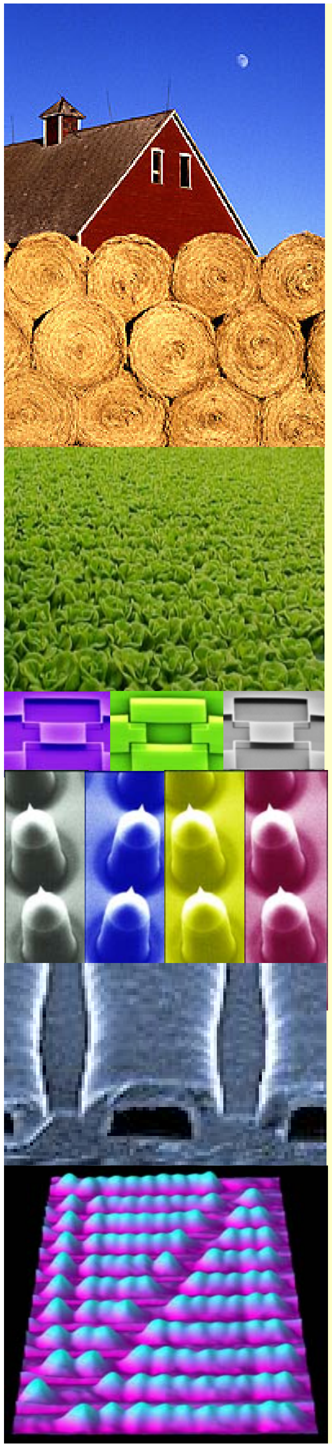
“Over the next two decades, the impact of nanoscale convergence on farmers and food will exceed that of farm mechanization or that of the Green Revolution”

etc group



Future Directions for Nanotechnology in Agriculture and Food Systems

1. **Food quality and safety:**
   - presence of residues, trace chemicals, viruses, antibiotics, pathogens, toxins
   - integrated, rapid DNA sequencing to identify genetic variation and GMO's
   - integrity of food during production, transportation and storage
   - reduce calories while retaining flavor, powder suspension, keeping foods fresh, micronutrients
2. **Animals health monitoring:**
   - developmental biology
   - presence of residues, antibiotics, pathogens, toxins
   - disease detection, diagnosis, therapy & prevention
   - integrated health monitoring/ therapeutic intervention



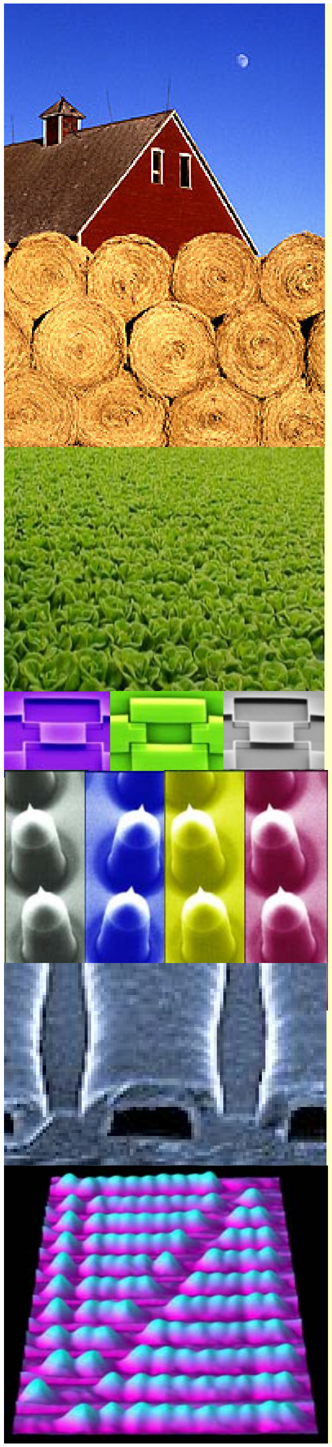
Future Directions for Nanotechnology in Agriculture and Food Systems

3. Plant systems:

- "smart field systems" to detect, locate, report and direct application of water, fertilizers & pesticides
- bio-selective surfaces for early detection pests & pathogens
- laboratory-on-a-chip proteomics technology for microbial biocontrol agents

4. Environmental issues:

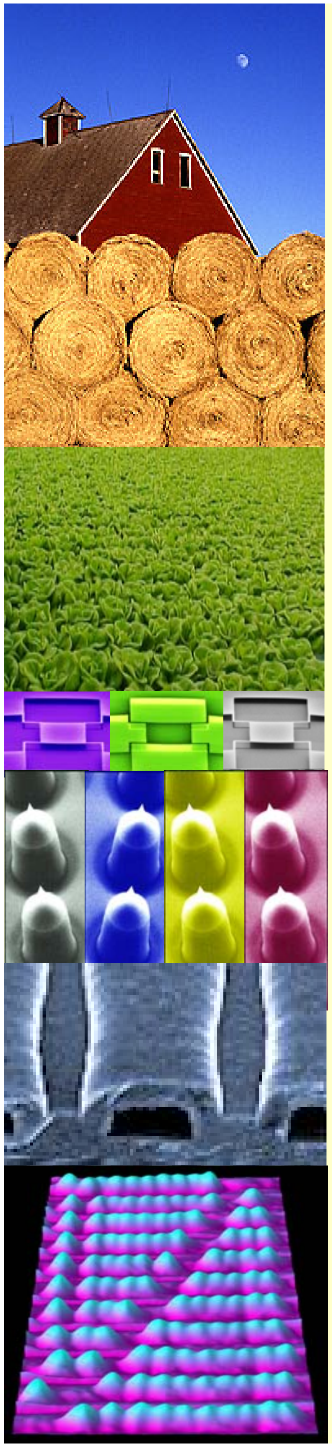
- nanophase soil additives (fertilizers, pesticides soil conditioners)
- nanoparticles in transport & bioavailabilty of nutrients
- understand soil as a complex nanocomposite
- land, water and air pollution (detection & remediation)



Budget Proposal

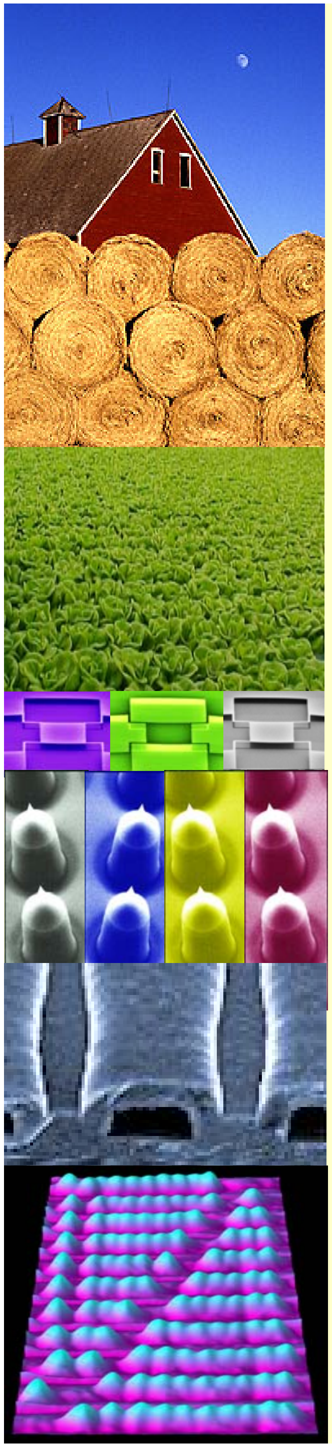
	Million $
Fundamental Research (PI Initiated) (6 areas* x 3 projects/area x $250K/project)	**4.5**
Theme Area Challenge (Multidisciplinary) (6 areas x 2 projects/area x $350K/project)	**4.2**
Centers of Excellence (4 regional @ $5M/center/yr) (Public outreach-1% of budget= $50K/center)	**20.0**
Research Infrastructure (Specialized equipment @ $5M/yr)	**5.0**
Education Graduate Fellowships ($32K x 50/yr.) Postdoctoral Training ($60K x 15/yr.) Professional Development ($10K x 10/yr.) Public Outreach & Education (see centers of excellence)	**2.6**
TOTAL	**$36.3 M/yr**

(*sensors, identity preservation, smart treatment & delivery, smart systems integration, molecular & cellular biology, & materials science)



Reality USDA/CSREES!!

	Annual $
FY 2004	$2 M (actual)
FY 2005	$3 M (actual)
FY 2006	$4 M (actual)
FY 2007	$4 M (request/ actual 0)
FY 2008	$3 M (request)



FY 2004 Grantees

Photosystem I Nanoscale Photodiodes for Creating Photo-chemical Devices (Jennings & Cliffels, Vanderbilt)

Using Nanotechnology to Identify and Characterize Hydrological Flowpaths in Agricultural Landscapes (Walter & Luo, Cornell)

Nanoscale Sensor Materials Incorporated in Near Nanoscale Fibrous Mats for Detection of Airborne & Condensed Phase Biohazards (Frey, Joo & Baeumner. Cornell)

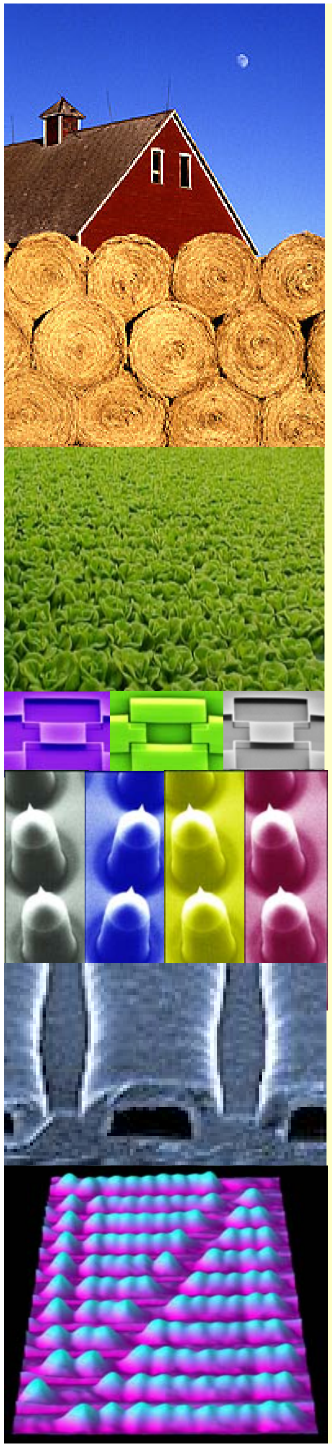
Virus Recognition Using Antibody Sensor Arrays on Self-Assembled Nanoscale Block Polymer Patterns (Kofinas, MD)

Use of Nanofabricated Surfaces for Studying Colonization & Dispersal of Bacteria in Water Conducting Plant Vessels (Hoch, Burr & Smart, Cornell)

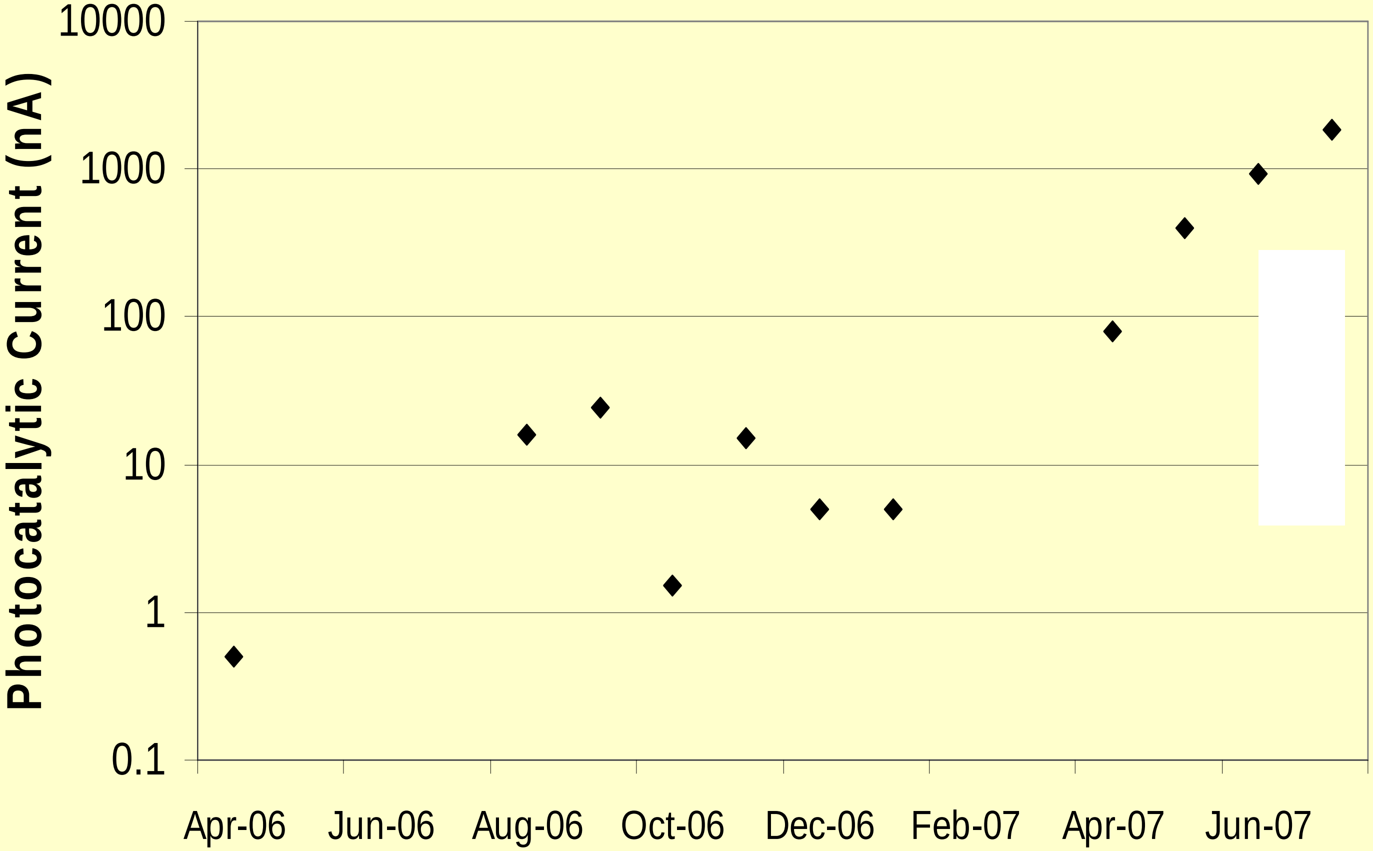
Engineering Ultrasensitive Electrically Addressable Nantube-wire Sensors Through Controlled DNA Nanotube Interfacing (Kim, Deaton & Tung, Arkansas)

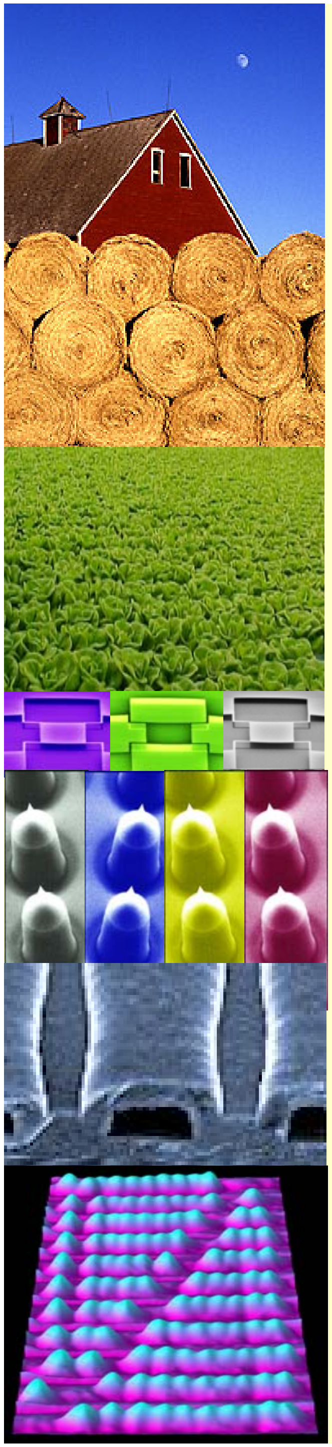
Protein Structure Sensors Through Molecular Imprinting: Applications Toward Prion Detection and Correlation (Britt, Utah State)

Development of Nanoscale Magnetostrictive Particles as Novel Biosensor (Cheng, Auburn)



Progress (Vanderbilt)





FY 2005 Grantees

Molecular Imprinted Polymers for Plant and Insect Virus Recognition (Kofinas, Culver, & Bentley, Maryland)

Nanoscale Self Assembly of Starch: Phase Relations, Formation and Structure (Ziegler and Runt, Penn State)

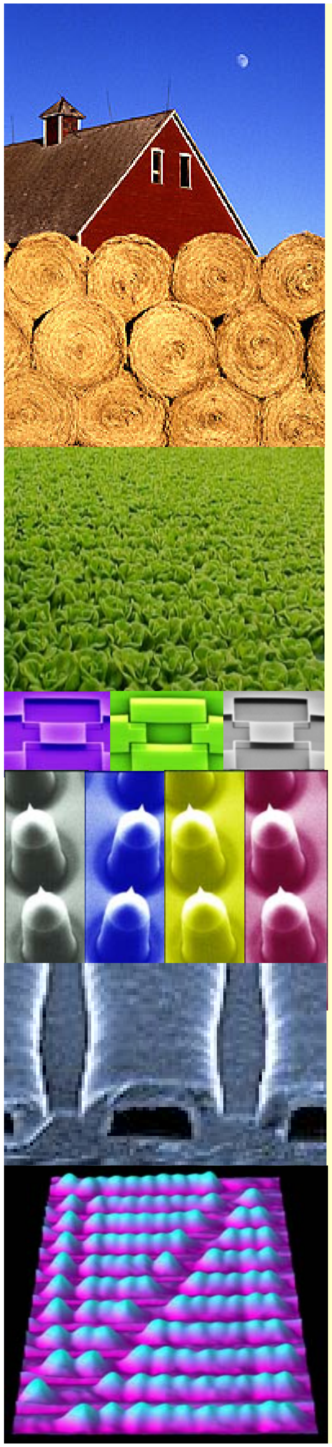
Zein Nanofabicated Biomaterials for Tissue Scaffolding (Padua, Crofts and Liu, Illinois)

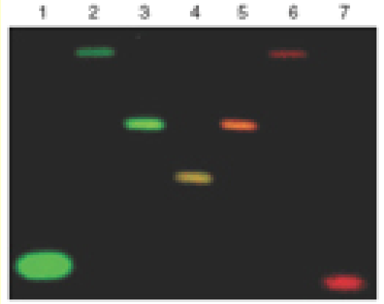
Engineering a DNA Nanobarcode to Track Bacterial Population in Agriculturally Important Microbial Environments (Luo, Walker and Chang, Cornell)

Development and Characterization of nanocomposite Materials for the Detection of Pore-forming Toxins (Rickus and Blunia, Purdue)

The Detection of Food-borne Toxins with Multifunctional Nanoparticles (Kennedy, Hammock and Gee, UC Davis)

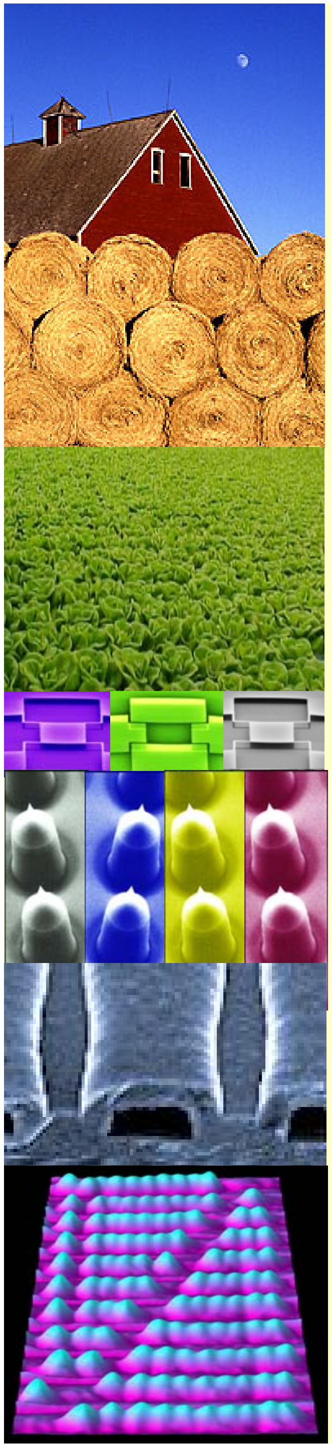
Development of Blood Protein Assays for Prions in Mammalian TSES (Lewis, and Brooks, Wyoming)



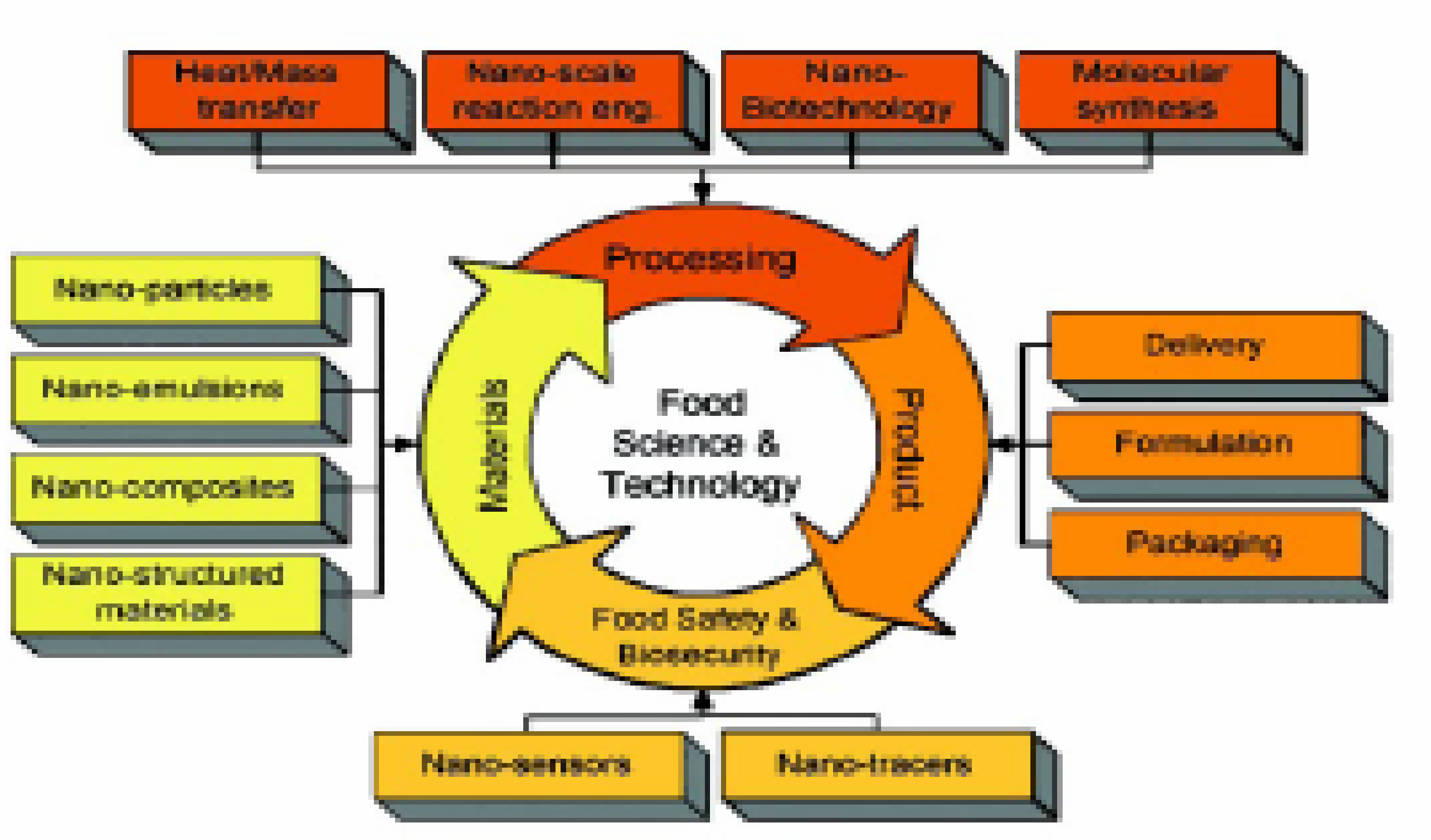


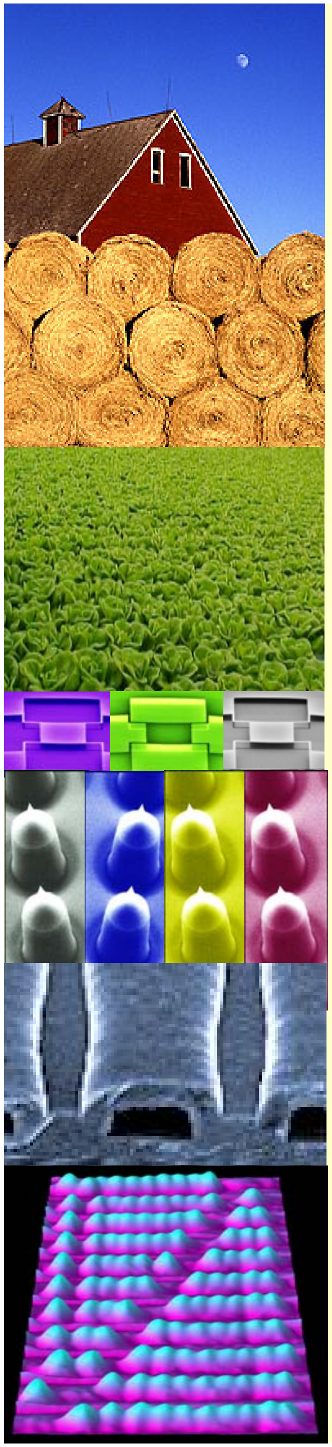
Luo and colleagues have developed a fluorescence nanobarcode-based DNA detection method to analyze samples containing pathogenic microorganisms such as the anthrax bacterium, Ebola virus or the severe acute respiratory syndrome (SARS) virus. The approach consists of fabricating Y-shaped, dendrimer- like DNA scaffolds that can form highly branched structures. A pathogen-specific probe is attached to one arm of the structure and green and red fluorescent particles in predetermined ratios (e.g., 1:1, 1:3, 4:1 or 3:2) to the other arms of the structure, effectively creating a specific ‘barcode’ for each target that could be identified based on fluorescence color (different mixes of red and green) and intensity.

A company, DNANO Systems formed



Nanotechnology in food science and technology (Moraru, et. al,2003)





FY 2006 Grantees

Multi-layered Surround SERS Nanosensor Array Syatem for the Rapid, Specific and Multiplexed Detection of Food-borne Bacteria and Toxins (Cullum, Chen and Chao, Maryland)

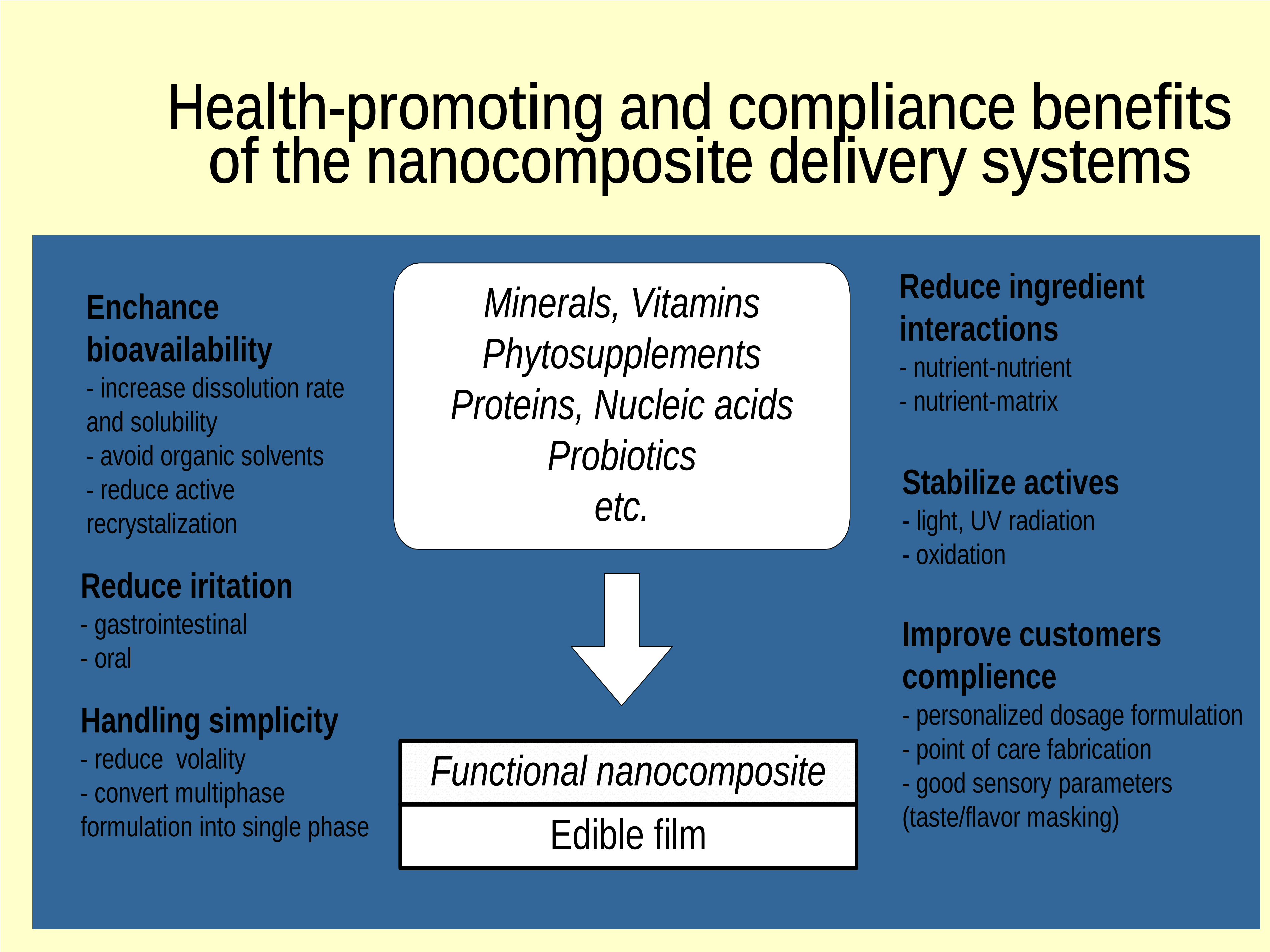
Self-amplifying Nanosensor for Direct Detection of Prions in Blood (Montagna, Innovative Technologies Int'l & Craighead, Cornell)

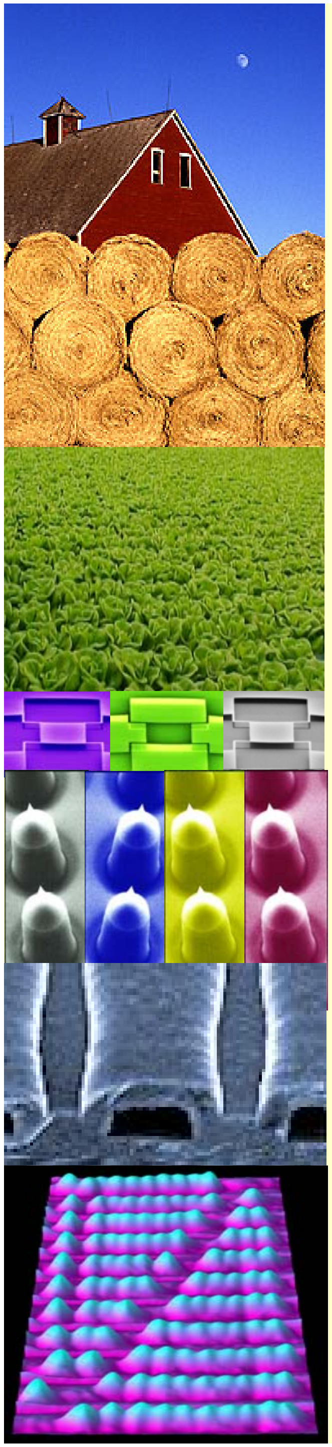
Luminous Edible Nanoparticles as Sensors of Food Quality and Safety (Ludescher, Rutgers)

Carbon Nanotube Arrays for Bacteria (Liu, Yap, Murthy & Thompson, Michigan Tech)

Food Micronutrient and Flavor Release in Nanostructured Matrices (Dungan,Ebeler and Phillips, UC Davis)

Fabrication of Nutraceutical Nanocomposites Utilizing Micro-dispensing Technology and Engineered Edible Films with Controllable Surface Morphology (Takhistov and Huang, Rutgers)


Health-promoting and compliance benefits of the nanocomposite delivery systems
Enchance bioavailability
- increase dissolution rate and solubility
- avoid organic solvents
- reduce active recrystalization
Reduce iritation
- gastrointestinal
- oral
Handling simplicity
- reduce volality
- convert multiphase formulation into single phase
Minerals, Vitamins
Phytosupplements
Proteins, Nucleic acids
Probiotics
etc.
Functional nanocomposite
Edible film
Reduce ingredient interactions
- nutrient-nutrient
- nutrient-matrix
Stabilize actives
- light, UV radiation
- oxidation
Improve customers complience
- personalized dosage formulation
- point of care fabrication
- good sensory parameters (taste/flavor masking)



FY 2006 Grantees (continued)

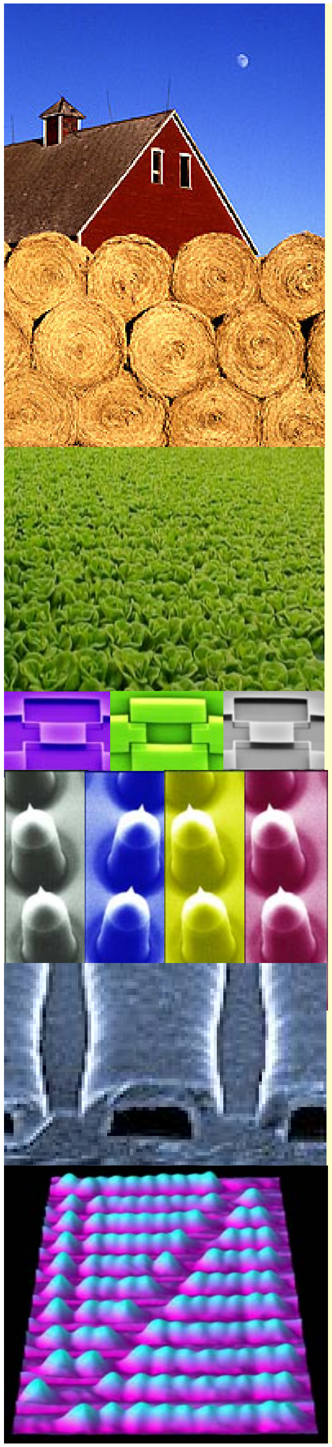
Synergistic Action of Electroporation and Controlled Release of Nanoparticle Additives to Promote Pathogen Lysis (Shapley and Tripathi, Columbia)

A Nanostructured Biosensor for the Detection of Microbial Pathogens (Ripp, Fleming, Sayler, Doktycz & Meleshko, Tennessee)

Exploratory Research : The Casein Micelle from Bovine Milk as a Carrier/Controlled Release Nanosystem (Harte, Davidson, Golden, Joy and Rouseff, Tennessee)

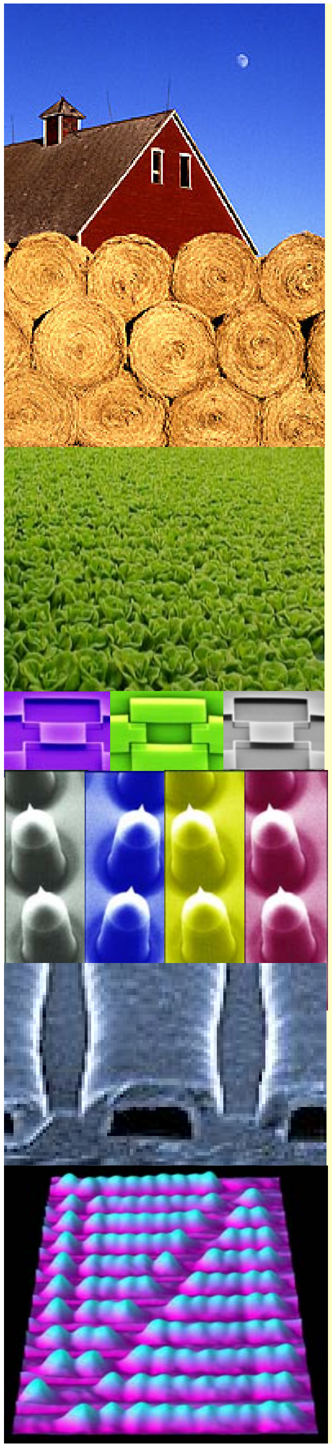
Bionanofabricated SERS-Based Arrays (Batt, Cornell)

A Soluble Nanoscale Self-Assembling Complex from Starch, Protein and Lipid for Healthy Nutrient Delivery (Hamaker and Campanella, Purdue)



Key Issues

- **Agrifood-biotech experience different than pharma-biotech**
- **Food is socially very sensitive**
  - **“Shoot it in my veins but don’t make me eat it.”**
- **Public perception “reactive engagement”**
  - **Little to no participation in technical applications, product development**



DOWN ON THE FARM

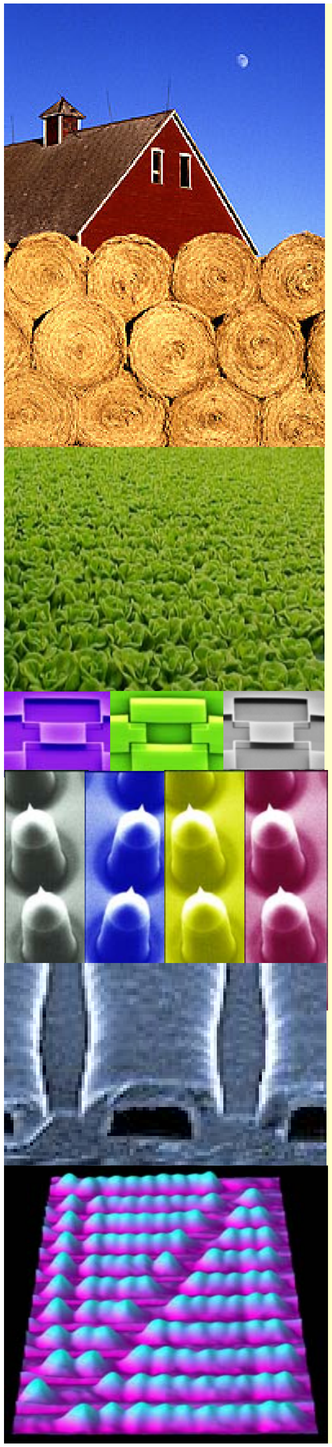
The Impact of Nanoscale Technologies on Food and Agriculture

etc group

Action group on erosion, technology and concentration

November 2004

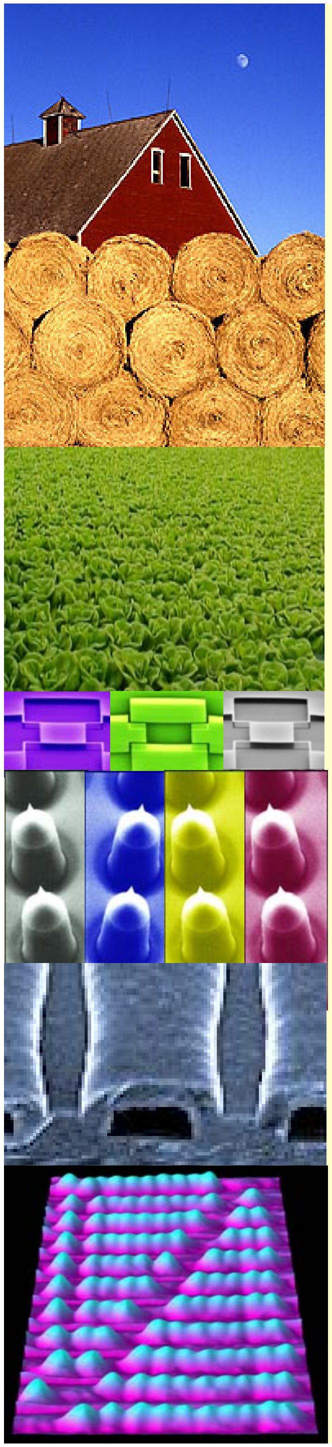
www.etcgroup.org



Social & Ethical Issues

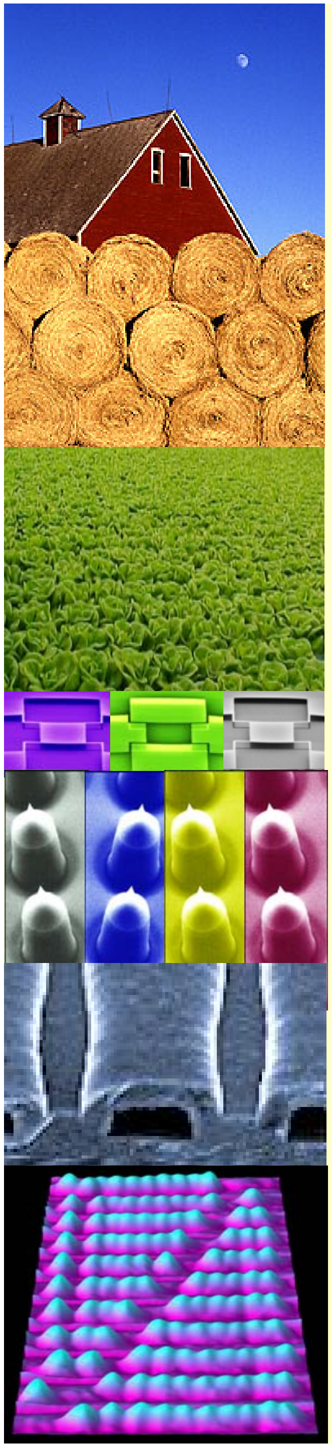
Gordijin (2003) characterizes the optimistic visionary perceptions as utopian dreams and the worst-case scenarios as apocalyptic nightmares. He argues that there is a need for a balanced ethical view and he has offered a six-step method to develop a more balanced view.

Nevertheless advances in nanotechnology in the agriculture and food system will likely continue to be a very contentious area for some time because of the concerns of many about the safety and health of food and others who are concerned about the possible implications on the structure of agriculture



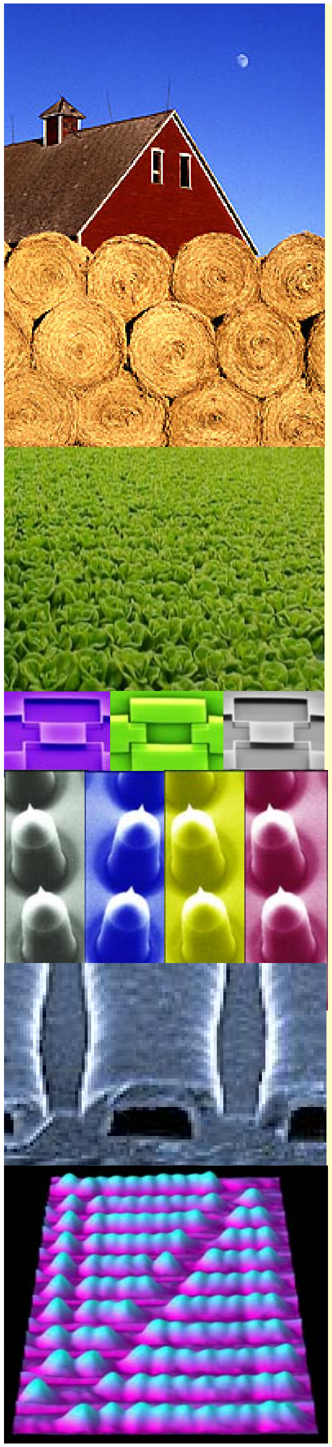
ISSUES

- Need regulatory regime to address nanoscale effects?
- Unknown societal & environmental effects of invisibly small?
- Effect of invisible, unlabelled & unregulated additives?
- Test ground for surveillance,social control & biowarfare?
- Unknown effects on environmental, health and biodiversity?
- Ownership and control issues?



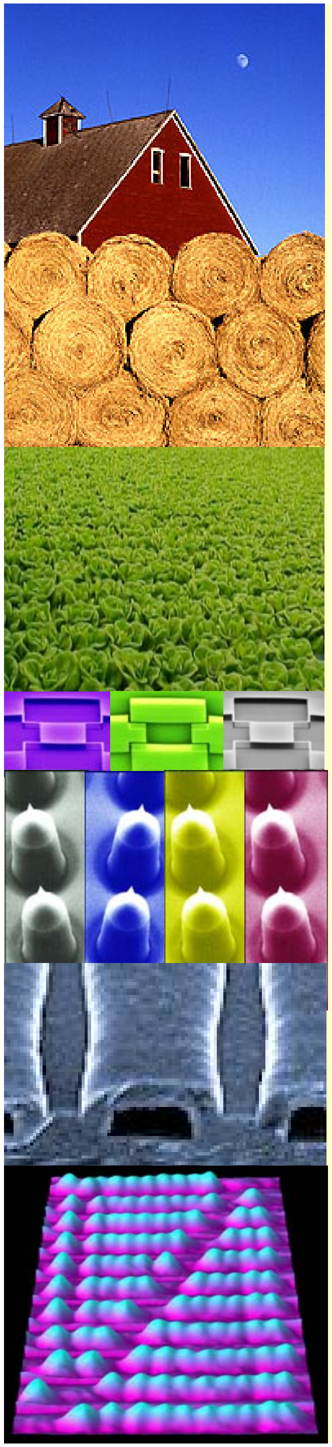
ISSUES (continued)

- **Who benefits? Poor are most vulnerable.**
- **Consolidation of corporate power, marginalizes farmers' rights**
- **Where do particles go?**



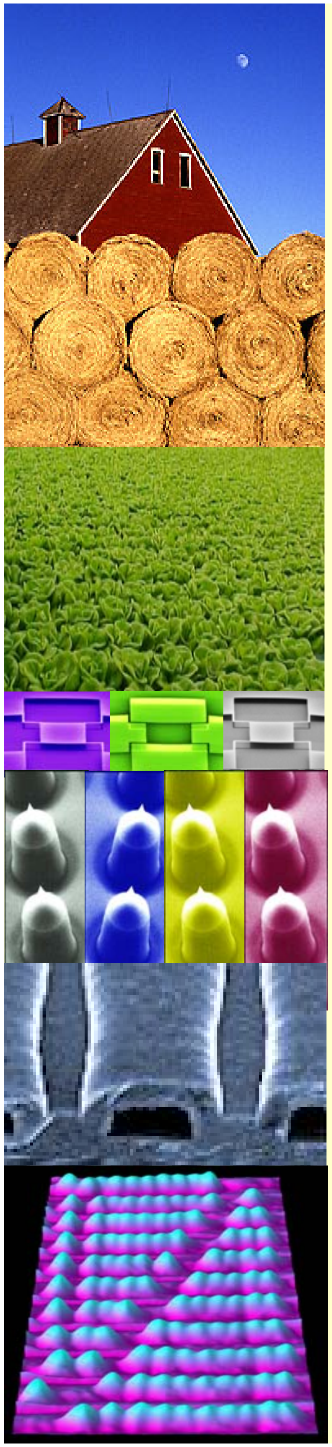
Reports- Nanotech

- **Woodrow Wilson Int'l Center (potential toxicity issues, oversight or regulations) Nature 2006**
- **Rice/UCL/LBS US consumers willing to use nano-containing products (even if health and safety risks) if potential benefits are high Dec, 2006 -Nature Biotechnology, 5500 survey responses- Zogby - drug, skin lotion, tires & refrigeration coolant**
- **Univ. Zurich-Trust key factor in public's acceptance- Lay persons perceptions of risks were higher than expert & experts have more trust in govt. agencies- Nature Nanotechnology, 2006**



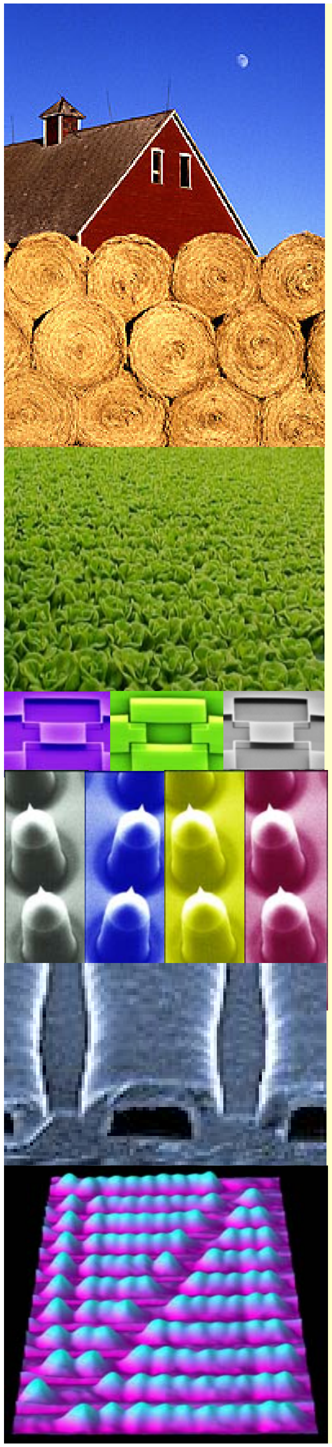
Reports- Nanotech

- US EPA Nanotechnology White Paper- 2007, Environ. Applications research, Risk Assessment Research, Pollution Prevention Sustainability, Collaboration & Leadership and interagency workgroups and education
- IFAS An Issues Landscape for Nanotechnology Standards, 2007, -MSU- Timing & Standards setting, Product vs Process Standards, International Harmonization, Integration of Organizational standards & participation and transparency in standards setting



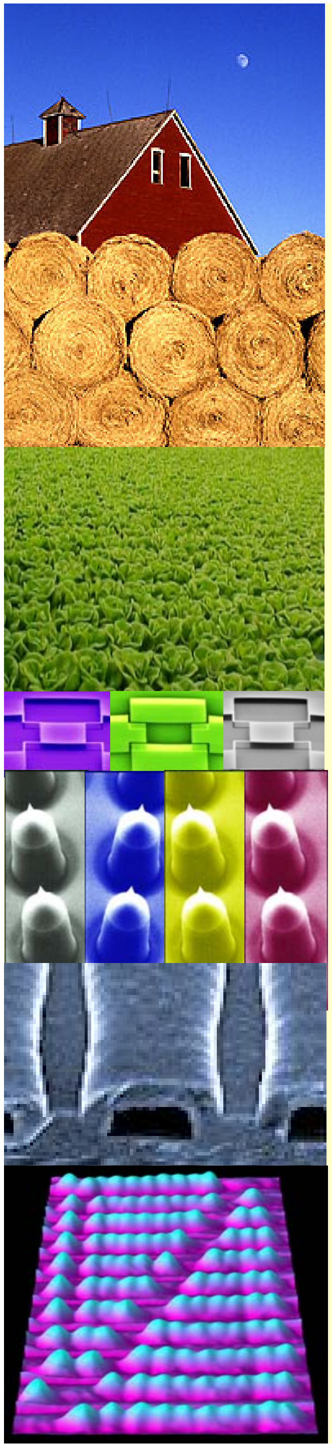
Reports- Nanotech (recent)

- **NANO Risk Framework, Environmental Defense – DuPont Nano Partnership, June 2007, (www.NanoRiskFramework.com)**
- **Fall 2006 USC Nanotechnology Expert Survey: Preliminary Results, June 2007**
- **IRGC, Nanotechnology Risk Governance: Recommendations for a global co-ordinated approach to the governance of potential risks, 2007, (www.irgc.org),**



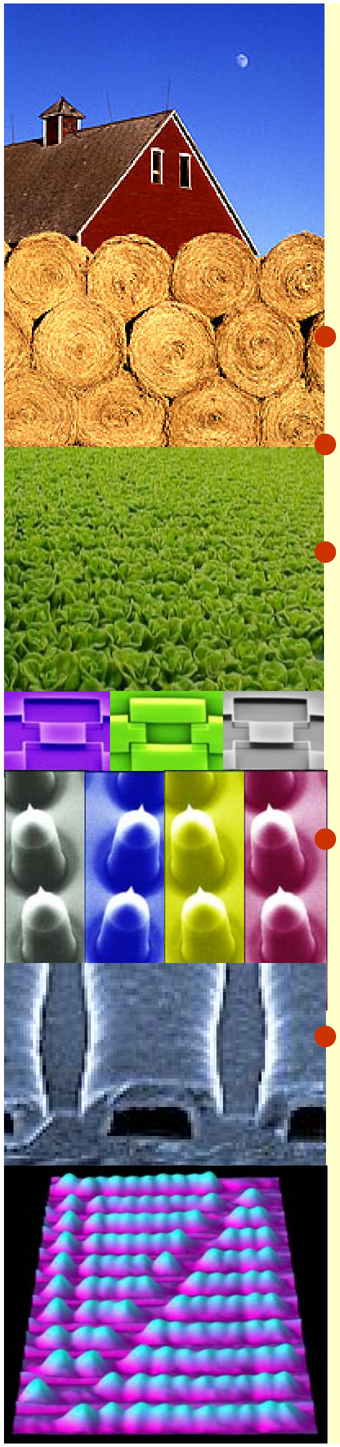
Now for the really big one

molecular manufacturing using a "bottoms–up" approach can be used to fabricate food, molecule by molecule, rather than growing it!! Food is a combination of molecules in a particular order. It is conceivable that by 2100 we will be engineering foods, molecule by molecule, by mass production to meet the nutritional needs of a hungry planet.



What To Do??

- In local settings convene meetings with broad and diverse groups and individuals
- Convene a panel of diverse “experts” to address the key issues
- Develop a scientific manuscript for publication in Science (AAAS) to address issues
- Develop a “factsheet” for USDA officials and to share with local groups
- Funding to address societal implications



CONCLUSIONS/ASSERTIONS

- **An enabling technology**
- **Revolutionize agriculture and food systems**
- **Existing research demonstrates many examples of possible applications of nanotechnology**
- **Building blocks exist and can/will/are being integrated into commercial products**
- **Food safety/health, social and ethical issues can delay or derail advancements**