

What Lies in the Future for Nanoscale Science and Engineering in Agriculture, Food and Natural Resources?

Dr. Norman R Scott

Biological & Environmental Engineering

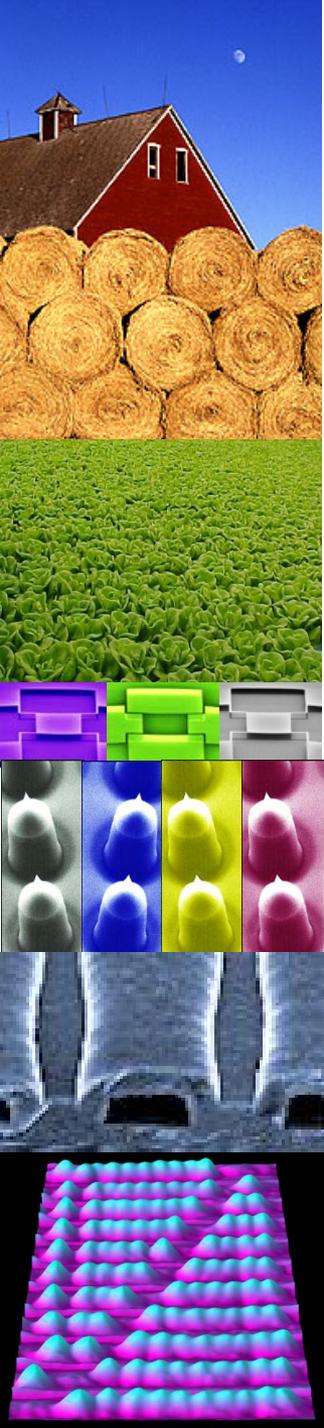
Cornell University

nrs5@cornell.edu

2014 USDA Agricultural Outlook Forum

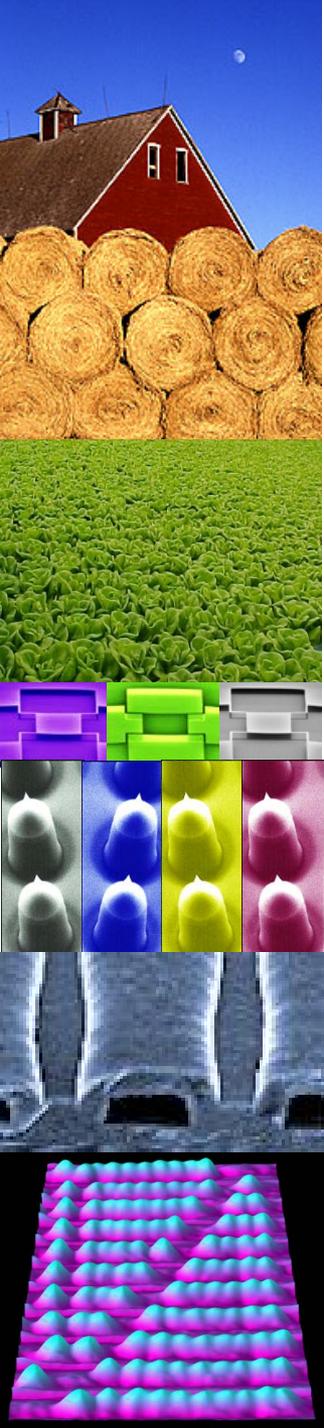
Arlington, VA

February 20, 2014



Where am I Going Today?

- **Setting the stage**
- **“Big” ideas**
- **Converging technologies**
- **Where are we today?**
- **Where will we 2020? (maybe!)**
- **Greater connection – agric. & medicine**
- **Some examples of NIFA-funded projects**
- **Barriers to advancement**
- **Overarching conclusion**



NAE on Grand Challenges

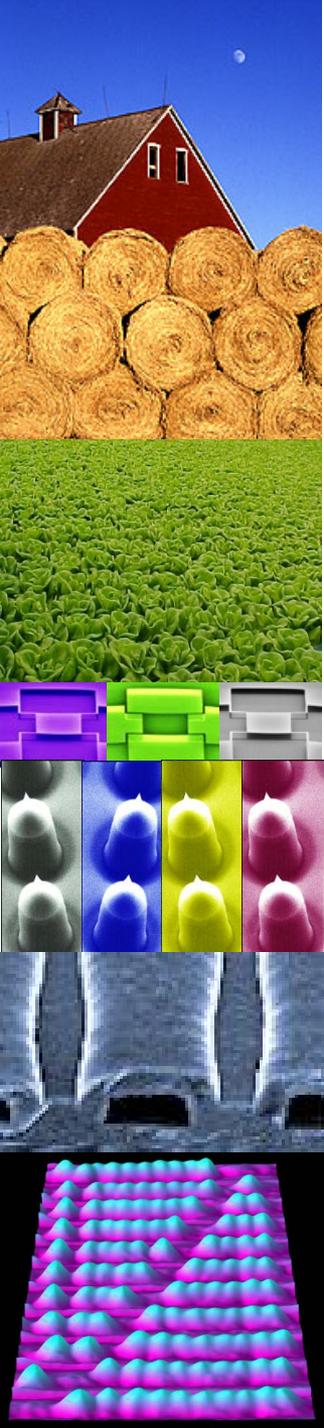
- The world faces grand societal challenges now and decades ahead – agriculture, food & natural resources
 - **Sustainability** – resolving diminishing natural resources against increasing demands of growing world population
 - **Vulnerability** – food safety, biosecurity, and others
 - **Human Health** – food and nutrition related developmental and degenerative illness
 - **Happy living** – improved working conditions, advanced education and learning, better environment, economic status, etc.

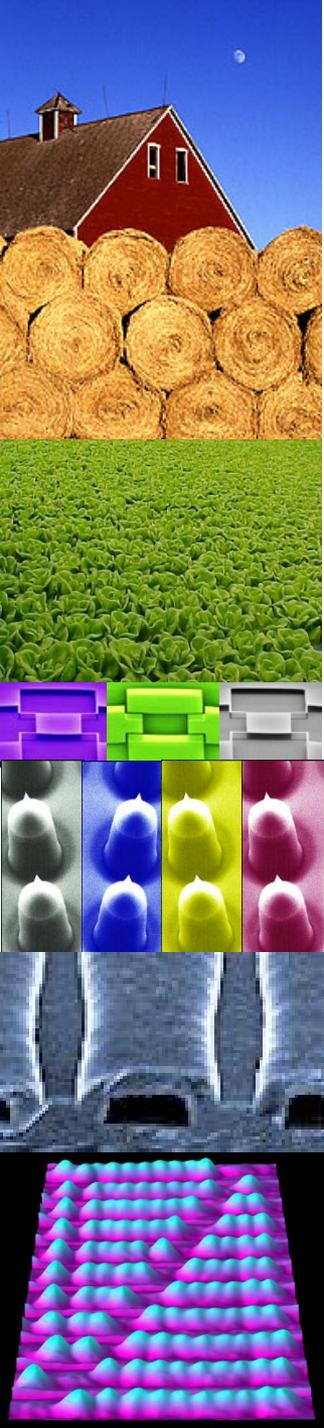
Agriculture, food and natural resources sector is a part of these challenges, and also could and should be a part of the solutions, provided we continue seeking appropriate research strategies.

AFRI Priority Areas

- **Plant Health, Production and Plant Products**
- **Animal Health and Production and Animal Products**
- **Food Safety, Nutrition and Health**
- **Renewable Energy, Natural Resources and Environment**
- **Agricultural and Food Security**
- **Agricultural Systems and Technology**
- **Agricultural Economics and Rural Communities**

2008 Farm Bill, 2014 Farm Bill (Foundation for Agriculture Research)

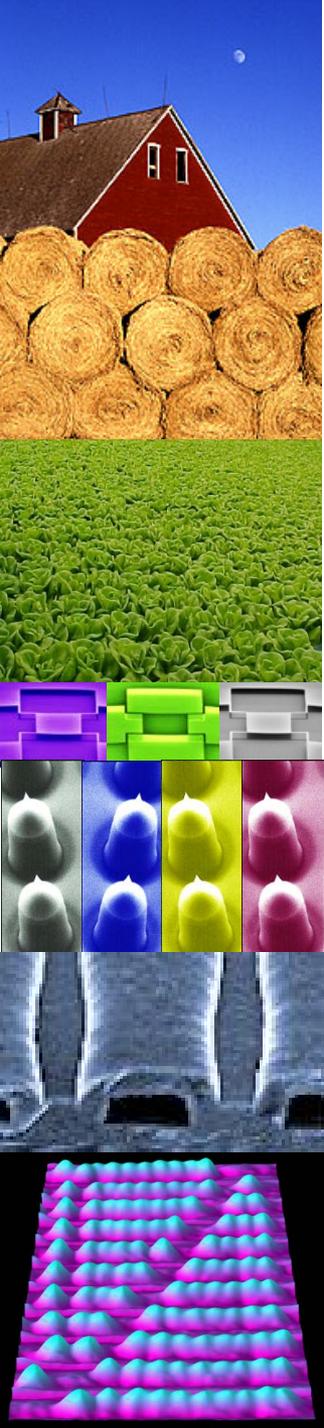




Our Culture War Over Food and Farming (Robert Paarlberg)

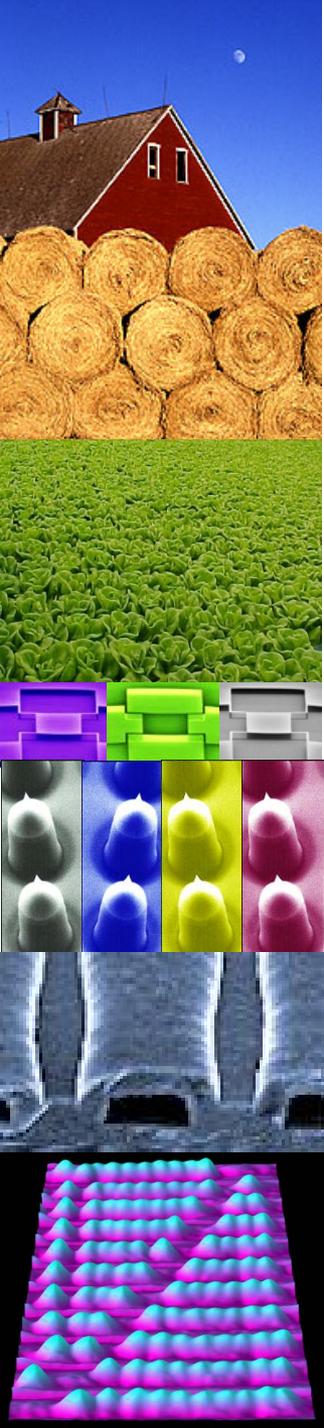
Some have concluded that our dominant food and farming systems are:

- **unhealthy,**
- **unsafe,**
- **environmentally unsustainable, and**
- **socially unjust**



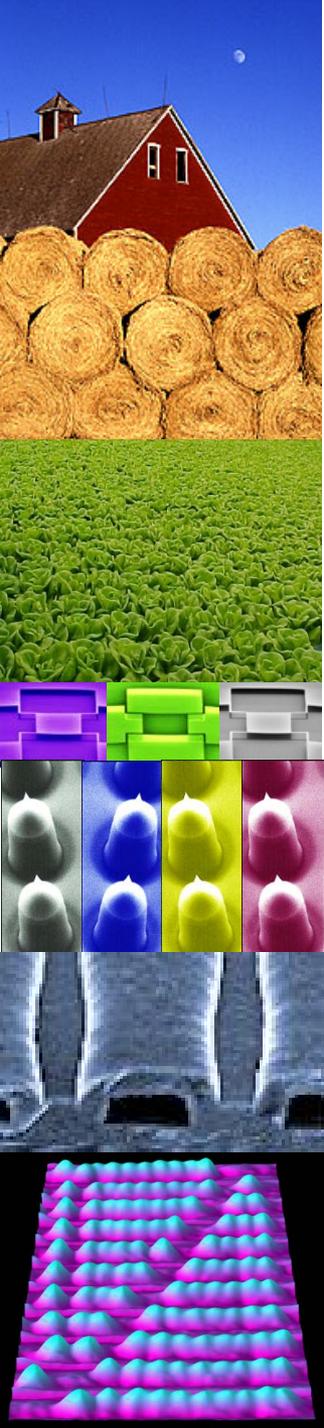
Behavior or Technology?

- **“Nobody” turns off the lights (create a motion detector)**
- **People do not eat healthy – obesity (replace fats and sugars OR prevent digesting or absorbing fats and sugars)**



Long range (end of 2100) goal

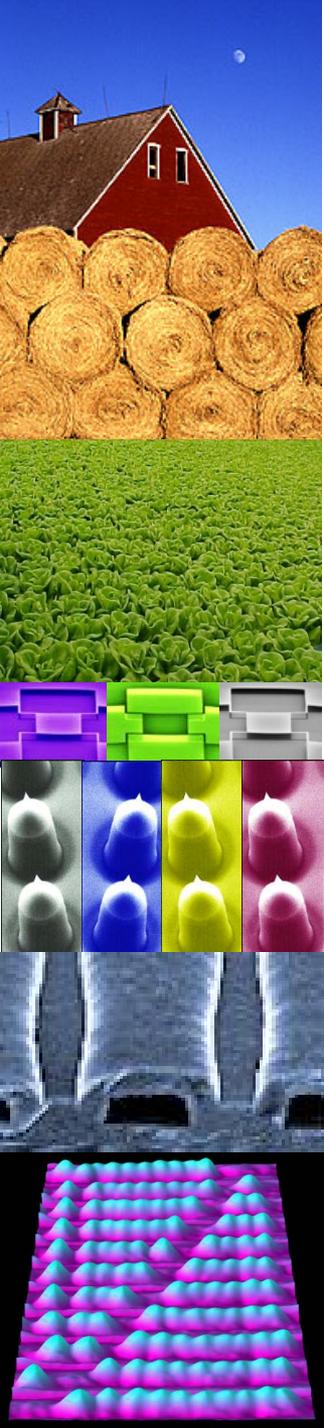
Way down the road one can envision that food could be produced by a “bottoms up” nanobiotechnology approach through a building of molecules, atom by atom!! Not likely to happen very soon, but after all food is just an assemblage of molecules arranged in a specific structure.



Technological Convergence

Create science and technology for converging platforms in areas of highest societal interest to address our common future (Roco, 2012)

I submit that the agriculture, food and natural resources system is clearly ONE of these platforms, never more important than now in preparation for the ~9B persons on our planet in 2050!

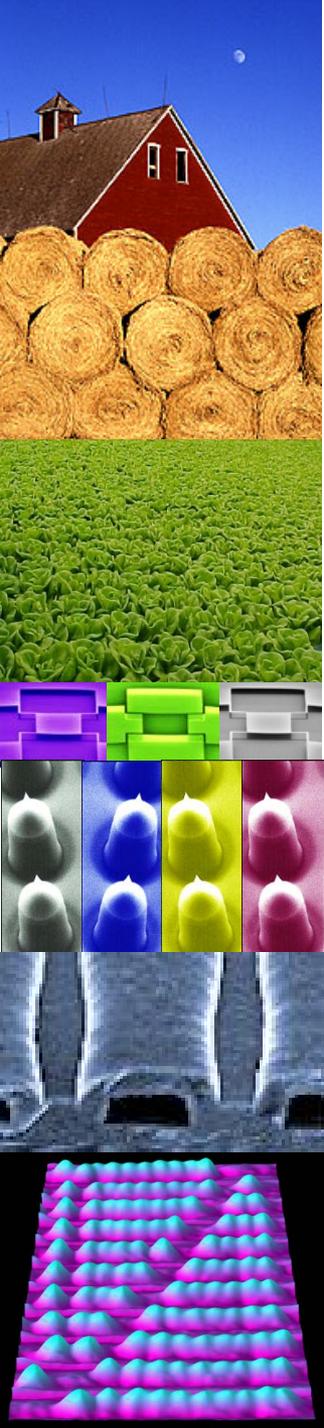


“Little” BANG Technologies

(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

Converging Technologies



Biotechnology

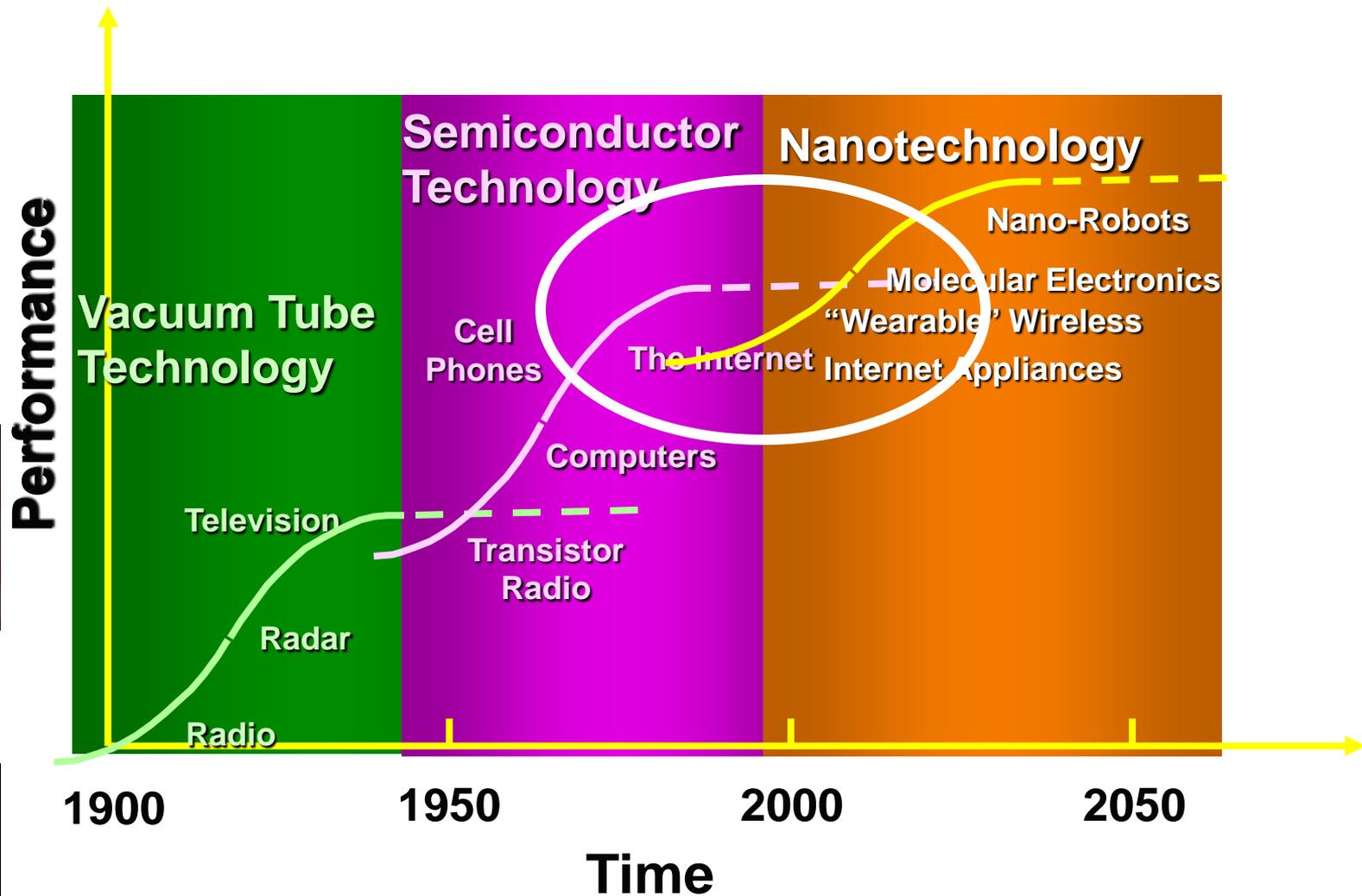
Nanotechnology

**Agriculture,
Food &
Natural Resources**

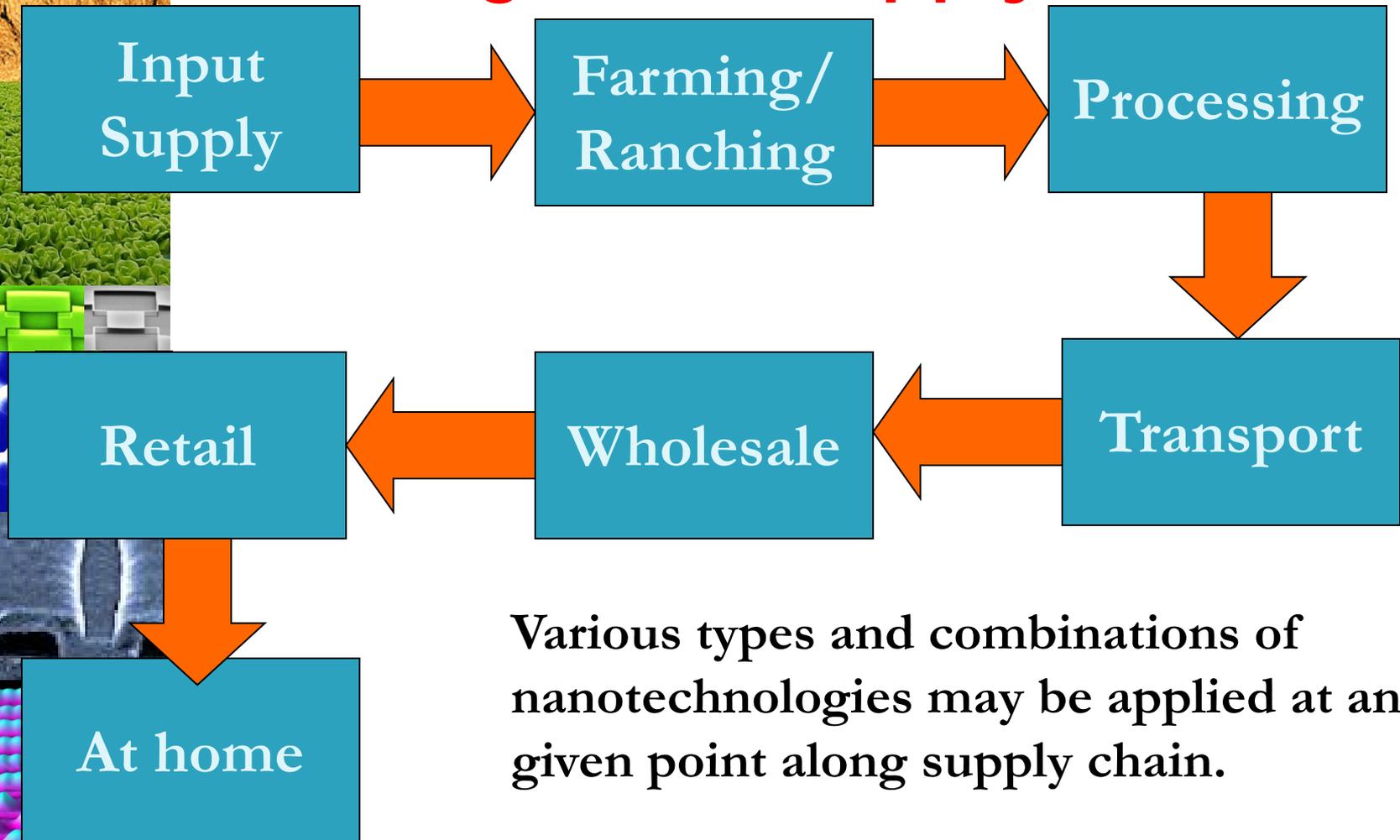
Information
Science

Cognitive
Science

Evolution of Technologies

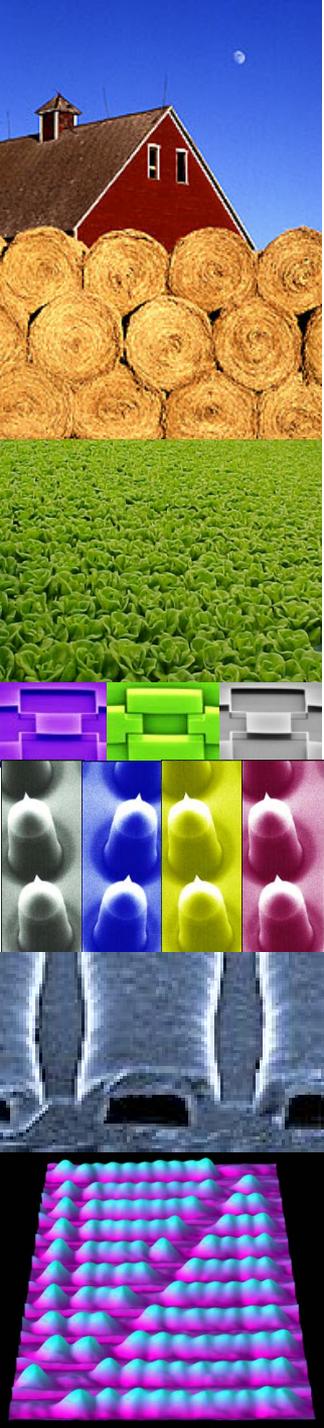


Organizing Principle: Agrifood Supply Chain



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

A National Planning Workshop

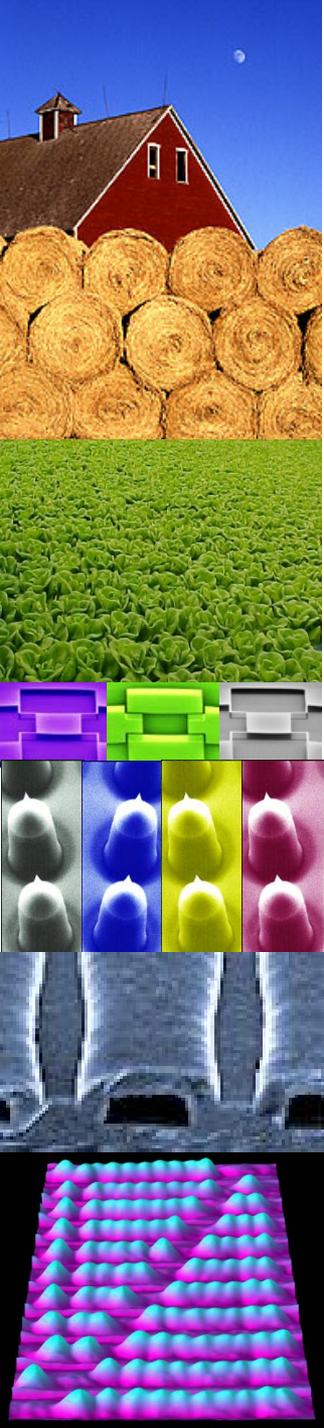


NANOSCALE SCIENCE AND ENGINEERING FOR AGRICULTURE AND FOOD SYSTEMS

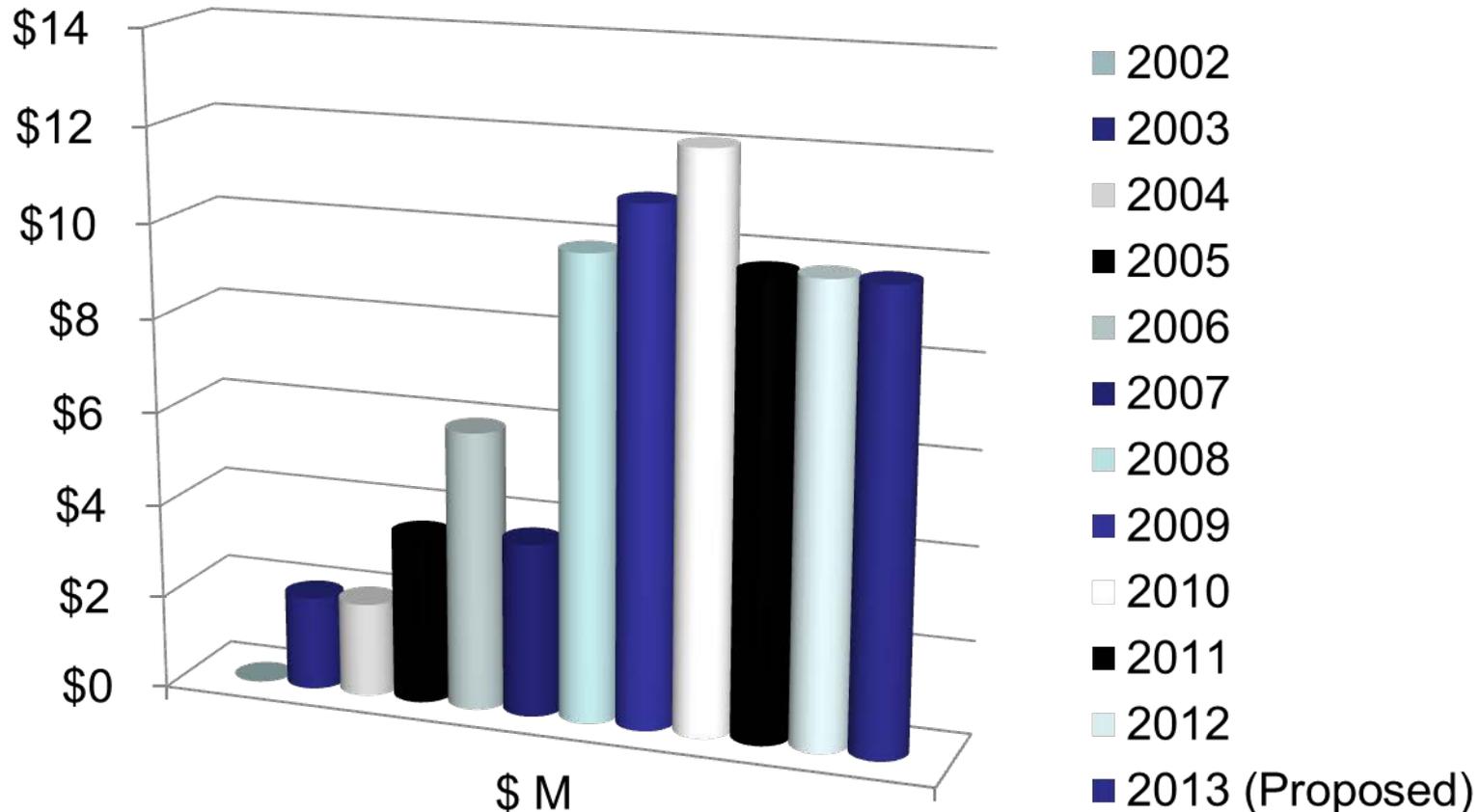
Workshop November 2002
Report September 2003

<http://www.nseafs.cornell.edu/web.roadmap.pdf>

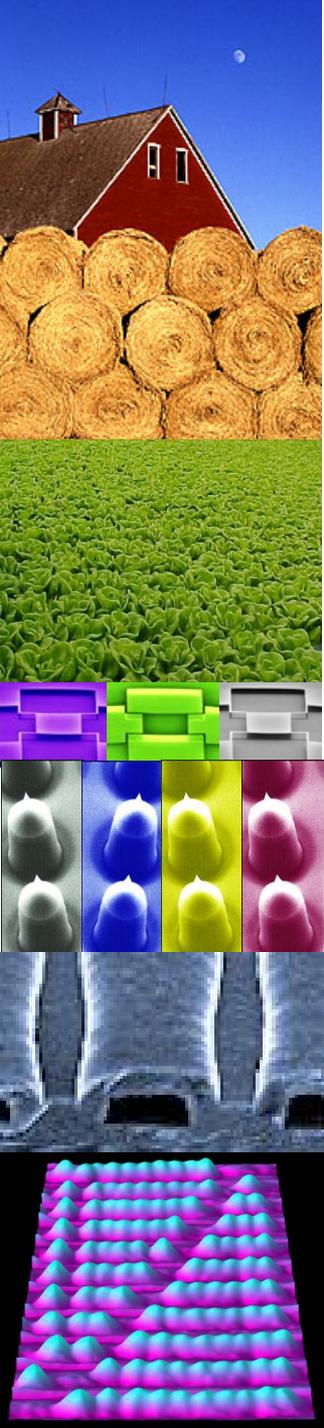
Norman R. Scott, Cornell University
Hongda Chen, USDA/NIFA



NIFA Investments in Nanotechnology R&D and Education started from zero and has grown significantly

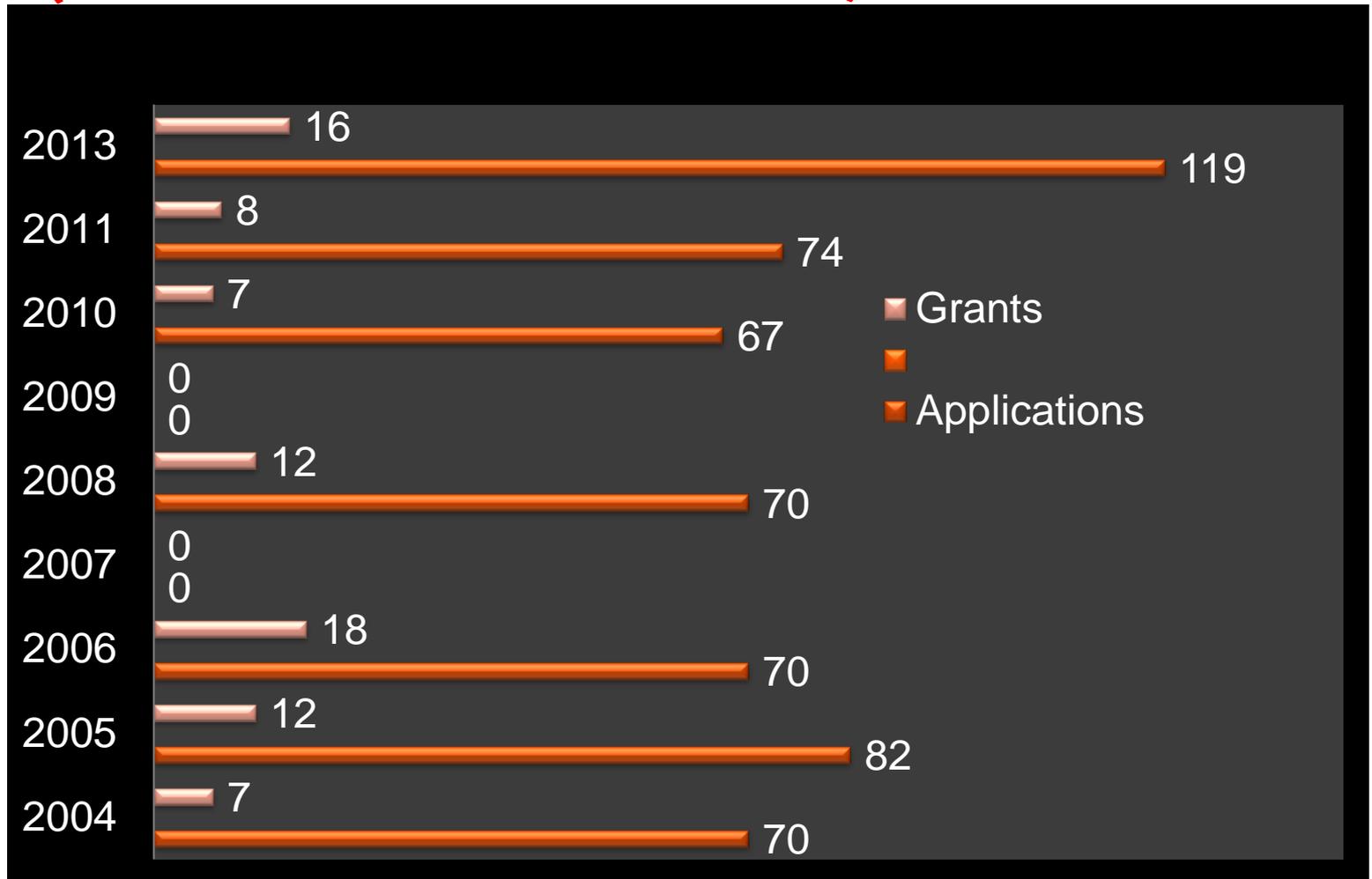


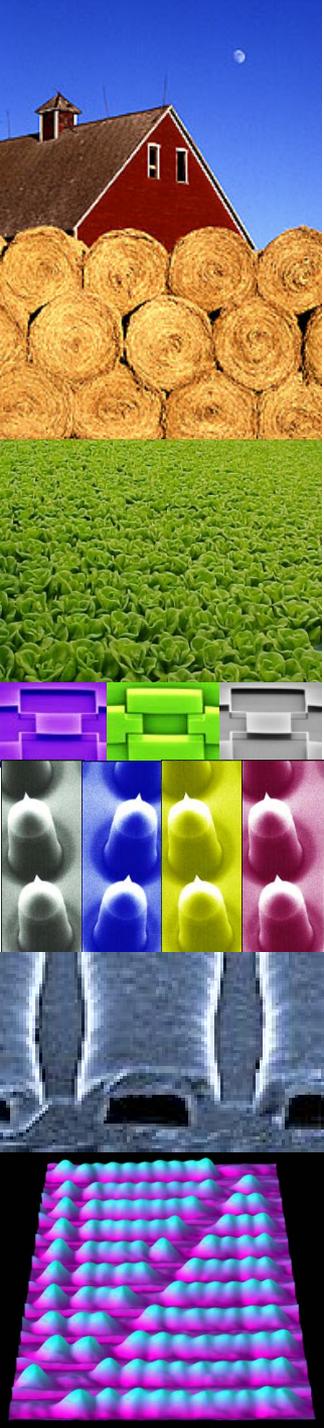
Source: The NNI – Supplement to the President's FY2012 Budget



History of NIFA Applications & Funded Projects (2004 – 2013)

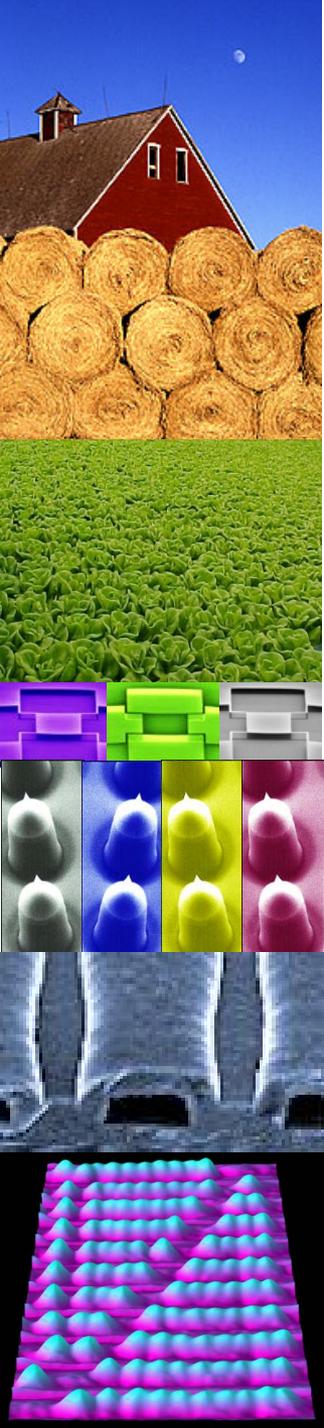
(Success rate $80/647 = 12\%$)





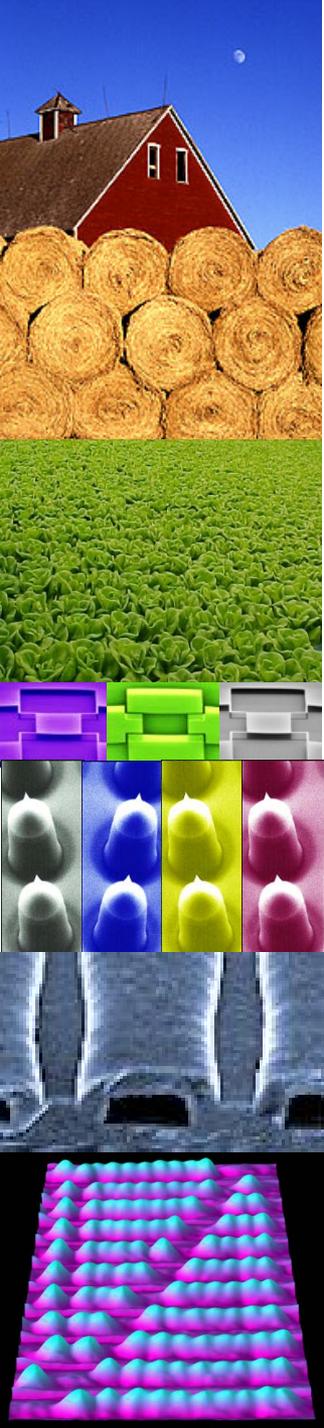
Grant Distribution (by Science/Engineering)

- **Sensors/sensing** **18**
- **Nanostructures/nanoparticles/
nanomaterials** **37**
- **Surfaces/coatings** **5**
- **Public perception/education** **3**
- **Conference** **1**



Grant Distribution (by application)

- **Food safety/health/nutrition** 35
- **Environment** 7
- **Plants/crops** 5
- **Animals/animal systems** 4
- **Bioenergy** 4
- **Public perception/education** 3
- **Gastrointestinal studies** 2
- **Other** 3
- **Conference (Food Initiative)** 1



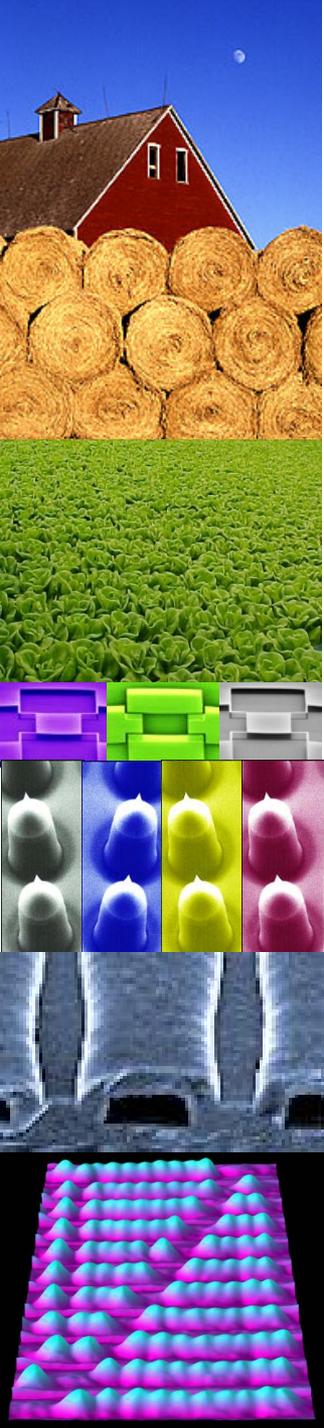
Major Look at Nanotechnology from 2000 to 2020 (includes agric, food and water)

- **Chapter 4. Nanotechnology Environmental, Health, and Safety**
- **Chapter 5. Nanotechnology for Sustainability: Environment, Water, Food, Minerals and Climate**

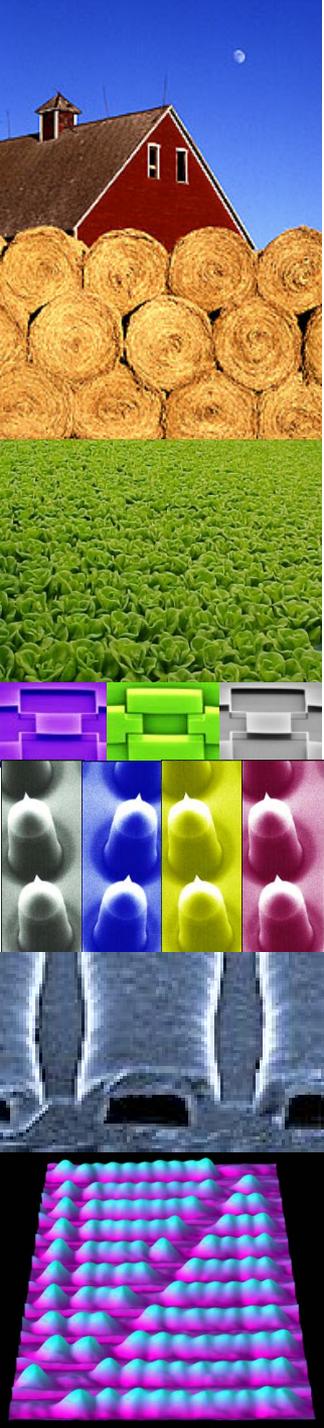


http://www.wtec.org/nano2/Nanotechnology_Research_Directions_to_2020/

Food quality and safety



- **Detection of presence of residues, trace chemicals, viruses, antibiotics, pathogens, toxins,**
- **An integrated, rapid DNA sequencing process to identify genetic variation and GMO's,**
- **Tracking process for integrity of food during production, transportation and storage,**
- **A delivery approach to reduce calories of food while retaining flavor, lowered fat, reduced salt, less sugar, improved texture,**
- **A system to enhance bioavailability and delivery of nutraceuticals, nutrigenomics, increased vitamins and nutrient content of foods,**
- **Introduction of “personalized nutrition” to meet very specific individualized health needs**
- **Major improvements in food manufacturing processes,**
- **Wide-spread advances in food packaging and food contact materials for quality assessment and enhanced shelf life (eliminate need for refrigerated storage) and**
- **Technologies and processes to substantially reduce crop and post-harvest losses from production to consumer**

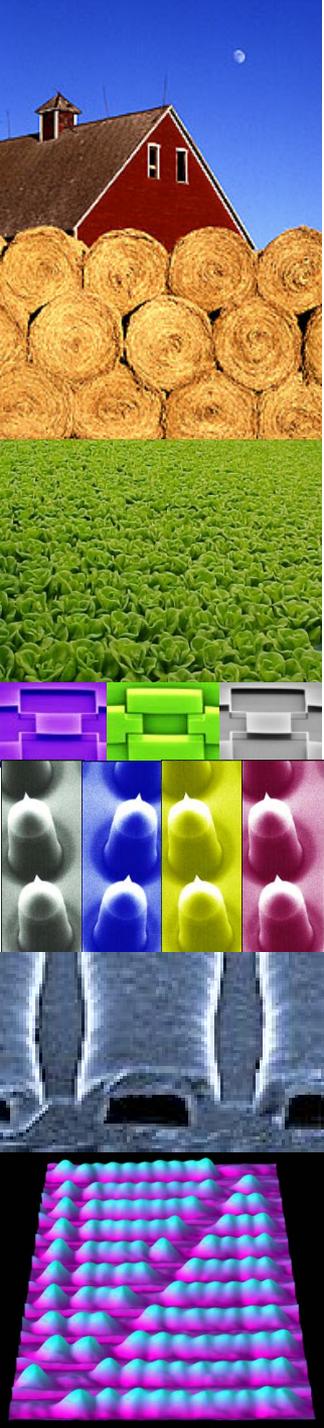


Animal Health monitoring and management

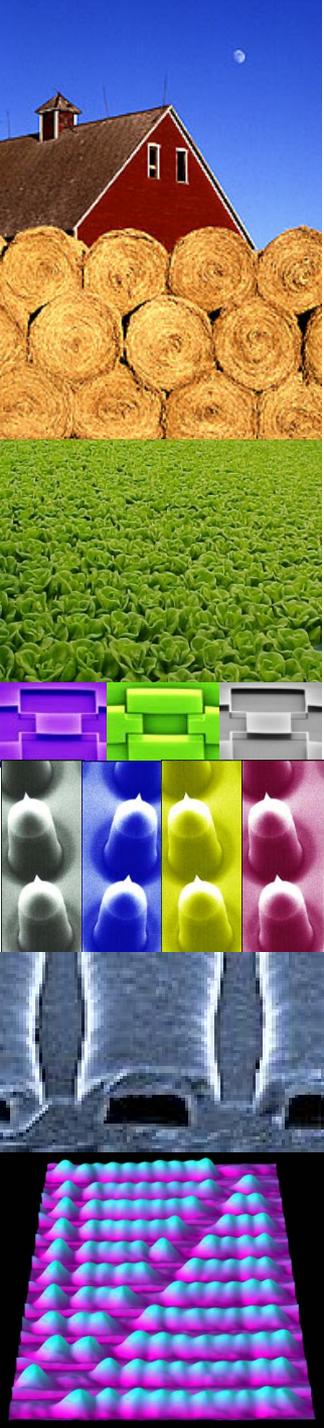
- Applications of developmental biology for breeding,
- Detection processes to sense presence of residues, antibiotics, pathogens, toxins, etc.,
- Process for early, even, pre-disease detection, rapid diagnosis, and prevention of diseases
- An integrated health monitoring process including therapeutic intervention as necessary,
- A process for identity tracking of animals from birth to the consumer's plate,
- New technologies such as nutrigenomics which will influence or control genetic expression,
- Major nutritional platforms which will alter food products (milk and meat) with healthful human benefits,
- Approaches to lessen greenhouse gas emissions (GHG) from livestock, and
- Application of manure management processes to reduce GHG and produce renewable energy as distributed generators of electricity and heat.

Plant Systems

- Development of “smart field systems” to detect, locate, report and direct application of water, only as needed and in required quantity,
- Development of “smart field systems”(possibly electronic “dust” particles) for early detection and monitoring of diseases for intervention,
- Applications of precision and controlled release of fertilizers and pesticides,
- Utilization of bio-selective surfaces for early detection of pests and pathogens,
- Applications of a laboratory-on-a-chip proteomics technology for microbial biocontrol agents
- Development of “new” plant varieties with characteristics of drought resistance, salt tolerance and excess moisture tolerance,
- Plants (nonfood crops) for bioenergy (e.g. photosystems), and
- Use of specialized (nonfood) plants, including trees, for nanocellulose and biofuels.

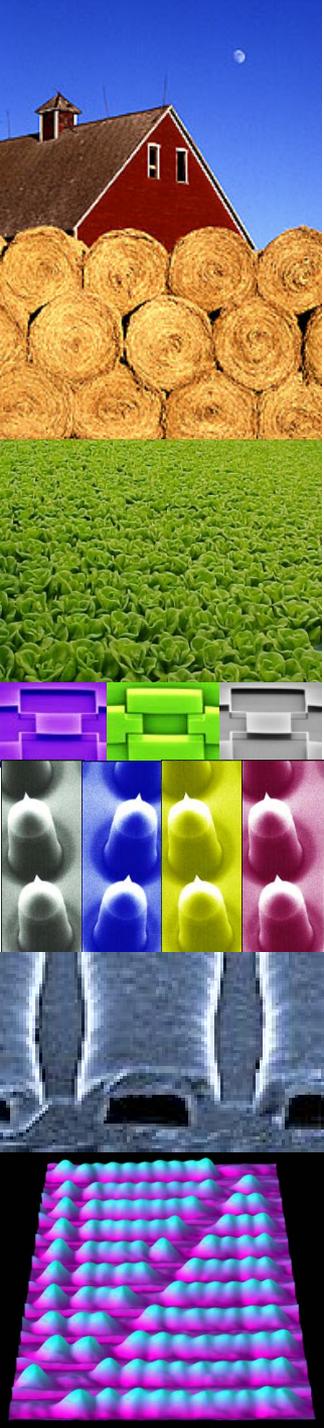


Environmental management

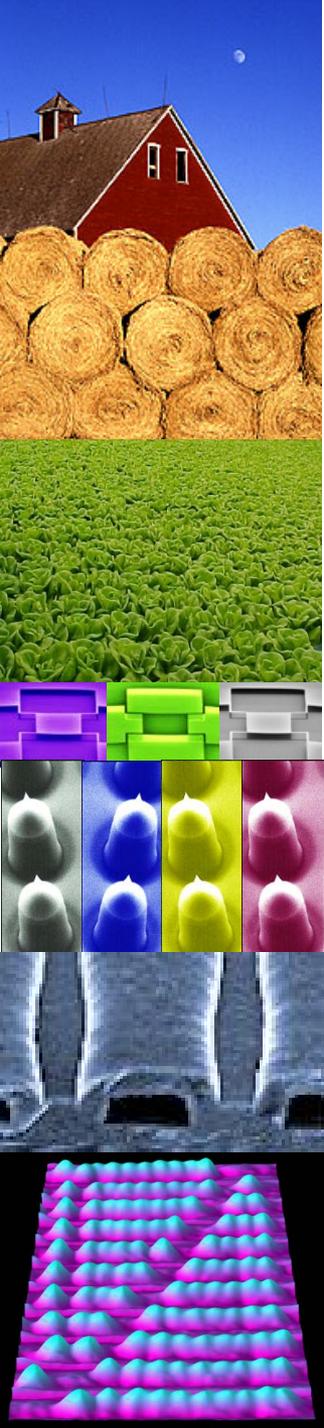


- Utilization of nanophase soil additives (fertilizers, pesticides and soil conditioners),
- Nanoparticles in transport and deliver bioavailability of nutrients to plants,
- Developed an understanding of soils as a complex nanocomposite,
- Comprehensive management of land, water and air pollution (detection and remediation processes)
- Low cost, effective water filtration at point of use
- An ability to track hydraulic and nutrient flows in the landscape

Social/Ethical Issues



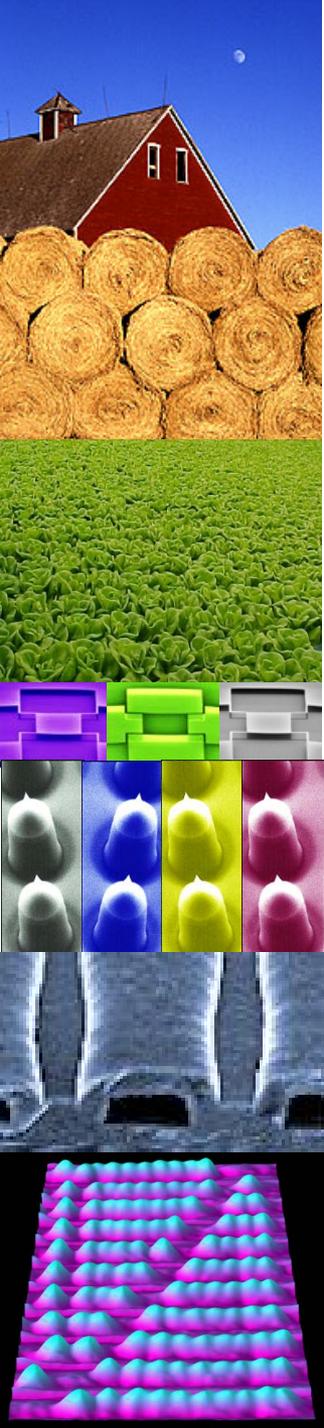
- **Unknown effects on environmental, health and biodiversity?**
- **Labeling of foods?**
- **Ownership and control issues?**
- **Who benefits? Poor are often most vulnerable.**
- **Consolidation of corporate power marginalizes farmers' rights.**
- **Lack of effective public/private partnerships (companies, academe and governments),**
- **Food is socially very sensitive,**
- **Lack of regulations? Standards?**
- **Public engagement is typically a “reactive engagement” rather than an inclusive and participatory one,**
- **Resistance of food companies to engage and communicate about their research and products.**



Examples from Medical Research

Sticky nanoparticles- “cancer-killing machines” through the bloodstream

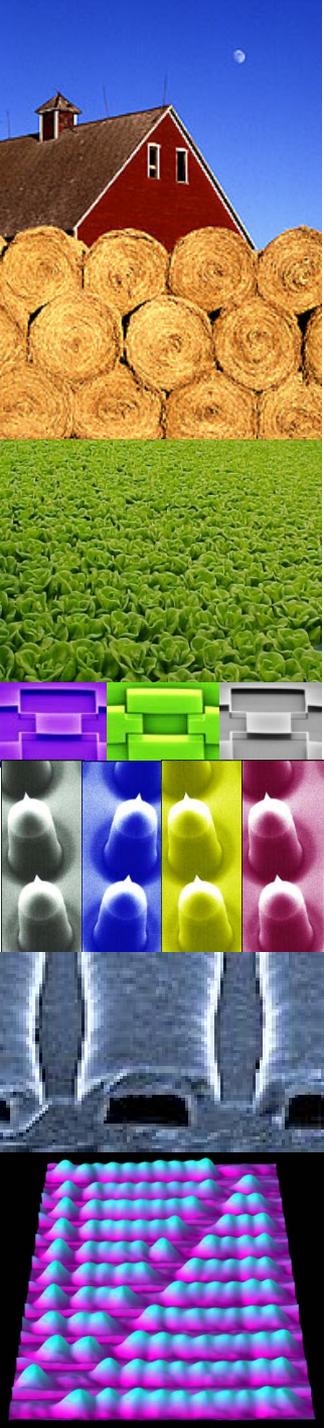
- **designed to combat metastasis**
- **a major route for cancer spreading is through circulation**
- **design of nanoscale liposomes that have two proteins attached to their surface—E-selectin and TRAIL**
- **E-selectin is an adhesive molecule that binds to other cells & TRAIL is a therapeutic protein made by immune cells that can program cancer cells to die off**



Examples from Medical Research

A noninvasive screening test of saliva (quick and non-invasive):

- **Saliva cortisol – a measurement of stress**
- **Saliva diabetes - Reduced sugar – measured by 1.5 anhydrogluticol**
- **Test for ovulation**
- **Test for growth of certain cancerous tumors**
- **Test for cardiovascular disease**



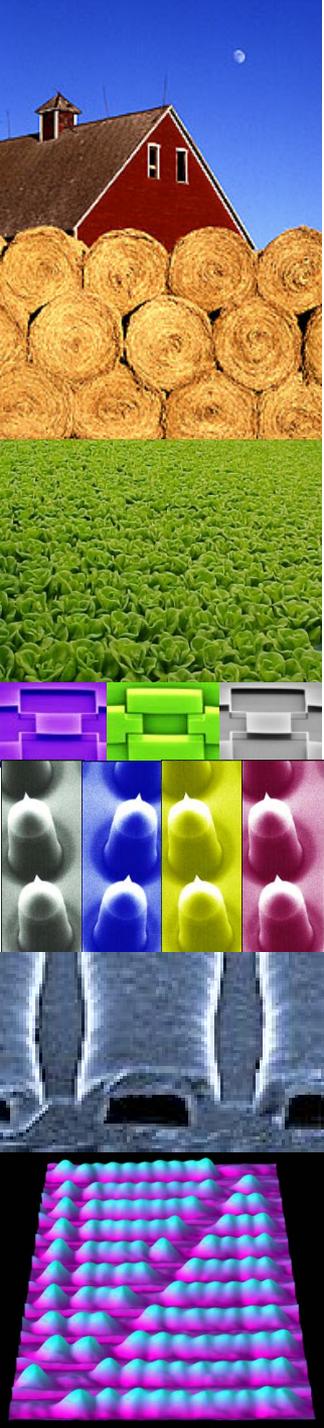
A Few International Applications

- Storage bag lined with nanoparticles retains quality of cassava
- Milk container with nanopatterned, antimicrobial coating prolongs quality before able to get to cooling
- Nanopatterned paper sensor to detect pregnancy – dry milk due to pregnancy or disease
- Nanopatterned paper within fruit/vegetable container prolongs quality w/o or with refrigeration (e.g. Fresh Paper)

Nanotechnology Consumer Products Inventory

- Now (10/2013) 1628 consumer products have been introduced to market since 2005 (and 24% increase since 2010)
- 200 classified as food & beverage >supplements > storage
- Just a few common examples: cheese, cookies, coffee creamer, pudding, mayonaise, beverages, cereals, jello, crackers, M&Ms, milk, popcorn, salad dressing, and many more!
- Nanomaterial – often titanium dioxide

Collaboration of the Woodrow Wilson International Center & Virginia Tech Center for Sustainable Nanotechnology (2013)



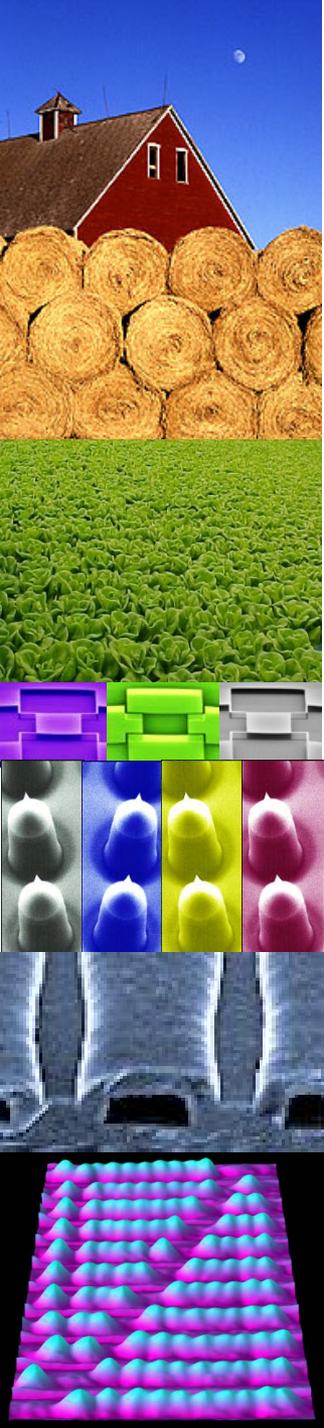
FDA's Role in Nanotechnology

Draft Guidance for Industry: Assessing the Effects of Significant Manufacturing Process Changes, including Emerging Technologies, on the Safety and Regulatory Status of Food Ingredients and Food Contact Substances, Including Food Ingredients that are Color Additives

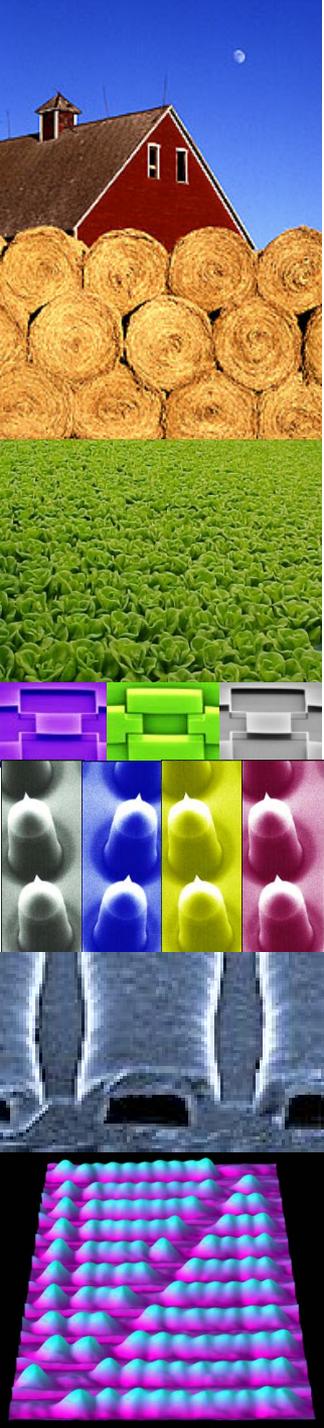
The draft foods guidance alerts manufacturers to the potential impact of any significant manufacturing process change, including those involving nanotechnology, on the safety and regulatory status of food substances. This guidance describes the factors manufacturers should consider when determining whether a significant change in manufacturing process for a food substance already in the market:

- Affects the identity of the food substance;
- Affects the safety of the use of the food substance;
- Affects the regulatory status of the use of the food substance; and
- Warrants a regulatory submission to FDA.

The draft foods guidance also recommends manufacturers consult with FDA regarding a significant change in manufacturing process for a substance already in the market



Barcode decoding via fluorescent microscopy



4G

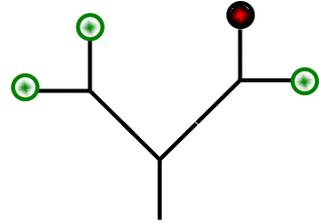
1G/3R

4R

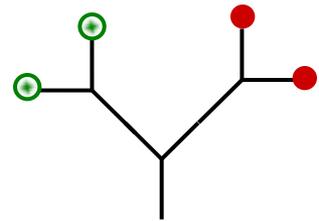
3G/1R

2G/2R

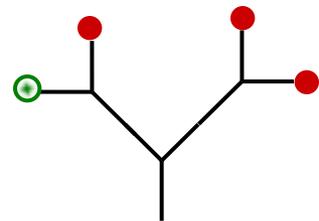
3G/1R



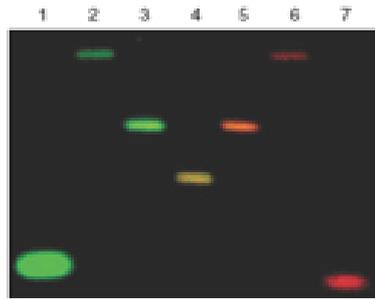
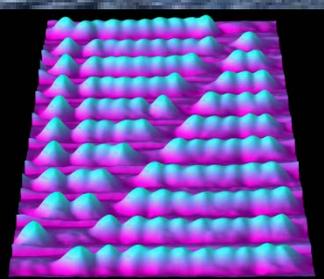
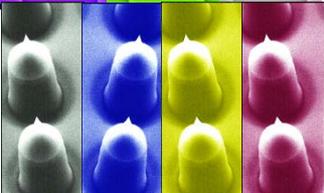
2G/2R



1G/3R



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



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

Avian Influenza Biosensor

Novel concepts for the biosensor:

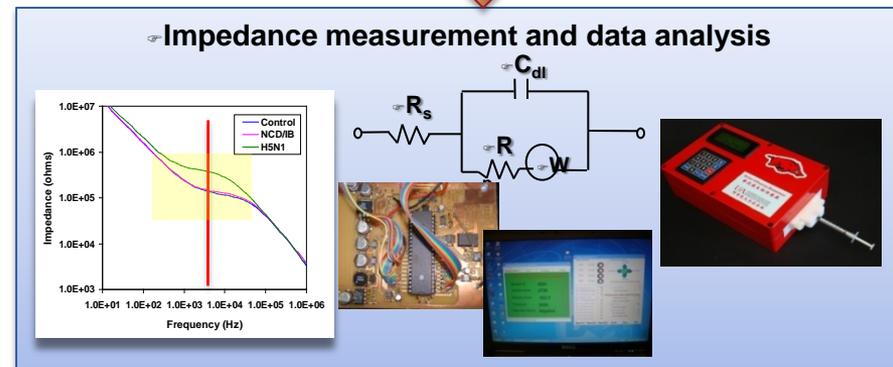
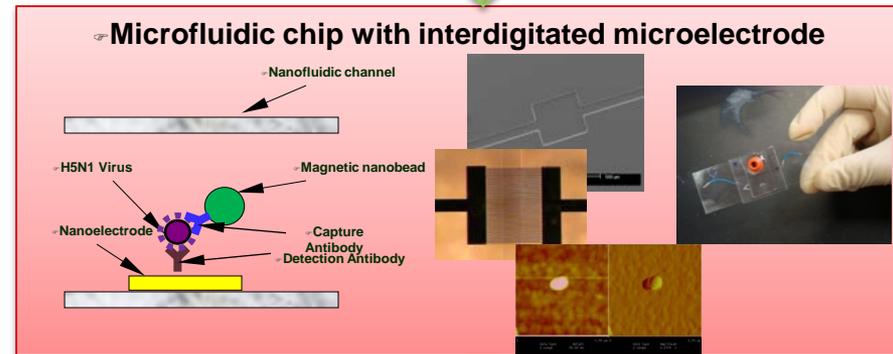
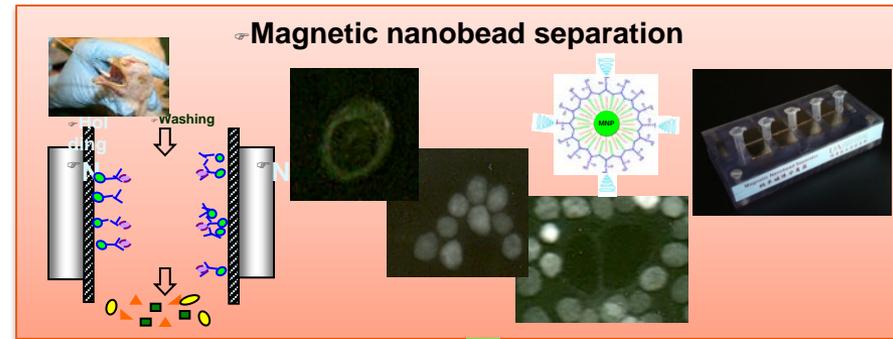
- Magnetic nanobeads (coated with anti-H5 antibody) based sample pretreatment for highly efficient capture and separation of target AI virus
- Micro/nanofluidic chips based sample control for high ratio of surface area/volume with accurate, small volume of sample
- Interdigitated micro/nanoelectrode (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-alone or connected to a laptop.
- The software: easy way to control the biosensor and to collect and analyze the data.

Advantages

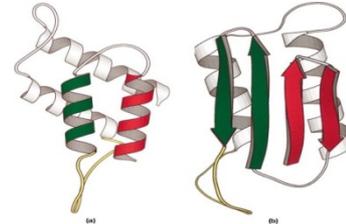
- Rapid
- Easy to operate
- Portable
- Quantitative
- Cost-effective
- Multiple uses
- Reusable



Protein Conformational Diseases

- Examples of protein “conformational diseases”

- Alzheimer’s & Parkinson’s
- Cataracts
- α 1-antitrypsin deficiency
- Transmissible Spongiform Encephalopathies (TSEs)



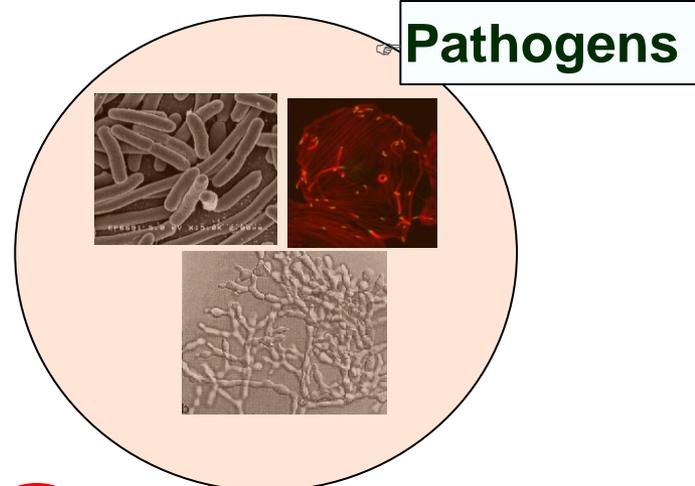
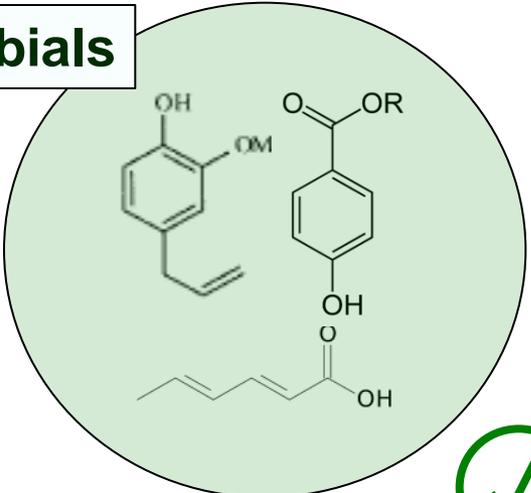
- Creutzfeldt-Jakob Disease (CJD)
- Bovine spongiform encephalopathy (BSE)
- Scrapie
- Chronic wasting disease

- 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.

The Fundamental Issue !!



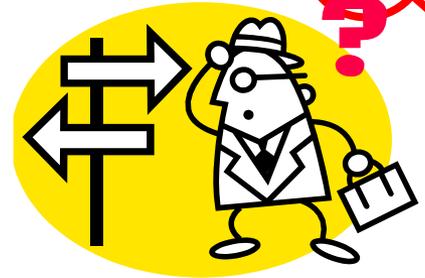
Antimicrobials



Pathogens



Model Micro-Systems



Foods



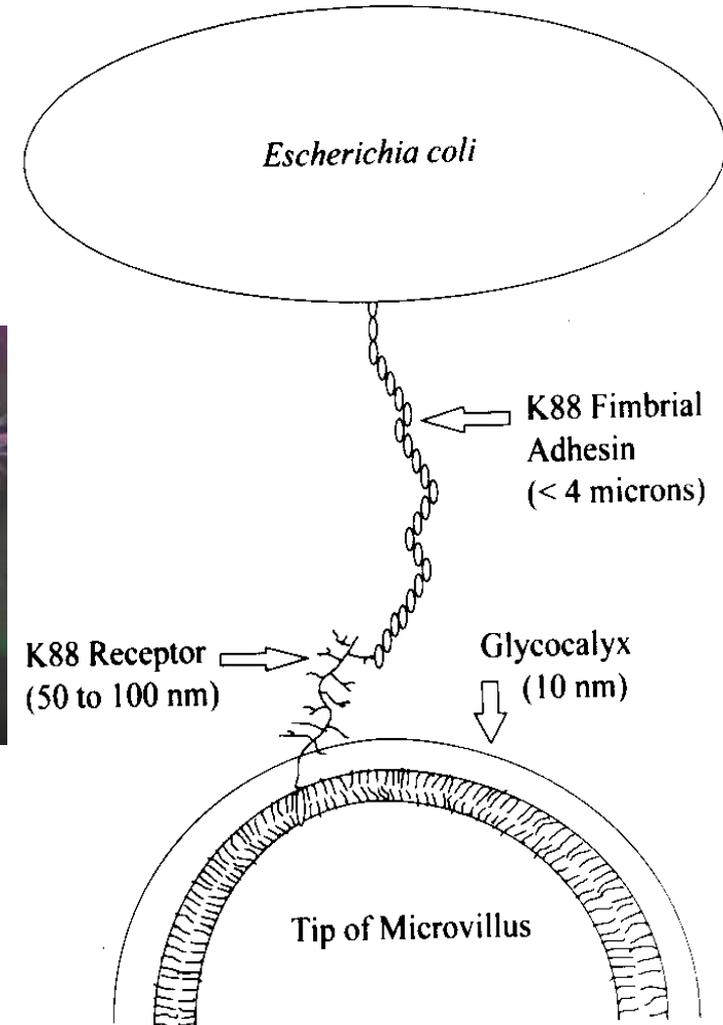
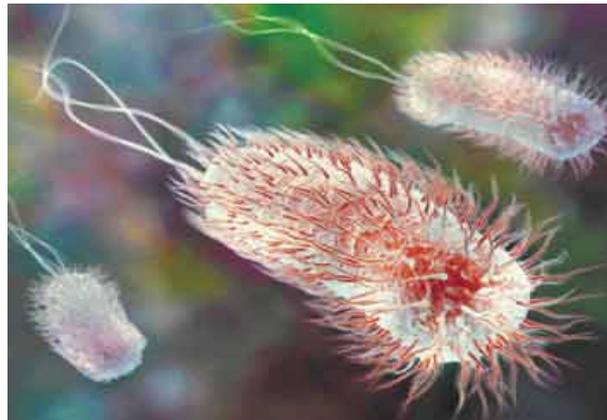
Ingredient Interactions!!!

Courtesy of J. Weiss

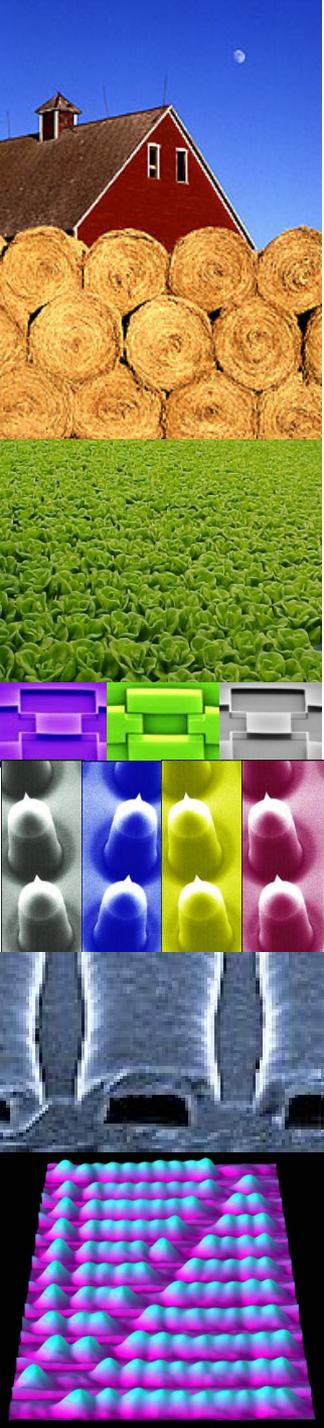
Food Safety Intervention

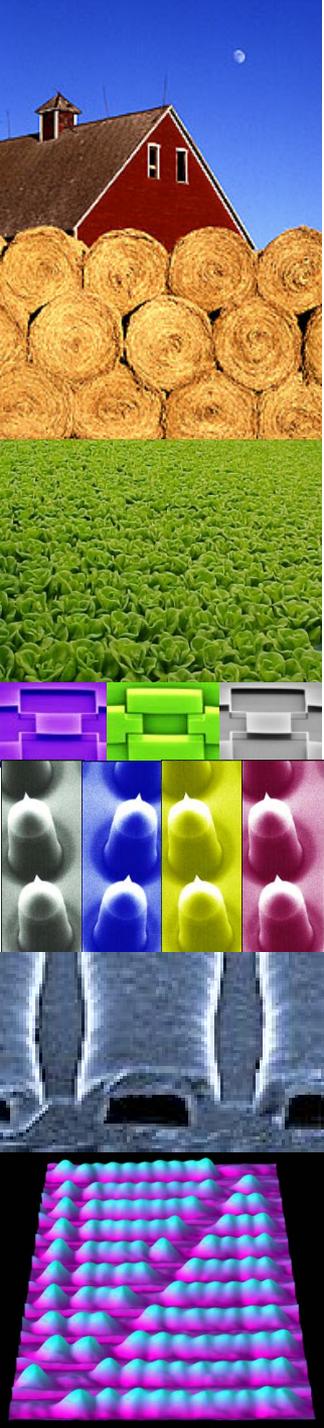
- **ADHESIN-SPECIFIC NANOPARTICLES FOR REMOVAL OF PATHOGENIC BACTERIA FROM POULTRY**

- Latour, R. A., etc., Clemson Univ. 2000-05336



➔ **Bacterial Binding to Host is Mediated by Adhesins**

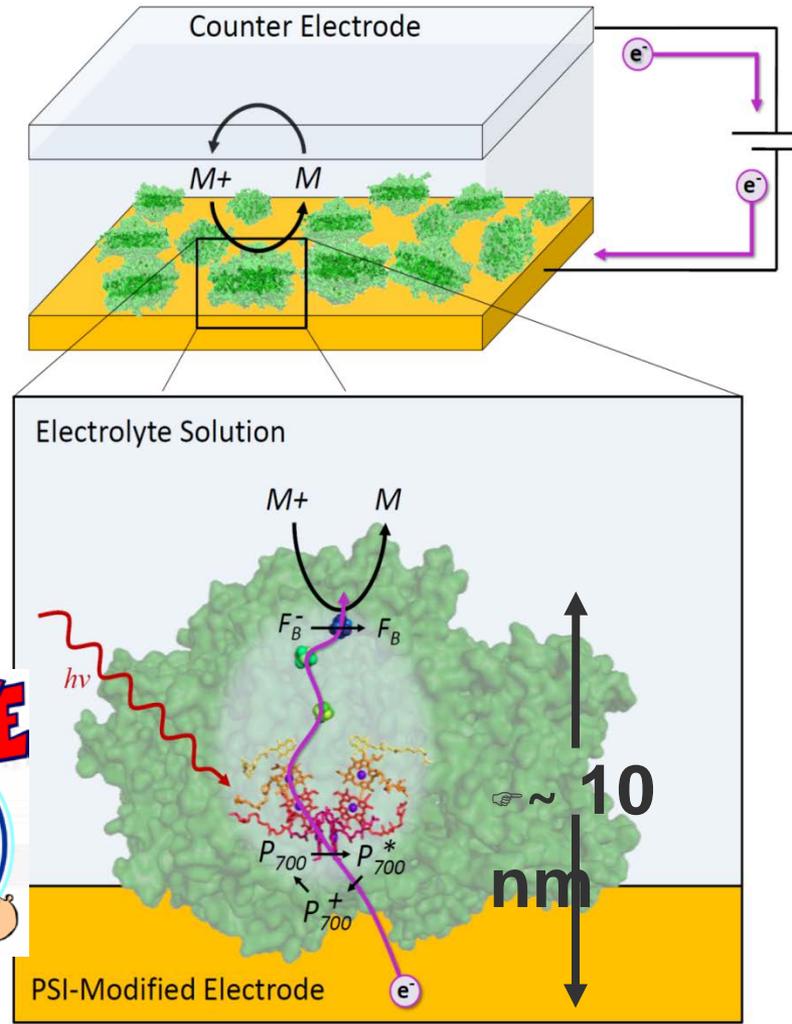




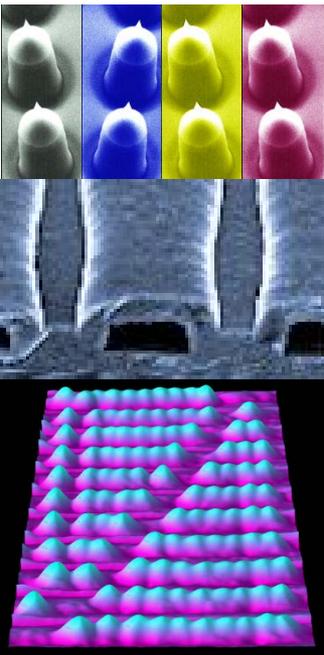
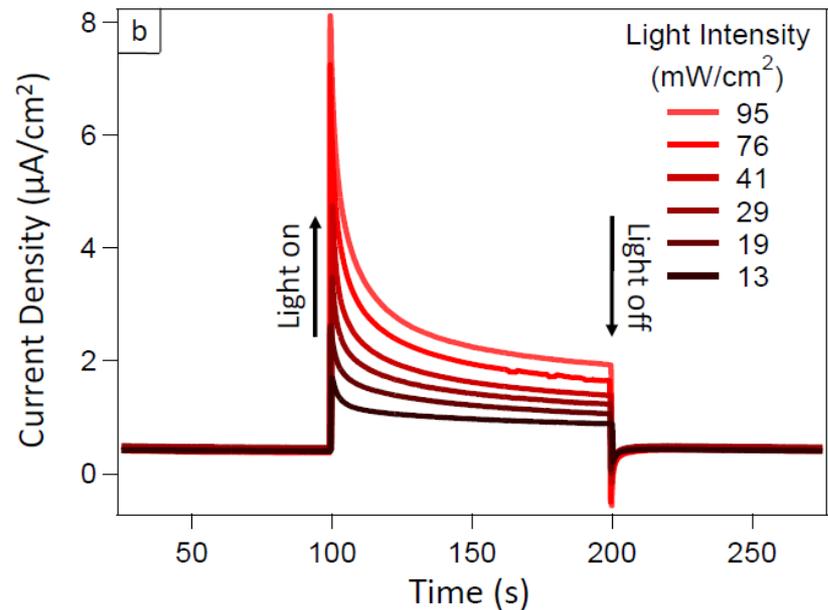
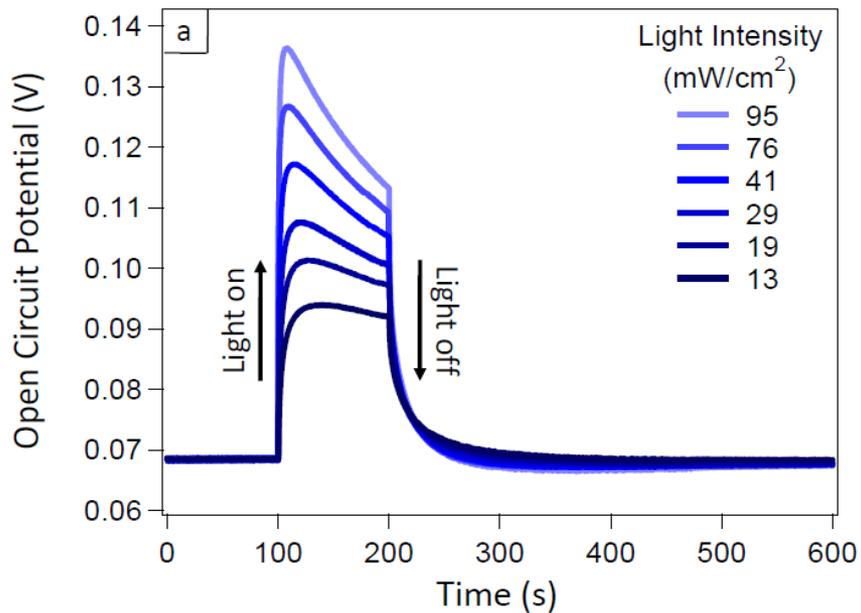
☞ Photocurrent

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.

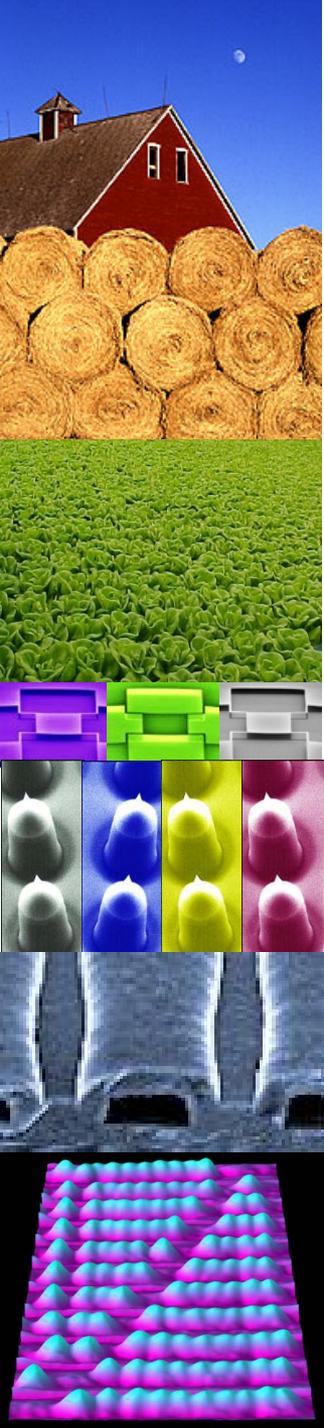


☞ Figure courtesy of Peter Ciesielski

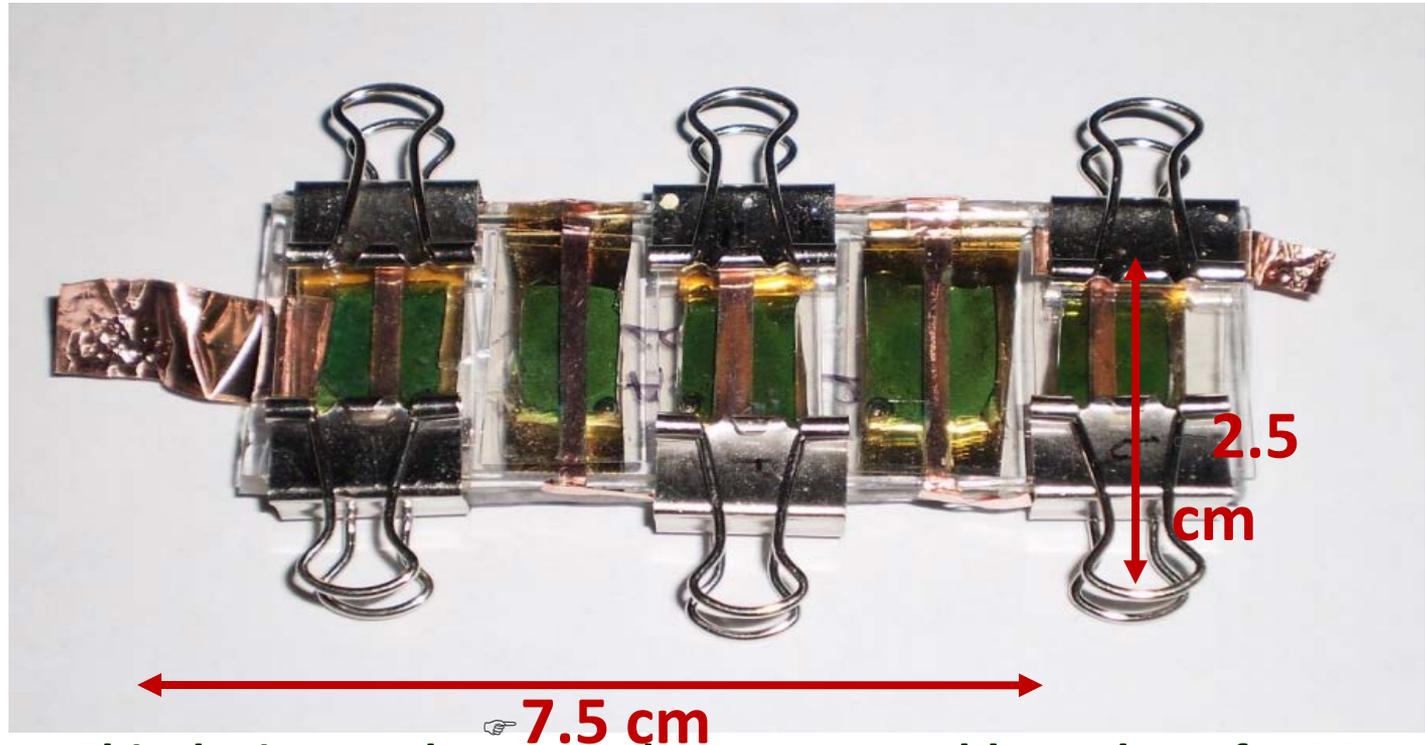


While still low compared to mature silicon photovoltaic technology, the photocurrent produced by this device represents an increase of 10,000 x in less than 3 years over previously reported photocurrents produced by PSI-modified electrodes.

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

Effective in touch with people to improve perception



Q&A: FOUR QUESTIONS for SIX EXPERTS

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THE FOOD ISSUE

THE NANOSCIENCE OF LIPID LIPOSOMES IN YOUR FOOD, OH MY! NATURE'S NANO MACHINES NANOTECHNOLOGY IS IT SAFE? NANOSENSORS, LASERS, AND CROPS

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Nanotechnology In Agriculture

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Interviews

4 Questions for 6 Experts

Thoughts on Nanotechnology and Life



Jennifer Kuzma
University of Minnesota

What first comes to your mind when you think of "nanotechnology"?
Applications at a small scale. The ability to accomplish more using less and more targeted materials.

If you weren't in science, what else would you be doing?
The five arts. I always wanted to be a musician. I did play piano and classical guitar, but I dream of playing cello in an orchestra. Another dream is being a painter.

What do you recall made you decide that you wanted to be in science?
I was fascinated by my general history and chemistry classes, and the explanation of macro-scale world phenomena looking at molecules and cells.

In 20 years what do you imagine will be the most revolutionary change in our lives that involves nanotechnology?
I hope it occurs in the medical and environmental areas—using less material and promoting sustainability or more targeted treatment of diseases like cancer. I like to think of the social benefits (environment and health) as the potential revolution. But it will take targeted public funding to reap those benefits. Currently, nanotechnology in the market (for example, in better tennis rackets or cosmetics) does not reflect our greatest societal needs.



George Whitesides
Harvard University

What first comes to your mind when you think of "nanotechnology"?
Electronics, quantum, molecular, strange and cool.

If you weren't in science, what else would you be doing?
Teaching. Teaching is no more than science, so I don't think about an alternative.

What do you recall made you decide that you wanted to be in science?
I had washing dirty labware when I was a lab tech as a teenager, but that was my moment when I decided that I wanted to be in science.

In 20 years what do you imagine will be the most revolutionary change in our lives that involves nanotechnology?
It's already in progress. The remodeling of the world by nanotechnology has contributed in many ways to the means through which we communicate. Think back before the internet and the level of connection—we have already gone through a revolution.



Aaron Strickland
Cornell University

What first comes to your mind when you think of "nanotechnology"?
Science fiction coming to life. On several occasions the whimsical success in an experiment or proof-of-concept study that at first seemed like a very futuristic idea.

If you weren't in science, what else would you be doing?
I'd be an architectural engineer. Designing and building buildings seems incredibly exciting and challenging, kind of like building molecules in the lab (or carefully, but on a slightly different scale).

What do you recall made you decide that you wanted to be in science?
I was surrounded by science and scientists most of my life. My father is an embryologist. However, I did not really decide on a career in science until my college life, and I can trace this back to a few great teachers who inspired me to pursue science to me in a way that was very compelling. Science is interesting, challenging, competitive and fun all at the same time.

In 20 years what do you imagine will be the most revolutionary change in our lives that involves nanotechnology?
Twenty-five years from now nanotechnology will have changed our computing systems, our food processing, our medical procedures, entertainment, transportation systems, the way we fight wars, the way we socialize and communicate. How do we work and, let's see, what else? Just about everything except maybe the way we work. In order to make these revolutionary changes, I see fundamental change in what it feels like to be alive, only we will still struggle to apply to humans.



Rosalyn Berne
University of Illinois

What first comes to your mind when you think of "nanotechnology"?
The first thing I think of is, "that's nature's world way down there!" Because so much of what nature does starts at that nanoscale. But nanotechnology is about humans working in that world, that domain of the exceedingly small.

If you weren't in science, what else would you be doing?
I study scientists, and I think and write about what scientists do. Maybe if I wasn't doing that I would be a scientist. I am really interested in ornithology, marine biology, and geology.

What do you recall made you decide that you wanted to be in science?
When I was in middle school I used to do experiments on mice and plants in my bedroom. I started working to understand scientists instead of doing the actual science when I became curious about why humans interact with the physical and natural world in the ways we do.

In 20 years what do you imagine will be the most revolutionary change in our lives that involves nanotechnology?
I believe the advancements of nanotechnology in agriculture and food will be revolutionary in terms of how we produce, process, store and package food products. Nanoparticles will provide us the tools to produce healthier and more nutritious foods. Also, products will be created from irrigation in the table and ultimate point of consumption.



Rorm Scott
Cornell University

What first comes to your mind when you think of "nanotechnology"?
The world of "yummy stuff" with tremendous opportunities for the agriculture and food systems.

If you weren't in science, what else would you be doing?
I really have no idea because otherwise my first love was to be a major league baseball player, but talent and skills were not there! For sure I was going to be an engineer in some way!

What do you recall made you decide that you wanted to be in science?
A deep interest in mathematics and science through my high school years and success in them in college. In addition, growing up on a farm led to a very developed work ethic and an inquisitiveness about how things work!

In 20 years what do you imagine will be the most revolutionary change in our lives that involves nanotechnology?
That is difficult to say since the field is moving forward so quickly, but I see most of the advances being made in the development of new materials that are useful in a large number of applications that span all kinds of industries.



Jason Weiss
University of Nebraska, Omaha

What first comes to your mind when you think of "nanotechnology"?
A tremendous step forward with an as yet not fully explored potential for innovation. An incredibly exciting area to work in. As in all new technologies, though, the risks need to be critically evaluated.

If you weren't in science, what else would you be doing?
I decided to become an engineer when I was 15. My father was an engineer and I always wanted to follow in his footsteps. While studying chemical engineering in Germany I did a great Ph.D. advisor that got me on the path to become a professor in food science instead.

What do you recall made you decide that you wanted to be in science?
I am a huge fan of science fiction and I have always been interested in future technologies and the development of new scientific devices. Really young, I started out studying the design of large scale process equipment that can handle tons and tons of product. It's a little more that I ended up working on the tiny nanoscale scale.

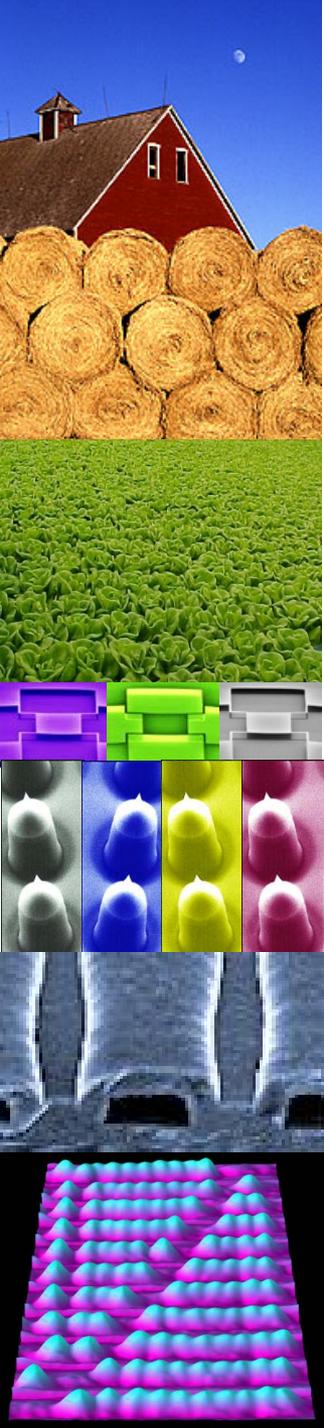
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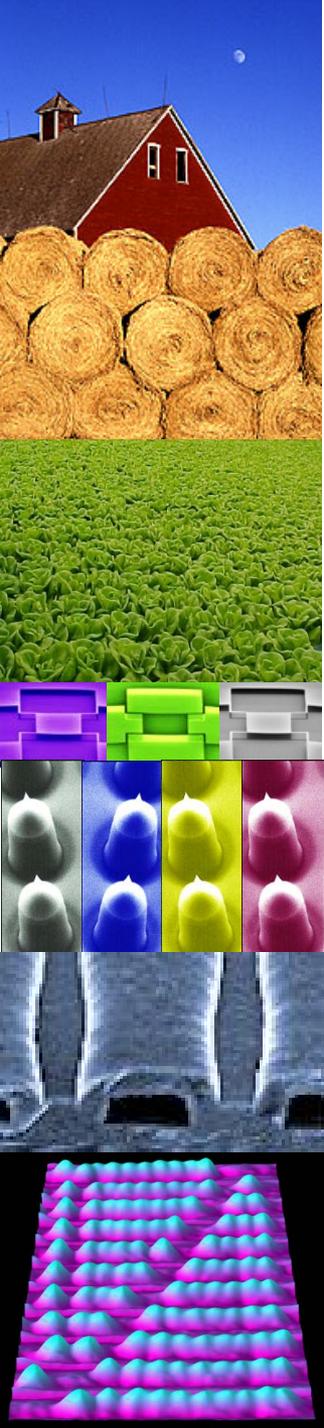
Rosalyn Berne urges caution for nanotechnology in agriculture

Rosalyn Berne studies the ethics of nanotechnology. She said we don't understand what happens to nano products used in agriculture, at the point when that product with nano particles washes into the soil.



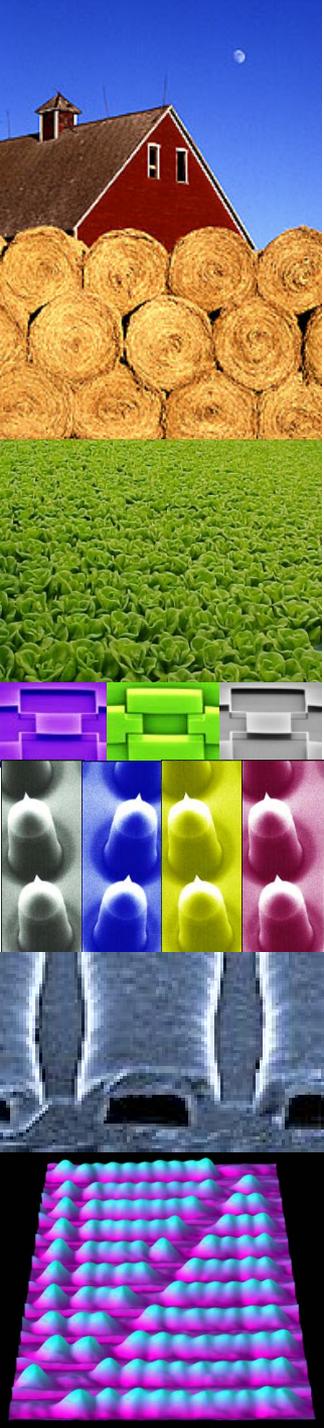
Lessons Learned Over Decade

- Program attractive to young scientists /engineers (an aging demographic)
- Embraced by the other research agencies
- Effectively flat funding (no “real” growth)
- Program under the radar (not necessarily good, particularly for future)
- Limited commercialization so far
- New programs require time to grow
- Grantees need to be active communicators
- Need to return to fundamentals?



VISION: Sustainable Agric. & Food Production (Convergence of nanotechnology, biotechnology, plant science, animal science, crop, and food science/technology will lead to revolutionary advances by 2020)

- **“Reengineering” of crops, animals and microbes at the genetic and cellular level**
- **Nanobiosensors for identification of pathogens, toxins, and bacteria in foods**
- **Identification systems for tracking animal and plant materials from origination to consumption**
- **Development of nanotechnology-based foods with lower calories and with less fat, salt, and sugar while retaining flavor and texture**
- **Effective systems for delivery of micronutrients, nutraceuticals and vitamins in foods for enhanced human health**
- **“Personalized nutrition” to meet very scientific, individualized health needs**
- **Integrated systems for sensing, monitoring, and active response intervention for plant and animal production**
- **Smart field systems to detect, locate, report and direct application of water**

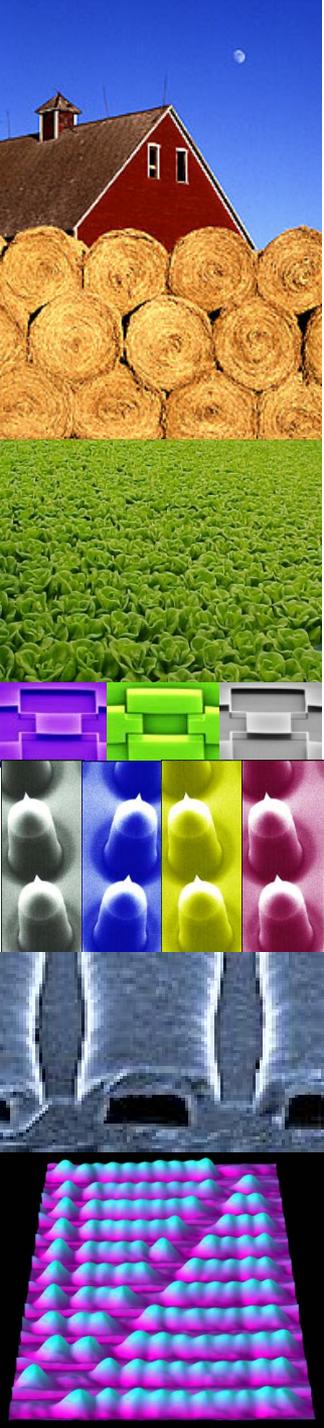


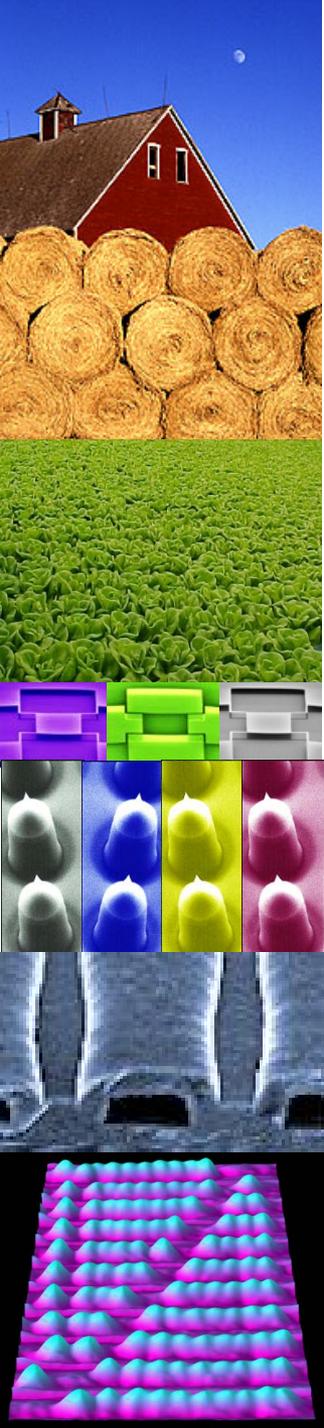
VISION: Sustainable Agric. & Food Production Convergence of nanotechnology, biotechnology, plant science, animal science, crop, and food science/technology will lead to revolutionary advances by 2020

- **Precision - and controlled release of fertilizers and pesticides**
- **Development of plants that exhibit drought resistance and tolerance to salt and excess moisture**
- **Nanoscale films for food packaging and contact materials that extend shelf life, retain quality and reduce cooling requirements**
- **Real time monitoring of soil conditions and intervention through control systems**
- **Water filtration and desalination**
- **Plants which capture N from air**
- **Nonintrusive nanodetection devices (saliva)**
- **Nanostructured catalysts conversion of biomass (cellulosic) materials for energy (fuels)**

Barriers to advancements

- Potential rejection by public
- Food is socially very sensitive
 - **“Shoot it in my veins but don’t make me eat it.”**
- Lack of regulations? standards? A need or not because GRAS foods
- Public perception “reactive engagement”
 - **Little to no participation in technical applications, product development**
- Insufficient research funding to capitalize on potential opportunities
- Resistance of food companies to engage & communicate about their research & products





Barriers to advancement

- Unknown effects on environmental, health and biodiversity?
- Labeling of foods?
- Ownership and control issues?
- Who benefits? Poor are most vulnerable.
- Consolidation of corporate power, marginalizes farmers' rights
- Lack of effective public/private partnerships (companies, academe & gov't)

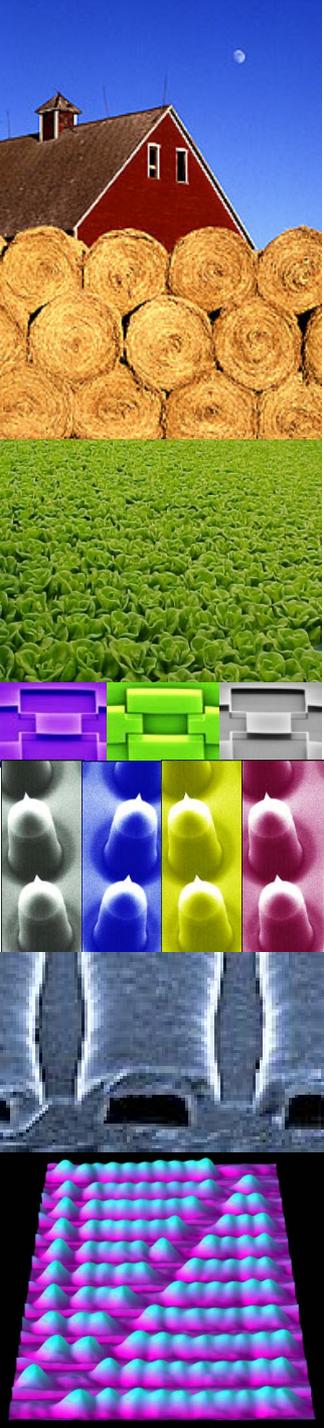
Governing Nanotechnology: Lessons from Agricultural Biotechnology Regulation

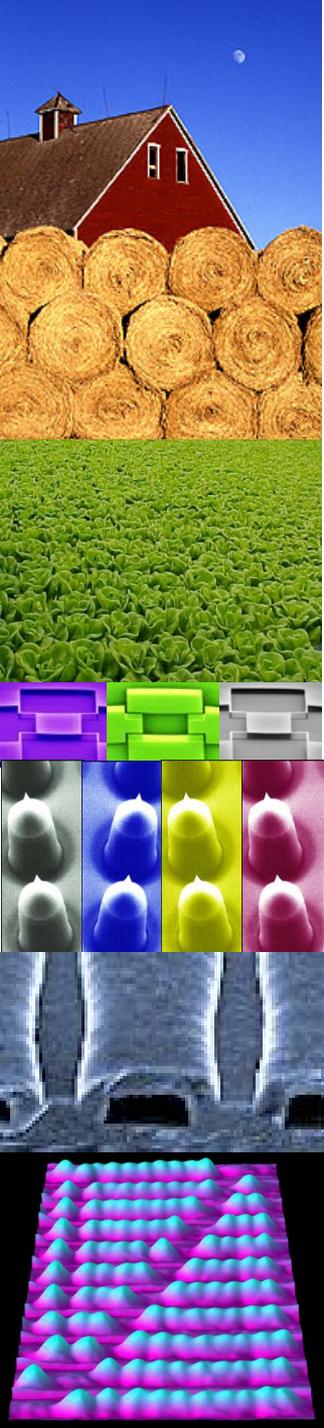
Robbin Johnson, J. Nanoparticle Res. (2011) 13:1467–1476

One way of designing oversight to achieve purpose is to think about it in three phases—

precaution, prudence, and promotion.

- Precaution comes early in the technology or product's development and reflects real and perceived uncertainties.
- Prudence governs when risks and hazards have been identified, containment approaches established, and benefits broadly defined. Transparency and public participation rise to the fore.
- Promotional phase moves toward shaping public understanding and acceptance and involves marketing issues rather than safety ones.





Conclusions and Priorities

There is no area of human activity more basic to society than a sustainable agricultural, food and natural resources system.

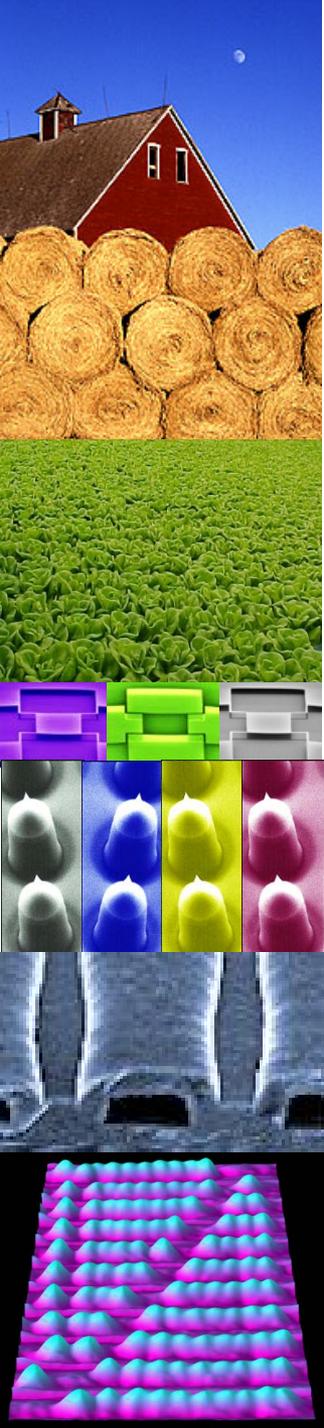
- An existing agricultural productivity system which has provided an abundant, affordable and safe food supply and many products faces the daunting challenge to meet the needs of a growing world population to approximately 9 billion people in 2050**
- Need to provide 60% increase in the amount of food now being produced.**
- However, it is more than just agricultural productivity because the system must function within the space of: minimum (zero) negative impacts on the environment, reduced (zero) greenhouse gas emissions (GHG), reduced water usage, world-wide adoption of emerging technologies, and major adoption of information technologies at all phases of the agricultural, food and natural resources system**

Thus, there is no system, more in need of and more likely to benefit from a comprehensive application of convergence technologies embodied in nanotechnology, biotechnology, information sciences and cognitive sciences.



**Systems make it possible,
but people make it happen.**

Christensen



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Science and Engineering in
Agriculture, Food and Natural
Resource Systems!