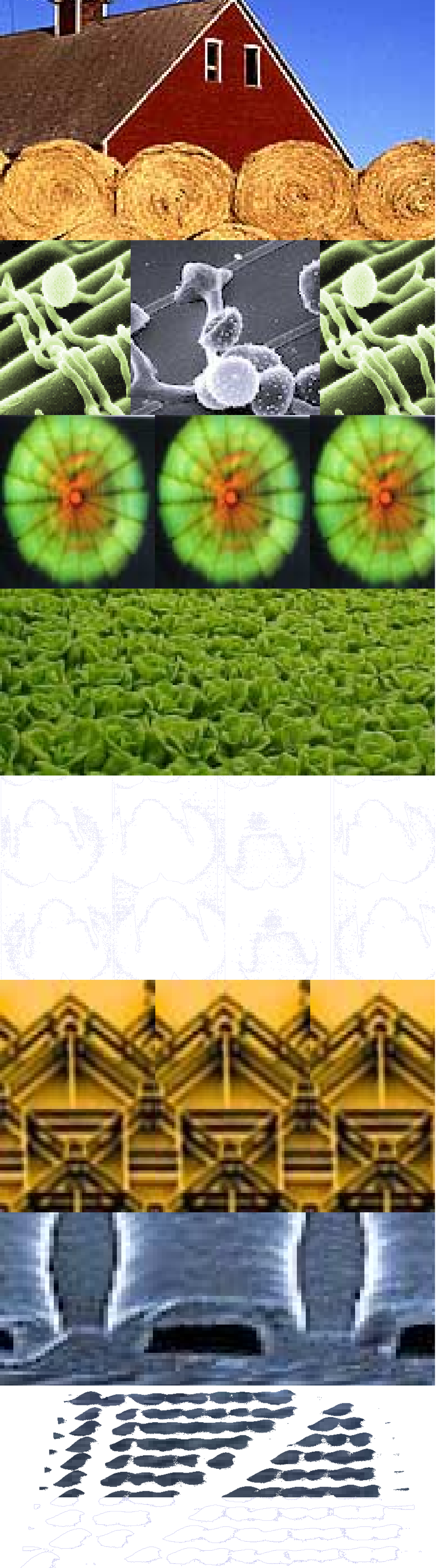
"We do not want science floating in the skies. We want to bring it down and hitch it to our plows."

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



NANOSCALE SCIENCE AND ENGINEERING FOR AGRICULTURE AND FOOD SYSTEMS

A Report Submitted to
COOPERATIVE STATE RESEARCH, EDUCATION, and EXTENSION SERVICE
THE UNITED STATES DEPARTMENT OF AGRICULTURE

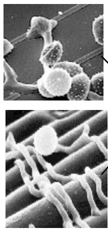
NATIONAL PLANNING WORKSHOP
November 18-19, 2002
Washington, DC

Co-Chairs:
Dr. Norman Scott, Cornell University
Dr. Hongda Chen, CSREES/USDA

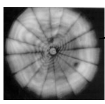
July 2003

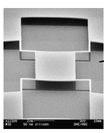
Front Page Photo descriptions and credits

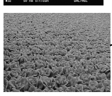

Small farm near Ames, Iowa.
Photo by Scott Bauer.
Source: ARS Image Gallery

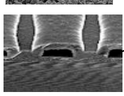

Source: Cornell NanoBiotechnology Center
Bioselective surfaces testing on fungal mycelium


Source: Cornell Nanofabrication Center
MEMS device.


Source: Cornell Department of Material Science
Micrograph of diamond anvil cell shows Hydrogen atom under ultra-high pressure in research that seeks to convert hydrogen gas to a metal. Photo by Arthur Ruoff.


Research into the physics of NEMS and MEMS
Source: Harold Craighead Reserach Group
Cornell University


Source: Cornell University CEA Program
Lettuce plants growing under controlled environment agriculture conditions at the Cornell CEA Greenhouse, Ithaca, NY


Source: Cornell NanoBiotechnology Center Scanning electron micrograph of a cleaved edge showing micron-sized tubes buried beneath an insulating layer. Photo by Steve Turner.


Source: Cornell NanoBiotechnology Center
Nanoscale surface features, such as these tips are used to produce substrates for attachment of biological motors
Photo by Dr. Hercules Neves.


Source: Dr. James Gimzewski, University of California, Los Angeles
Photo by Dr. Hercules Neves.
A Molecular abacus.

Forward

Nanotechnology has become a new and significant focus for federal investment in research. The National Nanotechnology Initiative (NNI), formed in 2000, is a crosscutting initiative involving ten federal departments and agencies. The NNI emphasizes long-term, fundamental research aimed at discovering novel phenomena, processes and tools. The USDA as a partner agency in the Federal NNI needs to identify opportunities and the potential to revolutionize agriculture and food systems through nanotechnology.

A National Planning Workshop: "Nanoscale Science and Engineering for Agriculture and Food Systems" was held at the USDA/CSREES Waterfront Center in Washington, D.C. on November 18 and 19, 2002. The objective of the planning workshop was to develop a science roadmap (strategic plan) with recommendations for implementation of a new program in nanotechnologies in the USDA (as a partner in the federal NNI) for agriculture and food systems. Planning workshop participants were leading nanotechnology researchers and administrators from Land Grant Universities and nanotechnology program leaders from other federal agencies. A list of the workshop participants and affiliations is provided in Appendix A and the workshop agenda is shown in Appendix B.

In development of this report, the planning workshop participants heard presentations reviewing the current programs by nanotechnologies leaders from DOD, DOE, NIH, NASA, DOC, EPA, FDA, the National Nanotechnology Coordinating Office (NNCO) and the National Science and Technology subcommittee on

Nanoscale Science and Engineering (NSET). The planning workshop participants also heard reviews of current Land Grant University research in the major research theme areas of microfluidics, bio-microelectromechanical systems, nucleic acid bioengineering, drug delivery, nanobioprocessing, biosensors, nanomaterials and bioselective surfaces.

Subgroups were convened on the second day of the Planning Workshop. In the subgroup sessions, participants identified specific goals of a national research program in nanotechnology for agriculture and food systems. The subgroup recommendations were presented for feedback from all meeting participants. After the Planning Workshop, the recommendations were compiled. The current report was edited through a coordinated effort, engaging the Subgroup Conveners and the Planning Workshop Chairs.

This report summarizes the recommendations of the National Planning Workshop and provides insights into the potential benefits of nanotechnologies in agriculture and food systems.

Executive Summary

Background

Nanotechnology is an enabling technology that has the potential to revolutionize agriculture and food systems. The National Nanotechnology Initiative (NNI) is a crosscutting initiative involving many federal departments and agencies and emphasizing long-term, fundamental research aimed at discovering novel phenomena, processes and tools. The USDA is a partner agency of the NNI. The Cooperative State Research, Education and Extension Service (CSREES) has identified specific priority research areas in agriculture and food systems, several of which will directly benefit from research in nanotechnology. Research areas, which are highlighted in this report, are complementary to and support the goals and missions of CSREES and the Experiment Station Committee on Organization and Policy (ESCOP). The research areas are: pathogen and contaminant detection, identity preservation and tracking, smart treatment delivery systems, smart systems integration for agriculture and food processing, nanodevices for molecular and cellular biology, nanoscale materials science and engineering, environmental issues and agricultural waste, and educating the public and future workforce.

Chapter Summaries

The fundamental areas of nanotechnology science and engineering that have the potential to serve as an enabling technology for agriculture and food systems are delineated in the following chapters of this report. The bullets below summarize the contents of each chapter.

- A brief description of the basic areas (microfluidics, BioMEMS, nucleic acid bioengineering, smart delivery systems, nanobioprocessing, bioanalytical nanosensors, nanomaterials and bioselective surfaces) is given in Chapter 1, a Nanotechnology Primer.

- Chapter 2 reviews the relationship of nanotechnology to science and engineering in agriculture and food systems. Nanotechnology holds the potential to revolutionize agriculture and food systems in the United States and the potential to place the US in a world-leadership position for new agriculture and food systems.
- Chapter 3 describes a critical agriculture and food systems capability: pathogen and contaminant detection. Through the use of bioanalytical nanosensors, new assay systems, sample retrieval systems and fundamental mechanistic sensor research and modeling are envisioned.
- Research into identity preservation and historical tracking of agricultural commodities is described in Chapter 4. Development of devices and data loggers for detection of pesticides, fertilizers and foreign matter for the life history of agricultural commodities is foreseen in a "Little Brother Technology*" research program.
- Chapter 5 envisions targeted research for treatment delivery systems that may have multiple applications having an impact on improved digestibility and flavor of food and for nutrient applications and implantable self-regulating drug delivery systems that might be activated to combat disease long before symptoms are evident.
- The research opportunities described in Chapter 6 include the integration of nanosensing systems with reporting, localization and control systems. These "Smart Systems" will allow real-time monitoring and control of plants and animals, and their local environment.

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* Terminology suggested by Dr. Michael Ladish

- Molecular and cellular biology are vital research fronts for agricultural scientists. The development of new research tools that operate at the nanoscale are described in Chapter 7, including nanofiltration devices and a nanobioreactor, critical for the study of enzymatic processes, microbial ecology and kinetics in biological communities such as compost systems. Nanodevices and materials for enhanced gene insertion and gene therapy for veterinary medicine are described.
- Chapter 8 describes research priorities such as new self-healing nanomaterials, bio-selective surfaces development and fundamental nanomaterials science research, including modeling of the process of self-assembly in biological systems as templates for nano-self-assembly.
- Environmental issues and agricultural waste challenges are addressed with nanotechnological concepts in Chapter 9 including the extraction of biopolymers from agricultural products and the design of nanocatalysts for waste bioprocessing.
- Educating the public and future workforce is discussed in Chapter 10, including the recommendation for active support of graduate research programs and the use of the exciting, highly visible aspects of nanotechnology to excite students about agricultural science, food science and agricultural engineering careers.
- Chapter 11 is devoted to budgetary considerations for a national program in nanotechnology for agriculture and food systems. Shared user facilities with existing nanotechnology research centers are recommended, however because agricultural and food research samples tend to be "dirty", dedicated equipment is needed within the existing centers of excellence.

- The Appendices provide additional information including: (A) a listing of the National Planning Workshop participants, (B) the meeting agenda, (C) a matrix of interactions and cross considerations between the proposed areas of research, (D) information sources and (E) a list of abbreviations.

Recommendations

The USDA/CSREES should significantly enhance support for research in nanotechnologies in agriculture and food systems through strong participation in the NNI goals. Areas of specific benefit to agriculture and food systems are identified in this report. The National Planning Workshop Participants recommend a significant financial investment in nanotechnology research as an enabling technology for agriculture and food systems.

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Chapter 1
A Nanotechnology Primer

What is Nanotechnology?

Nanotechnology is an exciting and rapidly emerging technology allowing us to work, manipulate and create tools, materials and structures at the molecular level, often atom by atom into functional structures having nanometer dimensions. Nature has been performing "nanotechnological feats" for millions of years. Through the arrangement of atoms and molecules, biological systems combine wet chemistry and electro-chemistry in a single living system. We are just beginning to catch glimpses of the nanoscale-methods used in nature to create self-replicating, self-monitoring, self-controlling, self-repairing, useful tools, materials and structures. "Nano" usually refers to a size scale between 100 and 0.1 nanometers (nm). For comparison, the wavelengths of visible light are between 400 and 700 nm. A living cell has dimensions of microns (thousands of nanometers) (Table 1.)

Table 1. Comparisons of scale from macro to molecular.

Size (nm)	Examples	Terminology
0.1 – 0.5	Individual chemical bonds	Molecular/atomic
0.5 – 1.0	Small molecules, pores in zeolites	Molecular
1 - 1000	Proteins, DNA, mesopores, inorganic nanoparticles	Nano
10^3 - 10^4	Microfluidic channels, MEMS, Devices on a silicon chip, living cells	Micro
> 10^4	Normal bulk matter	Macro

Microfluidics

Fluids are used to do work for humans at the macro-scale. As an example, rivers and canal locks move boats and barges carrying people and supplies all over the world. On the micro-scale, movement of fluids through micro-sized channels permit controlled, precise manipulation of the fluid environment around delicate microscopic cells. On the microscopic scale, fluids in micro-channels are very viscous and move more like molasses than like water. When two or more micro-fluidic channels are converged into a single stream, the converging streams do not mix easily; this is a property of laminar flow. Living cells can be arranged in single-file order using laminar flow of microfluidics, allowing new levels of precision science in cell biology. Other microfluidic applications are the potential for precision "point-of-care" diagnostics, drug screening, DNA manipulation and processing, monitoring of food, water supply, plant and animal health, and the environment.

Microfluidics is used today in animal science to significantly simplify traditional *in vitro* fertilization procedures used in animal breeding. Microfluidics also is an integral part of today's precision miniaturized "Lab-on-a-Chip" technology, allowing analysis and chemical manipulation of small samples. Microfluidics is at a larger scale than nanotechnology, but the merger of the dry world of nanotechnology with the "wet" world of biology will certainly involve the use of microfluidic techniques.

BioMEMS

Methods of making micro-sized machines, or microelectromechanical systems (MEMS) are already established. Fully functional pumps, rotors, sensors and levers exist at the micro scale. Moving from the micro to the nano scale NEMS devices will present new engineering challenges. However, as with microfluidics, the integration of existing MEMS technology with biological systems will yield a new class of machines, "BioMEMS", that will perform functions at the nanoscale or on nanoparticles. Biochips that are smaller than a postage stamp exist today. These biochips contain sealed channels and wells, electrodes for detection, connectors and fluidic input/output ports. BioMEMS will provide the interface between the macro and nano-worlds, as well as the interface between the biological and electromechanical worlds of technology.

<u>Nucleic Acid Bioengineering</u>

Many of the nanotechnology devices of today have been fabricated from larger pieces of silicon or other materials, through etching, much like sculpting away portions of the beginning material block to obtain the final structure. Nucleic Acid Bioengineering approaches manufacture from the opposite end – a "bottom-up" approach. Nucleic acid engineering utilizes DNA molecules as building blocks, and forms specifically shaped particles that can be used to build larger units. Nanowires and nanomembranes from these basic building blocks are envisioned. Nucleic acid engineering is a platform technology that can find a myriad of applications for agriculture and food systems through the development of novel materials.

<u>Smart Treatment Delivery Systems</u>

On the macro-scale, delivery systems such as the US Postal Service accepts items for delivery that are sealed in a package and have address instructions written on the outside of the package; both motorized and human carriers transport the package from one location to another. The development of "Smart Treatment Delivery Systems" on the nanoscale uses similar concepts applied at the molecular level. For example, smart drug delivery systems in animals will most likely contain small, sealed packages of the drug to be delivered. The packages will not be opened until they reach the desired location. A molecular-coded "address label" on the outside of the package will allow the package to be delivered to the correct site in the body. Nano and micro-scale mechanical systems may serve as the "carriers" in such a system. "Smart" delivery systems will also contain on-board chemical detection and decision-making capability for self-regulation that will deliver drug or nutrient treatments as needed. Remote activation and monitoring of intelligent delivery systems will assist agricultural growers of the future to minimize antibiotic and pesticide use.

Nanobioprocessing

Bioprocessing is the use of natural biological processes to create a desired compound or material from a defined feedstock, such as compost material from plant and animal wastes. Nanobioprocessing will focuses on and utilize nanoscale technology to achieve the goal of bioprocessing with greater efficiency. The use of molecular probes or development of devices that allow rapid identification of microbes present in a feedstock are examples of research at the nanoscale that will increase the efficiency of bioprocessing. The product itself may be bulk or nanomaterial.

Bioanalytical Nanosensors

Detection of very small amounts of a chemical contaminant, virus, or bacteria in agricultural and food systems are envisioned from the integration of chemical, physical and biological devices working together as an integrated sensor at the nanoscale. The bioanalytical nanosensors either use biology as a part of the sensor, or are used for biological samples.

Nanomaterials

Nanomaterials can be materials that are either newly-created through nanotechnology, or that exist in nature, such as nanoparticles found in soil (clays, zeolites, imogolite, iron and manganese oxides) that provide the potential to manipulate structures or other particles at the nanoscale and to control and catalyze chemical reactions. Materials are composed of particles. The shape, structure and aggregation of particles at the nanoscale influence the properties of the material at the macro-level. Nanoparticles have many applications in composite materials where they may provide transparency, or increased strength with decreased weight. "Smart fabrics" that can monitor the vital signs of the wearer are being investigated and is an example of some of the potential new uses and new processing methods envisioned for agricultural fiber products. Soils are aggregates of nanoparticles, layer particles and organisms and water. Nanoparticles are also produced as agricultural by-products: airborne dust and aqueous runoff that cause air and water pollution. Controlling these nanoparticles is in the best interest of efficient, cost-effective and environmentally responsible agriculture. Viewing soil as a nanocomposite, and applying the paradigms and technologies of nanoscale science to it, will lead to more efficient and environmentally friendly agriculture.

Bioselective Surfaces

Surfaces are the environment and location on which most chemical and biological interactions occur. A bioselective surface has either an enhanced or reduced ability to bind or hold specific organisms or molecules. Bioselective surfaces are important to the development of biosensors, detectors, catalysts, and the ability to separate or purify mixtures of biomolecules, as well as in the processing and packaging of food.

Interactions and Cross-Considerations between Research Theme Areas

Agriculture and Food Systems research themes such as environmental processing, pathogen detection, plant/animal production, bio-processing, biosecurity and sustainable agriculture may share common fundamental questions and research goals in the areas discussed above. The working group members identified cross-cutting common areas of research. These are shown in matrix form in Appendix C. For example, as seen in the matrix, the area of plant/animal production might benefit from research advances in the areas of bioselective surfaces, microfluidics, nano-bioprocessing, nucleic acid engineering, drug delivery technologies and nanomaterials research. The matrix of cross-considerations is provided as a guide for coordination of research between laboratories that may seem dissimilar but actually have a mutual interest in fundamental research questions.

Chapter 2
Relationship of Nanotechnology to Science and Engineering in Agriculture and Food Systems

Nanotechnology has the potential to revolutionize agriculture and food systems in the United States as a new enabling technology. Agricultural and food systems security, disease treatment delivery systems, new tools for molecular and cellular biology, new materials for pathogen detection, protection of the environment, and education of the public and future workforce are examples of the important links of nanotechnology to the science and engineering of agriculture and food systems. Some overarching examples of nanotechnology as an enabling technology are:

- Production, processing, and shipment of food products will be made more secure through the development and implementation of nanosensors for pathogen and contaminant detection.
- The development of nanodevices will allow historical environmental records and location tracking of individual shipments.
- Systems that provide the integration of “Smart System” sensing, localization, reporting and remote control will increase efficiency and security.
- Agricultural and Food Systems security is of critical importance to homeland security. Our nation’s food supply must be carefully monitored and protected. Nanotechnology holds the potential of such a system becoming a reality.

Today in agriculture, if a plant or animal becomes infected with disease, it can be days, weeks, or months before the presence of disease is detected by whole-organism symptoms. By that time, infection may be widespread and entire herds/fields will need to be destroyed. Nanotechnology is working at the same scale as a virus or disease infecting particle, and thus holds the potential for very early detection and eradication. Nanotechnology holds out the possibility that "Smart" treatment delivery systems could be activated long before macro symptoms appear. For example, a smart treatment delivery system could be a miniature device implanted in an animal that samples saliva on a regular basis. Long before a fever develops, the integrated sensing, monitoring and controlling system would detect the presence of disease and notify the farmer and activate a targeted treatment delivery system. Smart treatment delivery systems are envisioned for biology and bioactive systems such as drugs, pesticides, nutrients, probiotics, nutraceuticals and implantable cell bioreactors.

The fundamental life processes of agriculture are explored through research in molecular and cellular biology. New tools for molecular and cellular biology are needed that are specifically designed for separation, identification and quantification of individual molecules. This is possible with nanotechnology and will permit broad advances in agricultural research areas such as reproductive science and technology, conversion of agricultural and food wastes to energy and other useful by-products through enzymatic nanobioprocessing and disease prevention and treatment in plants and animals.

New materials that have special characteristics at the nanoscale will be a tremendous breakthrough in agriculture and food systems for pathogen and contaminant detection. Materials that have self-assembly and self-healing properties will find a multitude of applications in agriculture. Packaging of food in self-healing containers would prevent food microbial contamination and facilitate food preservation, storage and distribution.

Protection of the environment through the reduction and conversion of agricultural materials into valuable products is an exciting potential area of advancement made easier by nanotechnology. The design and development of new nanocatalysts for the conversion of vegetable oils into biobased fuels and biodegradable industrial solvents is one approach already under scientific examination that would be greatly enhanced with the addition of nanotechnological abilities.

Protection of the environment through management of local and environmental emissions is another exciting area of agriculture that could benefit from nanotechnology. Before reaching the dinner table, the lettuce salad, baked potato, broccoli and warm wheat bread have survived a formidable number of challenges from the environment and the environment has imposed decisions on the grower of each crop regarding the optimal timing of planting, irrigating, fertilizing and harvesting. Agricultural crops must be protected against the invasions of wild animals, weeds, insect pests, fungal pathogens, and the whimsy of the weather. Close daily scrutiny, or "scouting" of crops for potential problems is critical to the health of the crop and also reduces the amount of pesticides needed.

The Integrated Pest Management (IPM) approach, widely adopted in US agriculture today, reduces pesticide use on plant crops by only applying pesticides when needed, as determined by scouting the crop for pests. However, scouting is a time-consuming task for the grower, and requires a significant degree of expertise to recognize and diagnose symptoms of plant problems from insects, fungal pathogens, or animal-damage. Scouting for problems brought on by the environment also is important. The weather imposes challenges to plant growth through weather-induced water stress, heat stress, or through soil nutrient depletion. Timing and extent of irrigation or fertilization for various areas of the crop are determined by scouting. Many of these tasks could be simplified through nanotechnology.

Computerized control of the environment over small parcels of land is known as "Controlled Environment Agriculture" (CEA). CEA technology, as it exists today in the US, Europe and Japan, provides an excellent stage for the introduction of nanotechnology into plant production agriculture. With many of the monitoring and control systems already in place, nanotechnological devices for CEA that provide "scouting" capabilities could tremendously improve the grower's ability to determine the best time of harvest for the crop, the health of the crop, and questions of food security such as microbial or chemical contamination of the crop.

The National Nanotechnology Initiative's technical report (June 2002 supplement to the President's FY 2003 Budget) describes the initiative and its implementation plan. The President's supplemental report briefly identifies several impacts and applications of nanotechnology for agriculture and biotechnology. Among the exciting potential applications are biosynthesis and bioprocessing of new chemical and pharmaceutical products, integration of biological building blocks with synthetic materials, imitation of biological systems, molecular-engineered biodegradable chemicals for nourishing plants and protecting against insects, genetic improvement for animals and plants, drug and gene delivery to animals, and nanoarray-based technologies for DNA testing. This Workshop Report explores and expands the concepts of applications and impacts of nanotechnology for agriculture, agricultural biotechnology and food systems.

Chapter 3
Nanosensors for
Pathogen and Contaminant Detection

Today, sensors provide an abundance of information about such parameters as temperature and weather data and data that provide information on air, land and sea transportation, chemical contaminants, deceleration for release of airbags in automobiles and countless other variables. Biological organisms also have the ability to sense the environment. For example, humans sense the environment through sight, touch, taste, smell and sound. In living organisms, sensors operate over a range of scales from the macro (ear drum vibrations) to the micro (nerve cells) to the nanoscale (molecules binding to sensors in our noses).

The exciting possibility of combining biology and nanoscale technology into sensors holds the potential of increased sensitivity and therefore a significantly reduced response-time to sense potential problems. Imagine, for example, a bio-analytical nanosensor that could detect a single virus particle long before the virus multiplies and long before symptoms were evident in the plants or animals. Some examples of the potential applications for bioanalytical nanosensors are detection of pathogens, contaminants, environmental characteristics (light/dark, hot/cold, wet/dry), heavy metals, and particulates or allergens.

Desirable characteristics of biosensors were identified by the panel as: small, portable, rapid response and processing (i.e., real-time), specific, quantitative, reliable, accurate, reproducible, robust and stable.

Objectives and Opportunities of a National Research Program

Several sub-groups discussed the specific objectives of a national research program in bioanalytical nanosensors. The combined recommendations are: 1) to develop pathogen, nutrient, and contaminant detection systems and 2) to obtain an improved understanding of nanoscale sensor mechanisms through fundamental research and modeling.

Detection systems (Pathogen, nutrient deficiency or contaminant)

- *Sample Retrieval*: Develop retrieval nanosystems for sampling of specific components (from air, plant and animal organisms, water, soil).
- *Pathogen Detection*: Develop methods of near real time pathogen detection and location reporting using a systems approach, integrating nanotechnology micro-electromechanical systems (MEMS), wireless communication, chip design, and molecular biology for applications in agricultural security (economic, agricultural terrorism, agricultural forensics) and food safety.

Fundamental research and mechanistic modeling

In order to design the best nanosensors, we must understand the fundamental ways things work when sensing at the nanoscale. The following areas in our present day knowledge were identified as areas requiring more understanding for optimal nanoscale sensor development.

- New ways for nanosensors to capture and hold the pathogen or chemical of interest are needed. New immobilization techniques might be based on chemical, biological, or electrical methods of capture.

- New methods for sensors to "recognize" pathogens or chemicals must be found. The most promising areas for development of new recognition mechanisms are through fundamental studies in the areas of non-biomaterials, biomimetics, carbon nanotubes, molecular imprinted polymer (MIP), and recombinant/genetically engineered biosensors.
- New methods are needed for sensors to send a signal (also called "Transduction" of the signal) once it has recognized the pathogen or chemical of interest. Some promising possible methods for development of novel transduction mechanisms are mechanical, impedance, piezoelectric, optical, electrochemistry, transistor, DNA nanocircuits, and DNA resist/photolithography techniques.
- The above two steps (recognition and transduction of signal) must be integrated to work together. Promising areas for development of novel integration mechanisms between recognition element and the transducer may be found in utilization of the nanotechnology techniques of self-assembled monolayer (SAM) and directed/guided assembly.

Potential Outcomes and Impacts of the Research

Our nation's investment in this area of research has the potential to provide a safer world with respect to agricultural security, environmental preservation, and food and water safety.

Within 5 years

- Identification and control of pathogens, contaminants, and toxins throughout the food processing chain (i.e., at critical control points);
- Remote and continuous sensing of agricultural products during production in various environmental settings;

- Nucleic Acid Engineering-based probes and methods to amplify signals for detection of pathogens or contaminants;
- More rapid laboratory biosensors to detect pathogens or foreign materials that may be introduced during food processing;
- More rapid laboratory biosensors to detect pathogens on the farm (pathogens, viruses, chemicals);
- More rapid laboratory biosensors to detect proteins and genetically modified organisms (GMO's).

Within 5 to 15 years

- Rapid, real-time analysis of plant and animal health;
- Rapid response in agricultural systems via external and implanted sensor systems (realization of farm-to-table safety);
- Improved tools for veterinary medicine (for diagnosis, therapy, and disease detection and prevention);
- Hand-held sensors to detect pathogens, viruses, chemicals, proteins or GMO's introduced during food processing and on the farm;
- Disposable biosensor development;
- Consumer protection with over-the-counter sensors for food and environmental safety.

Chapter 4
Nanodevices for
Identity Preservation and Tracking

Nanotechnology in agriculture brings possibilities that at one time were only possible in science fiction. George Orwell's futuristic science fiction novel "1984" imagined a surveillance system named "Big Brother" watching over all peoples and locations. The Nanotechnology working group developing this chapter envisioned a less intrusive, nanoscaled surveillance system for the safety and security of today's agricultural products, coined, "Little Brother" technology.

Identity Preservation (IP) is a system that creates increased value by providing customers with information about the practices and activities used to produce a particular crop of food or other agricultural product. Certifying inspectors can take advantage of IP as a more efficient way of recording, verifying, and certifying agricultural practices. Today, through IP it is possible to provide stakeholders and consumers with access to information, records and supplier protocols regarding such information as the farm of origin, environmental practices used in production, food safety and quality and information regarding animal welfare issues. Some food or processed agricultural products may be stored for years, with intermittent samplings for storage pathogens or environmental storage problems. Each day, shipments of food and other agricultural products are moved all over the world. Currently, there are financial limitations in the numbers of inspectors that can be employed at critical control points for the safe production, shipment, and storage of food and other agricultural products.

Quality assurance of agricultural products' safety and security could be significantly improved through IP at the nanoscale. Nanoscale IP holds the possibility of the continuous tracking and recording of the history which a particular agricultural product experiences. We envision nanoscale monitors linked to recording and tracking devices to improve identity preservation of food and agricultural products.

Objectives and Opportunities of a National Research Program

In setting the objectives of a national research program in this area, the panel focused on the "first steps" of IP for agriculture and food systems involving a measurable, realistically attainable goal, based on temperature changes due to changes in metabolism. Other environmental/physiological factors could be added to the system as the technology allows.

Topics were identified as research priorities for a national research program in nanoscale identity preservation (Little Brother Technology) for agriculture and food systems.

Quantify metabolic process energetics at a macromolecular scale using biodegradable sensor devices.

Develop a nanothermal device/data logger (monitoring temperature changes) for life history of agricultural commodities (storage, shipping, delivery to store and transfer to the consumer).

Develop devices/data loggers for detection of pesticides and fertilizers for life history of agricultural commodities (storage, shipping, delivery to store).

Potential Outcomes and Impacts of the Research

Our nation's investment in this area of research has the potential to significantly enhance the safety, security, and quality of agricultural products and food systems.

Within 5 years

- Miniaturized (but not disposable) test kits for determining field pathogens;
- Miniaturized monitors for grain storage or feed storage facilities;
- Protein or microbial-based detectors on a chip.

Within 5 to 15 years

- Biodegradable sensors for temperature, moisture history of stored food;
- Biodegradable sensors that track both physical and biological parameters for crops and some types of processed foods;
- Nucleic Acid engineering-based, nanoelectronic devices that combine both organic and inorganic components for agricultural and food system identity preservation.

Chapter 5
Nanodevices for
Smart Treatment Delivery Systems

Today, application of agricultural fertilizers, pesticides, antibiotics, probiotics, and nutrients is typically by spray or drench application to soil or plants, or through feed or injection systems to animals. Delivery of pesticides or medicines is either provided as "preventative" treatment, or is provided once the disease organism has multiplied and symptoms are evident in the plant or animal. Nanoscale devices are envisioned that would have the capability to detect and treat an infection, nutrient deficiency, or other health problem, long before symptoms were evident at the macro-scale. This type of treatment could be targeted to the area affected.

The development of "Smart Delivery Systems" for agriculture is defined as any combination of the following: time-controlled release, spatially-targeted release, self-regulated, remotely regulated, preprogrammed, or multifunctional so as to avoid biological barriers to successful targeting. Smart delivery systems also could have the capacity to monitor the effects of the delivery of pharmaceuticals, nutraceuticals, nutrients, food supplements, bioactive compounds, probiotics, chemicals, insecticides, fungicides, or vaccinations to people, animals, plants, insects, soils and the environment.

Objectives and Opportunities of a National Research Program

The following areas are identified as research priorities for a national research program for agriculture and food systems smart treatment delivery systems research.

1) Develop delivery systems for biological and bioactive systems (drugs, pesticides, nutrients, probiotics, nutraceuticals and implantable cell bioreactors).

2) Develop integrated sensing, monitoring and controlling capabilities with on-board intelligence for self-regulation or remote activation for food production, storage and packaging applications.

3) Develop targeted site delivery capability from implants in animals and plants that are activated only as needed.

4) Design food nanostructure, oral delivery matrices, particulates, emulsions and nanodevices for enhanced food flavor and digestibility.

Potential Outcomes and Impacts of the Research

Our nation's investment in this area of research has the potential to reduce costs by treating only the diseased part of a crop at an early stage of infestation and to decrease the quantities of water, fertilizer, pesticide and medicinal products used in agricultural production.

Within 5 years

- Develop a health monitoring device for large animals utilizing saliva as a non-invasive indicator;
- Develop a non-invasive plant health-monitoring device for "early fault detection" in hydroponic plant growth systems (less complex than soil-based systems) based on detection of changes in plant metabolism, respiration, root-zone excretions and root zone microbial ecology.

Within 5 to 15 years

- Large animal health monitoring and therapeutic intervention;
- Small animal health monitoring and therapeutic intervention;
- Develop a non-invasive plant health monitoring system for "early fault detection" in field soil-based plant growth systems based on changes in plant metabolism, respiration, root zone excretions and root-zone microbial ecology;
- More efficient water, fertilizer and pesticide use, decreased pollution and greater economy in destroying only the diseased part of a crop at an early stage of infestation;
- Develop Nucleic Acid (e.g., DNA) delivery systems for value-added agricultural products (animals and plants) and other applications (transgenic, cloning, assisted reproduction, animal vaccines, animal disease control agents).

Chapter 6
Smart Systems Integration: Sensing, Localization, Reporting and Control

The nanotechnologies described in chapters 3-5 will only reach their full potential through integration. Thus, "Smart Systems Integration" is similar to designing and building the logic of a "nervous system" that will allow the individual parts to work together. Integration of the nanotechnologies into a working control system (whether remotely controlled or under automatic control) will require electronic communication between several technologies, including the sensing systems, reporting systems, localization systems and control systems. The logic to control the subsystems (control algorithms) must be developed and eventually translated into a computer language.

Objectives and Opportunities of a National Research Program

The following topics are recommended as Smart Systems Integration research priorities for Agriculture and Food Systems.

- Develop microfluidic devices that allow real-time temporal and spatial sensing and reporting for animal and plant production systems, food safety and security, biochemical/biomass processing or environmental monitoring applications.
- Integrate Nano-Electromechanical Systems (NEMS) with remote receive/transmit systems (embedded on the chip, satellite interaction, global positioning systems, remote powering, biopowering).

- Develop integrated sensing, monitoring and controlling capabilities with on board intelligence for self-regulation and remote activation for food production, storage and packaging applications;
- Design and develop automated integrated networks for monitoring and control of animal and plant production systems, food safety and security, biochemical/biomass processing or environmental monitoring applications.

Potential Outcomes and Impacts of the Research

Our nation's investment in this area of research has the potential to optimize the nanotechnologies developed through integration into working systems with the flexibility to evolve as new discoveries are made and new technologies evolve.

Within 5 years

- Develop control algorithms for the integration of sensing, reporting, localization (GPS), treatment delivery response, and control systems of nanotechnology devices for "Smart fields" and "Smart herds". The system logic should allow addition of new technologies as they evolve;
- Demonstration of the system using computer models of crops and herds.

Within 5 to 15 years

- Demonstration of a "Smart field System" that detects, locates, reports and applies water, fertilizers and pesticides only as needed;
- Demonstration of a "Smart herd System" that detects, identifies, reports and treats illness of a single infected animal in a herd prior to the onset of symptoms.

Chapter 7
Nanodevices for
Molecular and Cellular Biology

Molecular and cellular biology hold the tools to understanding the most fundamental life processes in agriculture. Agricultural research in these areas has broad applications including reproductive science and technology, plant and animal breeding, conversion of wastes to energy and useful by-products, composting science and technology, plant physiology, veterinary medicine, plant pathology, disease prevention and treatment to name a few.

Our ability to excel in these and other areas of agriculture will require novel tools allowing us to work and explore living cells and biomolecules at the scale of the molecule. Nanotechnology holds such a possibility.

Objectives and Opportunities of a National Research Program

Three areas have been identified as research priorities in the development of nanodevices for molecular and cellular biology.

1) Research and development of nanoseparation, identification and quantification devices is needed. Non-gel proteomic tools, membranes, sieves, and packings are needed to separate biomolecules in the range of < 100 nm in size. Tools for quantification also should be developed using fluorescent dyes attached to enzymes, nanoparticles, tags, markers, quantum dots, fiber optics or mass spectrometry.

2) Nanobioreactor development is needed for the study of enzymatic processes, microbial kinetics, molecular ecology, mixed enzyme systems and rapid assessment of response to environmental factors.

3) Research is needed in the development of nanodevices and materials for enhanced gene insertion processes, DNA delivery techniques for gene therapy, DNA vaccination, disease diagnosis and prevention for veterinary medicine and value-added plant and animal products.

Potential Outcomes and Impacts of the Research

Our nation's investment in this area of research has the potential to increase the efficiency and quality of the nation's agricultural production and food storage, to enhance the safety of food supplies for the protection of consumers and producers, and to introduce new functionality (value-added products) for food, fiber, and agricultural commodities.

Within 5 years

- New ways to study molecules, DNA and cells for food, nutraceutical and pharmaceutical applications;
  a) Provide higher resolution materials and devices for the separation of important enzymes and other biomolecules that are key catalysts for industrial biotechnology;
  b) Provide novel methods for observing single molecule events that will allow assessment of protein engineering efforts focused on important industrial polysaccharide degrading enzymes;

- Advanced instruments and methods for DNA and protein identification and manipulation;
    a) Provide novel laboratory-on-a-chip proteomics technology for assessment of metabolic pathways in important microbial biocontrol agents;
    b) Provide rapid and reliable DNA methods for detection of phytotoxins and pathogens in digested and composted animal waste to determine their subsequent safe use in agriculture;
- Novel Nucleic Acid Engineering-based films with more sophisticated and controllable nano, and micro structures for agricultural and food applications (e.g., protein separation from agriculture products).

Within 5 to 15 years

- Highly sensitive field instruments for monitoring food safety and plant and animal health;
- Highly sensitive, field instruments for monitoring environmental factors and product quality;
- Improvement of food safety, plant, animal and consumer health, and the quality and nutritional value of food.

Chapter 8
Nanoscale Materials Science and Engineering, Environmental Issues, Agricultural Waste, and Nanoparticles in the Environment

Nanoparticles are naturally occurring or human-made particles with nanoscale size or surface features that yield unique properties in materials at the macro scale. Nanoparticles currently have applications in imaging, printing, advanced materials, medicine, pharmaceuticals and drug delivery. The panel identified potential applications for and novel sources of nanoparticles in agriculture and food systems.

Novel materials developed through materials science and engineering are critical to the advancement of agriculture and food systems. Natural nanoparticles in soil, water, and air must be understood to the point that their characteristics and behavior can be controlled so that this natural resource may be more fully utilized. Agricultural practices also create and disperse nanoparticles. The environmental abundance of nanoparticles produced by agriculture must be understood and any negative effects mitigated.

Objectives and Opportunities of a National Research Program

National research priorities for agriculture and food systems in this area are:

1) New nanomaterials development

- Develop novel nanomaterials (DNA nanowires, DNA-microelectronic hybrids, bioseparation/biofilms) by design using DNA as a building block. Building up from individual blocks rather than starting with a material and etching/carving away portions is referred to as a "bottom-up" approach to nanomaterial construction.

- Investigate self-healing materials from self-assembled fatty-acids, surface modification (plasma technique) and coatings to modify properties of agricultural materials and packaging for the improvement of food packaging and prevention of food microbial contamination,
- Develop better nanophase soil additives (fertilizers, pesticides, and soil conditioners).

<u>2) Materials science: bio-selective surfaces development</u>

- Develop surfaces with enhanced selectivity or that select against molecular interactions through biological, chemical, physical (including atomic, molecular, and nanoscales) for cells and biomolecules.
- Develop smart surfaces that have controllable active spatial and temporal binding and release properties that are adaptable to agriculture and food systems (limited sample preparation, complex systems (dirty), more robust.
- Develop novel bioselective surfaces (bind different molecules to DNA, DNA pattern at surface, porous metal with DNA, controlled pore size of DNA film, controlled molecular structure for filtration) using "bottom-up" approach.

<u>3) Fundamental nanomaterials science research</u>

- Conduct research to increase our understanding of the mechanics of nanomaterials; the transition from bulk to nanoscale behavior and chemical behavior in agricultural materials, changes in morphology, texture, chemistry.

- Develop measurement methods and apply new measurement techniques to apply multiscale modeling to agricultural systems.
- Characterize and model the physiochemical properties of natural and synthetic surfaces at the nanoscale to understand their basis for bioselectivity.
- Characterize and model the process of self-assembly in biological systems such as triglycerides as templates for nano-self-assembly.

<u>4) Nanoparticles in soil and air</u>

- Understand the role of nanoparticles (inorganic and organic) in the transport and bioavailability of nutrients and pollutants.
- Understand the transport and toxicity of nanoparticles in agricultural pollution (dust, feedlot runoff).
- Understand soil as a complex nanocomposite, using the chemistry and physics of nanoscale and molecular phenomena to better model its properties.
- Understand the role of nanoparticles in the global carbon cycle and the role of agriculture in global CO_2 levels.
- Understand the role of nanoparticles in water retention and conditioning of soils.

<u>5) Biopolymers from plant waste</u>

- Identify new agriculturally-derived biopolymers for industrial and biomedical applications.

- Explore more efficient methods of biopolymer modification; enhance processing for industrial products, harvesting, and fractionation.
- Conduct research leading to a greater understanding of the structural and functional aspects of biopolymers.

<u>6) Nanocatalysts design for waste bioprocessing</u>

- Design and develop nanocatalysts for conversion of vegetable oils and other plant wastes (e.g., corn stover) to biodegradable industrial solvents and bio-based fuels.
- Improve food quality through nanoscale processes that enhance the nutritional or nutraceutical composition of foods.

<u>7) Waste management and environment</u>

Conduct research into nanoscale processes or nanoscale phenomena that lead to the reduction and/or conversion of animal or plant waste into value-added products, and assist in the management of local and environmental emissions from agricultural or food production/processing systems.

Potential Outcomes and Impacts of the Research

Investment in nanotechnology materials research has the potential to reduce usage and costs of agricultural chemicals (fertilizers, pesticides), enhance environmental quality by detecting and mitigating environmental contaminants and provide longer shelf life and less contamination of food products.

Within 5 years

- Development of instrumentation based on bio-selective surfaces for early detection of plant and animal pest and pathogen detection;
- Development of "smart detectors" for spoilage organisms in consumer packaged food-stuffs leading to longer shelf life and reduced contamination of food;
- Demonstration of nucleic-acid engineering based "bottom up"[*] material-by-design approaches to new materials for agriculture and food systems.

Within 5 to 15 years

- Develop inexpensive "smart one season use" field deployed microsensors for detection of pests and pathogens and improved soil health;
- Develop nanosurfaces for remediation of pollutants, pathogens, bioactive molecules from the environment, plants and animals prior to processing, and food products;
- Develop anti-fouling nanosurfaces for food processing equipment and bioreactors;
- Have a positive impact on global carbon dioxide management;
- Improved environmental practices including more efficient use of water, fertilizer and pesticides, decreased salt build-up and nutrient leaching from soils, decreased agricultural pollution.

[*] Fabrication of new materials through the "bottom up" approach refers to using nucleic-acid molecules as building blocks rather than the traditional method of starting with blocks of materials that are etched/sculpted away to create a building block or sub-unit.

Chapter 9
Educating the Public and the Future Workforce

Nanotechnology is a part of our nation's future and the future of agriculture and food systems. Thus, it is critical that the future workforce be trained in nanotechnology. The first step is informing the public at large about the advantages and challenges of nanotechnology for agriculture and food systems. As the public awareness increases, so will interest in the study of nanotechnology by today's students increase. Transfer of technology to industry is another national priority identified by the panel and will further serve to educate the public and future workforce about the potential advances offered by nanotechnology for agriculture and food systems.

Objectives and Opportunities of a National Research Program

This recommendation of investment in education of the public and future workforce includes both educational grants and funding for research infrastructure. Recommendations of the panel are:

<u>Education of students</u>

Nanotechnology is an exciting, futuristic, highly visible research frontier that can be utilized in education to excite students about agricultural science, food science, and agricultural and biological engineering careers. Showing the continuity between the fundamentals of nanotechnology and applied agriculture will draw attention to nanophenomena in agriculture, in nature, and will capture the imagination of young people considering careers in agriculture and food systems science and engineering. Agriculturalists of the future need a solid grounding in quantitative science and engineering. Research grants or fellowships for graduate study and research are a priority.

Education of the public

Nanotechnology and nanomaterials have the potential to play a significant role in risk reduction for issues of agriculture and food systems security. The public should be educated through television, Internet, and point-of-sale informative bulletins that explain the value-added, increased safety and food security due to application of nanotechnology. In addition to security of tracking systems and contaminant detectors, agricultural and food systems processes can be made more efficient, and reduce the extent of pesticide use, increasing food safety for the consumer.

Infrastructure support

The National Nanotechnology Initiative currently funds several Centers of Excellence. Because the "dirty" nature of agricultural and food samples, it is recommended that separate, dedicated equipment be added to the existing centers for the analysis of agricultural samples.

Technology transfer

With the increase in industry working with academia and competing for government research funding, there is a need for restructuring of Intellectual Property issues.

Potential Outcomes and Impacts

Our nation's investment in this area of research has the potential to create a new generation of scientists proficient in both agriculture and nanoscale science and technology.

Within 5 years

- K-12 recognition of the impact of nanotechnology on everyday life;
- Motivation for pursuing engineering and science in high school curricula.

Within 5 to 15 years

- Engineers and scientists who will be leaders in agriculture, particularly as it applies to devices and technology developing from advances in nanotechnology research.

Chapter 10
Budgetary Considerations

Budgetary considerations were initially developed and reviewed at the National Planning Workshop: “Nanoscale Science and Engineering for Agriculture and Food Systems”, held at the USDA/CSREES Waterfront Center in Washington, D.C. on November 18 and 19, 2002. A follow-up teleconference to refine the budgetary considerations and recommendations was held February 14, 2003 and included all session leaders and the workshop chairpersons. The recommended budget is shown below, followed by a justification for each area of recommended funding.

Fundamental Research (Principal Investigator Initiated)	**4.5**
6 areas @ 3 projects per area x $250K/project	
Theme Area Challenge (Multidisciplinary)	**4.2**
6 areas @ 2 projects per area x $350K/project	
Centers of Excellence	**20.0**
4 regional Centers @ $5 Million/year	
Public Outreach/Ed. 1% of budget=$50K/y/Center	
Research Infrastructure	**5.0**
Specialized equipment @$5 Million/year	
Education	**2.6**
Graduate Fellowships ($32K/y * 50/y) = 1.6	
Postdoctoral Training ($60K/y * 15/y) = 0.9	
Professional Development ($10K * 10/y) = 0.1	
Public Outreach & Education (see Centers of Excellence)	
TOTAL	**36.3**

Fundamental Research: The fundamental research funding should be Principal Investigator initiated through competitive grants. It is recommended that each of the six areas (Sensors, Identity Preservation, Smart Treatment Delivery, Smart Systems Integration, Molecular and Cellular Biology, and Materials Science) provide funding for three new projects per year at approximately $250K/project.

Theme Area Challenge The Theme Area Challenge competitive grants should be Multidisciplinary. It is recommended that each of the six areas provide funding for two new projects per year at approximately $350K/project.

Centers of Excellence: It was recommended that the program utilize the NSF model of 1 to 2 primary University hubs, each with 3 to 4 collaborative University partners. PUBLIC EDUCATION/OUTREACH should be managed through the Centers, with 1% of the Center budget dedicated to Public Education/Outreach activities. Each Center would manage the Outreach Programs as they see appropriate for their region, rather than management at the National level.

Research Infrastructure: The funding level for specialized equipment is recommended to be $5 Million per year, as single-equipment items for Nanotechnology research are expensive.

Education: Graduate fellowships are recommended to be $30 per year, with 50 fellowships funded per year. Postdoctoral training grants (15 grants per year) are recommended to be $60K per year ($40K for salary plus 50% overhead). The working group also discussed the importance of professional development training for established professors interested in the emerging Nanotechnology fields and Nanotechnology experts interested in the fields of Agriculture and Food Systems. It is assumed that the professors' home institution will cover salary. Travel funds of $10K for 6 weeks (summer) for 10 professors per year are recommended.

Appendix A

National Planning Workshop –
Nanoscale Science and Engineering for Agriculture and Food Systems

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Appendix B

National Planning Workshop –
Nanoscale Science and Engineering for Agriculture and Food Systems
USDA/CSREES, Waterfront Center, Room 1410
800 9th Street, SW, Washington, DC
November 18-19, 2002

<u>Monday, November 18, 2002</u>

7:30	Registration and Continental Breakfast
8:00 – 8:10	Introduction Dr. Hongda Chen, NPL, USDA/CSREES Dr. Norman R. Scott, Professor, Cornell University
8:10 – 8:20	Opening remarks Dr. Rodney Brown, Deputy Under Secretary, USDA/REE
8:20 – 8:30	Welcome remarks Dr. Colien Hefferan, Administrator, USDA/CSREES
8:30 – 9:00	National Nanotechnology Initiative Dr. Mihail C. Roco, Senior Advisor, NSF and Chairman, National Science and Technology Council's Subcommittee on Nanoscale Science, Engineering and Technology (NSET)
9:00 – 9:20	Defense University Research on Nanotechnology Dr. Cliff Lau, Office of Basic Research, Deputy Under Secretary of Defense, Department of Defense
9:20 – 9:40	Nanoscale Science, Engineering, and Technology in the DOE Office of Science Dr. Walter J. Stevens, Office of Basic Energy Science, Department of Energy
9:40 – 10:00	Nanoscience and Nanotechnology Programs at NIH Dr. Eleni Kousvelari, Chief, Cellular & Molecular Biology, Physiology & Biotechnology Branch, Division of Basic and Translational Sciences, National Institute of Dental and Craniofacial Research, NIH
10:00 – 10:20	Morning Break
10:20 – 10:40	The Convergence of Bio and Nano Technologies: A NASA Perspective Dr. Minoo N. Dastoor, Senior Advisor to Associate Administrator, Office of Aerospace Technology, NASA
10:40 – 11:00	Measurements and Standards for Nanotechnology Dr. Michael P. Casassa, Director, Program Office, National Institute of Standards and Technology, Department of Commerce

11:00 – 11:20 Nanotech at EPA: Applications and Implications
Dr. Barbara Karn, National Center for Environmental Research, ORD, EPA

11:20 – 11:40 Regulatory Considerations for Nanotechnology in Public Health
Dr. Norris Alderson, Senior Associate Commissioner for Science, Office of Science and Communication, FDA

11:40 – 12:00 The NNI Grand Challenges - Selection, Investment Strategy and Metrics
Dr. James S. Murday, Director, National Nanotechnology Coordinating Office

12:00 – 1:30 Lunch.

Posters presentations displayed. All participants are welcome to present research results with a poster presentation. Posters will be on display for the duration of the workshop.

1:30 – 5:00 Presentations by Land-Grant University Researchers outlining major research themes in nanotechnologies:

1:30 – 1:50 Microfluidics: Microfluidic Technology for Assisted Reproduction. Dr. Matthew Wheeler, Professor, Animal Science Department, University of Illinois

1:50 – 2:10 BioNems: BioMEMS, Bio-Nanotechnology and Agricultural Research. Dr. Michael Ladisch, Professor, Agric. & Biol. Eng., Purdue University

2:10 – 2:30 Nucleic acid bioengineering; Dr. Dan Luo, Assistant Professor, Biol. & Env. Eng., Cornell University

2:30 – 2:50 Drug delivery: Dr. Mauro Ferrari, Professor, Biomedical Eng. Center, The Ohio State University

2:50 – 3:10 Nanobioprocessing: Dr. Larry Walker, Professor, Biol. & Env. Eng., Cornell Univ.

3:10 – 3:30 Biosensors: Nano-Biosensors for Sensing, Monitoring and Control in Agriculture and Food Systems. Dr. Antje Baeumner, Assistant Professor, Biol. & Env. Eng., Cornell University

3:30 – 3:50 Nanomaterials: Nanoparticles: Natural Agricultural Nanomaterials in Soil, Water, and Air. Dr. Alexandra Navrotsky, Professor, Chem. Eng. & Mat. Sci., Univ. of California, Davis

3:50 – 4:10 Bioselective surfaces: Bioselective Surfaces for Nanotechnology in Agriculture.
Dr. Harvey Hoch, Professor, Plant Pathology, Cornell University

4:10 – 4:30 The Involvement of Nanotechnology in the USDA SBIR Program: Dr. Charles Cleland, Director, SBIR Program, USDA/CSREES *(Special presentation)*

4:30 – 5:00 Discussion

6:30 – 10:00 Dinner meeting and cruise on the Potomac River. Spirit Cruise, Pier 4, 6th and Water Streets, S.W., Washington, DC. Speaker, Dr. Patrick Looney, Assistant Director, Physical Sciences, Office of Science and Technology Policy (OSTP), The Executive Office of the President (EOP).

<u>Tuesday, November 19, 2002</u>

7:30 Continental Breakfast

8:00 - 11:30 Breakout Sessions to develop roadmap/strategic plan for USDA Program in the National Nanotechnology Initiative. Breakout Sessions by theme area (listed above).

12:00 Lunch

1:00 - 4:00 Feedback Session from Breakout Groups. Drafting of the Science Roadmap for National Nanotechnology Rresearch for Agriculture and Food Systems.

Appendix C

Matrix of Interactions and Cross Considerations

USDA Nano-thematic Topics for Agriculture and Food Systems	Transport Processes	Bio-selective Surfaces	Bio-Separation	Micro-fluidics	NanoBio-Processing	Nucleic Acid Engineer-ing	Drug Delivery	Modeling	Nano-materials
Environ-mental Processing	●		●	●	●	●		●	●
Pathogen Detection	●	●	●	●	●	●		●	●
Plant/Animal Production Transgenics Cloning		●		●	●	●	●		●
Bio-Processing Foods Industrial Products	●	●	●	●	●				●
BioSensors (Biosecurity	●	●	●	●	●	●	●	●	●
Sustainable Agriculture	●	●	●	●	●	●			●

Appendix D

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Appendix E
List of Abbreviations

CEA	Controlled Environment Agriculture
CSREES	Cooperative State Research, Education, and Extension Service
DNA	Dioxyribonucleic acid
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
ESCOP	Experimental Station Committee on Organization and Policy
FDA	Food and Drug Administration
FY	Fiscal Year
GMO	genetically modified organism
IP	identity preservation
IPM	Integrated Pest Management
MEMS	microelectromechanical systems
MIP	molecular imprinted polymer
NASA	National Aeronautics and Space Administration
NEMS	nanoelectromechanical systems
NIH	National Institutes of Health
nm	nanometer
NNCO	National Nanotechnology Coordinating Office
NNI	National Nanotechnology Initiative
NSET	National Science and Technology subcommittee on Nanoscale Science and Engineering
SAM	self-assembled monolayer
USDA	United States Department of Agriculture