Report to the Governor and the General Assembly of the Maryland Task Force to Study Nanobiotechnology

January 1, 2011

Task Force Co-Chairs

The Honorable Jennie Forehand
The Honorable Susan Lee

Task Force Members

Dr. Judith Britz
Dr. Esther Chang
Dr. Stephen Desiderio
Dr. Nariman Farvardin
Dr. Patrick Lu
Ms. Lisbeth Pettengill
Mr. Robert Rosenbaum
Dr. Peter Searson
Dr. Peter Swaan
Dr. Lawrence Tamarkin
Ms. Renée Winsky

Table of Contents

MARYLAND TASK FORCE TO STUDY NANOBIOTECHNOLOGY

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FOREWORD

Maryland has one of the largest concentrations of life sciences in the country, giving the State unique opportunities to capitalize on important emerging biosciences such as nanobiotechnology. Maryland resources include proximity to the federal government, highly educated and skilled workers, and a culture of innovation and entrepreneurship. Specific to the life sciences, Maryland has over 500 bioscience companies with 30,000 employees, some of the top researchers in the world at our nation's highest university institutions, and federal laboratories, and 50 hospitals around the State with 100,000 employees.

In 2009, the BioMaryland 2020 ten-year strategic plan to maintain the State's life sciences preeminence was created by the Maryland Life Sciences Advisory Board, the commission appointed by Governor Martin O'Malley to oversee the State's biotechnology initiatives. The BioMaryland 2020 strategic plan sought to position Maryland for global leadership in cutting-edge areas of bioscience research and emerging growth markets. Also in 2009, the Maryland Department of Business and Economic Development (DBED) partnered with the Maryland Technology Development Corporation (TEDCO) to deliver the first-in-the-nation State direct funding exclusively for nanobiotechnology research, a $3 million program for collaborative industry-university-government nanobiotechnology research in Maryland. In 2008, the Maryland General Assembly had passed legislation that expressly authorized State funding for nanobiotechnology research.

To capitalize on this momentum and in order to best position Maryland to play a significant role in one of the nation's highest scientific priorities, the 2010 General Assembly enacted legislation creating the Task Force to Study Nanobiotechnology. Pursuant to the legislation, Governor O'Malley appointed the Task Force chaired by Senator Jennie Forehand and Delegate Susan Lee in August of that year. The Task Force held its inaugural meeting on September 29, 2010. A second Task Force meeting was held on November 10, 2010. As enacted by law, the Task Force shall prepare this report to the Governor and the General Assembly by January 1, 2011. The authority of the Task Force expires on May 31, 2011.

This Task Force report provides an analysis of current Maryland programs and resources for nanobiotechnology and offers a series of recommendations to support its research and commercialization, consistent with and growing out of the BioMaryland 2020 strategic plan. The Maryland Life Sciences Advisory Board, a permanent commission created by law and charged to oversee the implementation of the BioMaryland 2020 strategic plan, intends to carry forward the Task Force recommendations through its Emerging Technologies Working Group.

TASK FORCE STATUTORY AUTHORITY

The 2010 Maryland General Assembly enacted legislation that created the Task Force to Study Nanobiotechnology. House Bill 795, Task Force to Study Nanobiotechnology, was introduced in February 2010 by Delegate Susan Lee and 16 cosponsors. H.B. 795 was approved in March with amendments by the House Economic Matters Committee and the House of Delegates. The Senate Finance Committee took up the bill, which subsequently passed the Senate with amendments in early April. H.B. 795 was returned to the House for concurrence with amendments and given final passage. The Governor signed the bill in mid-April and appointed the Task Force on Nanobiotechnology as prescribed by the legislation in August, 2010. By statute, the authority for the Task Force expires after one-year on May 31, 2011.

The preamble of the statute reads:

> *WHEREAS,* Recent advances in nanotechnology and nanobiotechnology have the potential to revolutionize the treatment of cancer and other serious diseases as well as the development of state–of–the–art electronics, medical equipment, chemical processes, building materials, and a wide array of other commercial products; and
>
> *WHEREAS,* Robust nanotechnology and nanobiotechnology industries in the State will create jobs, generate significant revenue for the State, and improve the quality of life for countless individuals.

The composition of the Task Force to Study Nanobiotechnology and the appointed members are:

- One (1) member of the Maryland Senate, as appointed by the Senate President *(Senator Jennie Forehand);*
- One (1) member of the Maryland House, as appointed by the House Speaker *(Delegate Susan Lee)*;
- The DBED Secretary, or his designee *(Judith Britz)*;
- The TEDCO Chair, or his designee *(Rob Rosenbaum/John Wasilisin)*;
- The Tech Council of Maryland Chair, or his designee *(Renee Winsky)*;
- Three (3) representatives of Maryland higher education institutions involved in research or scholarship on nanobiotechnology, as appointed by the Governor *(Nariman Farvardin-UMD, Peter Searson-JHU, Peter Swaan-UMB)*;
- Three (3) representatives from regional or local organizations that advocate on behalf of the life sciences, as appointed by the Governor *(Esther Chang-ASN, Lisbeth Pettengill-GBC, Steve Desiderio-LSAB)*; and
- Two (2) individuals who serve as CEOs of private nanobiotechnology companies, as appointed by the Governor (*Larry Tamarkin-CytImmune, Patrick Lu-Sirnaomics)*.

In addition, representatives of the National Institutes of Health, the National Institute of Standards and Technology, the Food and Drug Administration, and the U.S. Patent and Trademark Office were invited to join and participate in Task Force meetings. By statute, the appointed legislators serve as the Task Force Co-Chairs. Biographies of Task Force members are included in the Appendices of this report.

The charge to the Task Force is to "make recommendations regarding actions that the State should take to promote the growth of nanobiotechnology industries, with particular emphasis on:

(1) ***The benefits of nanobiotechnology***, with attention to job creation; development of lifesaving treatments; reductions in health care costs; development of state-of-the-art electronics, medical equipment, chemical processes, and other commercial products; and generation of revenue for the State; and improvements to the quality of life for the State's citizens; and

(2) ***The State's role in supporting Maryland's leadership in nanobiotechnology***, with attention to promoting public-private partnerships; assisting companies in technology transfer, including from research to commercial product; promoting research; protecting intellectual property; offering appropriate financial incentives, including tax credits; and capturing and leveraging federal funds for both public and private ventures

TASK FORCE MEETINGS

Upon its formation, the Task Force held two public meetings in locations throughout Maryland. The minutes of these meetings are included in the Appendices of this report.

The inaugural Task Force meeting was held on September 29, 2010 at the Maryland Biotechnology Center in Rockville at the Shady Grove Innovation Center to review and assess State resources for nanobiotechnology.

Presenters at the September 2010 meeting included:

- Delegate Susan Lee, discussing H.B. 795, the legislation that created the Task Force on Nanobiotechnology;
- Judith Britz, Ph.D., Executive Director, Maryland Biotechnology Center, Maryland Department of Business and Economic Development discussing the Maryland Biotechnology Center resources, the Maryland Life Sciences Advisory Board, and the BioMaryland 2020 Strategic Plan;
- John Wasilisin, Vice President, Maryland Technology Development Corporation (TEDCO), discussing TEDCO resources and the 2009 General Assembly enactment of the Coordinating Emerging Nanobiotechnology Research (CENTR) in Maryland legislation;
- Ben Wu, Senior Technology Policy Advisor, Maryland Department of Business and Economic Development and Linda Saffer, Ph.D, Program Manager, University Programs, Maryland Technology Development Corporation (TEDCO) discussing the 2009 $3 million Maryland Nanobiotechnology Research and Industry Competition Grants Program;
- Renee Winsky, Chief Executive Officer, Tech Council of Maryland, discussing TCM/MdBio resources for the nanobiotechnology industry;
- Nariman Farvardin, Ph.D, Provost, University of Maryland College Park, discussing State support of nanobiotechnology programs for the University System of Maryland (USM) research, faculty, and facilities;
- Peter Swaan, Ph.D, Director, Center for Nanomedicine and Cellular Delivery, University of Maryland School of Pharmacy, discussing nanobiotechnology research at the University of Maryland, Baltimore;
- Peter Searson, Ph.D, Director, Johns Hopkins Institute for Nanobiotechnology, discussing the Institute for Nanobiotechnology at Johns Hopkins University;
- Stephen Desiderio, M.D.,Ph.D, Director, Johns Hopkins Institute for Basic Biomedical Sciences and Director, Immunobiology Unit, Institute for Cell Engineering, Johns Hopkins School of Medicine, discussing nanobiotechnology research at the Johns Hopkins School of Medicine and the Maryland Life Sciences Advisory Board (LSAB) Emerging Technologies Work Group;
- Esther Chang, President, American Society for Nanomedicine, discussing nanobiotechnology and the American Society for Nanomedicine; and
- Larry Tamarkin, CEO and Founder, CytImmune Sciences, Inc., providing an industry perspective on nanobiotechnology commercialization.

The second Task Force meeting was held on November 10, 2010 at the Maryland Biotechnology Center in Baltimore at the World Trade Center to discuss opportunities for the State to collaborate with the National Nanotechnology Initiative and federal research efforts to promote nanobiotechnology research, policy, and regulation.

Presenters at the November 2010 meeting included:

- Lisbeth Pettengill, Vice President, Greater Baltimore Committee, discussing Greater Baltimore Committee (GBC) resources for the nanobiotechnology industry;
- Sally Tinkle, Ph.D, Deputy Director, National Nanotechnology Coordination Office, discussing the National Nanotechnology Initiative (NNI) and opportunities to coordinate federal nanotechnology research and innovation;
- Michael Weinrich, M.D., National Institutes of Health (NIH), discussing the NIH approach to nanobiotechnology;
- R. Alta Charo, Senior Advisor, Food and Drug Administration (FDA) Office of the Commissioner, discussing FDA approaches to nanotechnology regulation;
- Nakissa Sadrich, Ph.D, Office of Pharmaceutical Science, FDA Center for Drug Evaluation and Research (CDER), discussing CDER/FDA regulatory perspective on nanomedicines;
- Lloyd Whitman, Ph.D, Deputy Director, Center for Nanoscale Science and Technology, National Institute of Standards and Technology (NIST), discussing NIST, a national nanotechnology resource for innovation and economic development;
- Patrick Lu, Ph.D, President and CEO, Sirnaomics, discussing nanoparticle-enhanced multi-targeted siRNA therapeutics;
- Martin Woodle, Ph.D, Chief Scientific and Executive Officer, AparnaBio, discussing tissue targeted RNAi particles; and
- Dietrich Ruehlmann, Ph.D, Director of Business Development, Izon Science USA, discussing an industry perspective on nanobiotechnology commercialization.

INTRODUCTION TO NANOBIOTECHNOLOGY

Nanotechnology is the understanding and control of matter at dimensions between approximately one and 100 nanometers (one billionth of a meter), where particles are not simply small, but have unique characteristics that enable novel applications, as defined in the National Nanotechnology Initiative 2010 report. A nanometer is one ten-thousandth the width of a human hair. In nature, DNA is two to twelve nanometers (nm) diameter, the HIV virus 130 nm, hepatitis virus 45 nm; and hemoglobin (made up of four protein molecules) is 6.5 nm. A bacterium, at 2.5 micrometers (µm), is 1,000 times the size of DNA. Using physical, chemical, biological, and engineering science, novel techniques are emerging for probing and manipulating single atoms and molecules. At this scale, the electronic, mechanical, thermal, optical, and catalytic properties of matter can be altered.

As its name suggests, **molecular biology** is the study of life at the molecular level, and advances have enabled scientists to sequence; that is, to determine the primary structure of molecules that make up the human genome and to combine the genetic elements of two or more living cells. The human genome is a human's hereditary information.

The field of **biotechnology** involves the use of living organisms and bioprocesses in engineering, technology, medicine, and other fields aimed at improving the human condition. It has ancient origins in the use of yeast in fermentation, bacteria to make cheese, and selective breeding of livestock. It includes genetic engineering as well as cell and tissue culture technologies.

The intersection of nanotechnology and biotechnology, or **nanobiotechnology**, the science and engineering of nanobiosystems, holds great promise. The similarity in size of nanomaterials and most biological molecules and structures make them useful for both biomedical research and applications. To date, this integration has led to the development of diagnostic devices, contrast agents for imaging, analytical tools, therapy applications, and highly targeted drug delivery vehicles, among others.

Medical nanomaterials include drug nanoparticles, DNA materials (including RNA), quantum dots, dendrimers, fullerenes, nanotubes, and nanowires; some would include monoclonal antibodies in the definition of nanobio products.

Nanomedicines include, nanopolymer medicines, PEG-based nanomedicines, crystalline nanomedicines, liposomal nanomedicines, and, some would argue, monoclonal antibodies.

Nanodiagnostics include *in vitro* nanodiagnostics (monoclonal antibody-based nanodiagnostics, immunological reagents, cellular analysis reagents, immunohematology reagents, research reagents, DNA-based nanodiagnostics, amplified DNA probes, direct DNA probes, DNA microarrays) and *in vivo* diagnostics such as MRI imaging agents.

MARYLAND NANOBIOTECHNOLOGY ASSETS SNAPSHOT:

In a field in which basic research is the critical bedrock, Johns Hopkins University has competed successfully for large scale nanobiotechnology federal funding. The University of Maryland is achieving national recognition as a nanotechnology powerhouse.

Multiple large companies based in Maryland are working at the nanoscale and partnering with universities and a host of smaller companies to commercialize resultant products.

More than a dozen federal laboratories located in Maryland or near its borders provide research funding, nanobiotechnology workforce development, and shared user facilities for prototyping and scale-up of nanobiotechnology-enabled products.

State organizations to foster technology commercialization and facilitate public-private-academic partnerships include the Maryland Department of Business and Economic Development (DBED), the Maryland Biotechnology Center (MBC), and the Maryland Technology Development Corp. (TEDCO).

With the leadership and support of the Governor and the General Assembly, Maryland's head start toward the future of nanobiotechnology includes, among other initiatives:

* A $3 million, first-in-the-nation State funding program exclusively for nanobiotechnology research;

* Existing statutory authority for Maryland to provide nanobiotechnology research grants;

* Large scale Sunny Day funding for university laboratory facilities and faculty to support nanotechnology research;

*Incubation of over half of Maryland's start-up nanobiotechnology companies in State-supported facilities;

*Maryland Venture Fund public-private financing support for companies at all stages of commercialization; and

*Appointment of a Task Force to Study Nanobiotechnology and make recommendations for State policy

Nanotechnology medical supplies include wound management products (wound dressings, wound closures), bone substitutes, dental products, surgical supplies and devices (surgical textiles and surgical devices), medical implants (orthopedic implants, cardiac implants, cochlear implants), ophthalmic products (nanocoated lenses, retinal implants), catheters and related devices, disinfectants, and artificial skin.

It is important to note that definitions in this field are being actively debated, which may have implications for developing robust regulatory regimes on which technology developers can depend.

In nature, molecules are capable of assembling themselves through naturally-occurring selective intermolecular binding forces, for example base pairs in DNA, highly specific enzyme/substrate interactions, and the self-assembly of bacteriophages, which are machines for the injection of viral DNA into a host cell. Visionaries are working on using both bottom-up self-assembly and mechanically-engineered techniques to produce molecular "machines" that can re-order matter at the atomic scale. For example, sensing the difference from a healthy cell upon entry and making modifications to its structure – powered by the energy generated by normal life functions, such as blood flow.

Nanobiotechnology-based advances in biological research and medicine require physics, engineering, computer science, chemistry, and biology expertise to design and fabricate nanoscale molecules, devices, and systems, to deploy them with beneficial results, and to assess their life cycle impact on human and physical environments.

Sophisticated characterization equipment and techniques are needed to measure and precisely control the morphology, size, and dimensions of materials in the nano range. A recent overview of the industry predicts that "wet" nanotechnology – nanobio – rather than hard crystalline materials will become the dominant form of nanotechnology, and that increasingly the latter will need to be able to interface with biological systems.

New instruments may well be required, moving on from the electron microscopy tools used in semiconductors to new tools capable of direct visualization of the size, size distribution, and concentration of nanoscale particles in solution[1] or airborne.[2] The requirements of scaling up for mass production will also lead to new techniques and instruments different from those developed for laboratory experimentation.

The use of nanobiotechnology in medicine is termed **nanomedicine**, research in which includes the development of diagnostics for rapid monitoring, targeted cancer therapies, localized drug discovery, improved cell material interactions, scaffolds for tissue engineering, and gene delivery systems.

[1] For example NanoSight, www.nanosight.com
[2] For example WRAS (wide range aerosol spectrometer) by Ecomesure, www.ecomesure.com

BENEFITS OF NANOBIOTECHNOLOGY AND ITS FORESEEABLE IMPACT

Nanobiotechnology holds great promise and is being used for:

- Identifying the molecular origins of many diseases, which is paramount for effective treatment, and monitoring predictive molecular changes through molecular assembly and biosensors, paving the way for personalized medicine;

- Developing more selective therapies that minimize medical side effects (including the synthesis of new multifunctional, highly targeted devices that enhance efficacy and reduce toxicity);

- Enabling health monitoring and early diagnosis of disease through novel lower cost diagnostic tool kits;

- Advanced imaging techniques using magnetic nanoparticles in MRI and quantum dots (nanoscale crystals that emit light) in x-ray analysis for real time assessment of molecular activity, including labeling and tracking stem cells;

- Establishing the knowledge base needed for biocompatible prosthetics and regenerative medicine, including stem cell-based scaffolds for tissue engineering and neuromorphic engineering;

- Supporting continued research, e.g. through chip-based nanolabs for rapid analysis; and

- Assessing and, in some cases, ameliorating the human and physical environmental damage created by human activity.

INDUSTRY SPOTLIGHT

CytImmune Sciences, Inc. was founded in 1988. Its patented colloidal gold nanotechnology, Aurimune®, consists of a colloidal gold nanoparticle with a one-molecule thick polymer coating that absorbs water and shields the nanoparticle from detection by the immune system. On one side there is a molecule that only binds to tumor cells and on the other a therapeutic "payload," for example an anti-cancer agent that disrupts the blood supply to the tumor. This approach limits the exposure of healthy tissue to the potent anti-cancer agent, enabling the use of more powerful doses. Aurimune has successfully been tested in a Phase I clinical trial in advanced cancer patients. The National Cancer Institute in Bethesda, MD conducted the study and the results of that study were just published in Clinical Cancer Research (Libutti et al, 2010). Now located in Rockville, the company began in the UMD TAP incubator and has won federal Small Business Innovation and Advanced Technology Program (now TIP) awards to further its research and used the NCL and the GMP facility at CARB.

The first benefits from nanobiotechnology applications have been realized in the research field, where nanoarrays are replacing microarrays in proteomic and genomic activities because of superior performance and cost. Not only do the nanoarrays use 1 billion times less fluid than conventional microarrays, they also use 50-100 times less of the sample being analyzed. *(Hussey 2010)*

Nanobiotechnology also holds great promise for research on manufacturing tiny carriers of drugs and modifying the carriers so that they localize at disease sites, using the exquisite selectivity of biology, as reflected in both DNA and proteins, to direct the assembly of nanostructures. Maryland researchers are "decorating" nanotubes or other nanoparticles with biological molecules, transporting them through microfluidic environments to complementary targets, and using inherent bioselectivity and other means to put the nanostructures together into circuits and systems. The interdisciplinary marriage of nano and bio promises tremendous advances spanning the spectrum from new paradigms in fundamental scientific inquiry to health, security, and everyday consumer applications. *(www.nanocenter.umd.edu)*

Biomimetic approaches are being used to mimic cells and entrap and destroy harmful viruses when they attack, and implanted sensors coated with nanogels for biocompatibility, now being tested in animals, can be controlled externally via wireless transducers. For example, the sensors can serve as continuous glucose monitors.

Earlier this year, researchers at MIT and Harvard announced that they believe they have found a way to use nanotechnology to replace the drug-coated heart stent, a product plagued with safety concerns. The research is very preliminary and only tested in rats. The approach being tested would inject heart patients with nanoparticles that will cling to artery walls and gradually release medicine that helps stop the growth of scar tissue.[3]

[3] http://web.mit.edu/press/2010/nanoburrs

A FUTURE ROAD MAP FOR NANOBIOTECHNOLOGY[4]

The National Nanotechnology Initiative (NNI) was begun in 2001 to create a coordinated U.S. framework to develop priorities and actions. Currently totaling $1.7 billion, the NNI completed its first decade ("Nano1") in 2010. This milestone led one of its architects, Dr. Mihail Roco,[5] to summarize the long view of the field that emerged from five global "Nano2" workshops, summarized in the following paragraphs.

The first generation nanotechnology products were considered "passive" nanostructures used as components to improve existing products. Starting in 2005, however, "more sophisticated products with 'active' nanostructures have been introduced, such as point-of-care molecular diagnostic tools and life-saving therapeutics. [During the past five years,] entirely new classes of materials have been discovered and developed … Nanoscale medicine has made significant breakthroughs in the laboratory, advanced rapidly in clinical trials, and made inroads in biocompatible materials, diagnostics [e.g. Verigene system], and treatments [e.g. Abraxane, a cancer therapy] … Over 50 cancer-targeting drugs based on nanotechnology are in clinical trials in the U.S. alone."

Industry R&D in nanotechnology overall has already exceeded the total federal investment. Products derived from industrial research have yielded approximately $91 billion, primarily in industrial sectors. Between 2000 and 2008, worldwide primary nanotechnology (including nanobiotechnology) employment has grown 25 percent per year to 400,000 (150,000 in the U.S.), the Scientific Citation Index up 23 percent, patent applications up 35 percent, final products up 25 percent, public and private R&D funding up 35 percent, and venture capital investments up 30 percent.[6]

The global competitiveness for nanotechnology is severe. NNI statistics show that Japan and South Korea have been investing more in nano R&D per capita than the U.S; the EU and Taiwan totals are close behind. Japan, South Korea, and Taiwan have built stronger R&D capabilities in chemistry, physics, and particularly material science, while U.S. dominates the life science, environmental, and, to a lesser extent, information technology nanofields. Given the worldwide race for nanotechnology innovation, the federal government is welcoming any and all State assistance to assert U.S. leadership in this growing market.

Dr. Roco continues his future outlook by stating that , in "Nano2, "the next decade's challenge of building systems from the nanoscale will require the combined use of nanoscale laws, biological principles, information technology, and system integration. The semiconductor industry, which already incorporates nanotechnology in over half its output, will derive 100 percent of its value from nanotechnology by 2020 and pharmaceuticals, 50 percent.

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[4] This section is based on the soon-to-be-published *Nanotechnology Research Directions for Societal Needs in 2020 Retrospective and Outlook*

[5] Mihail Roco, the National Science Foundation's senior advisor for nanotechnology and key architect of the National Nanotechnology Initiative

[6] NNI statistics did not break out nanobiotechnology; see MARKETS section for more detail.

INDUSTRY SPOTLIGHT

Sirnaomics, a biopharmaceutical company, was launched in 2007 in Gaithersburg and Shanghai. It discovers and develops novel targeted therapeutics for critical human diseases by using multi-targeted design of small interfering RNA (siRNA) and nanoparticle-enhanced delivery. The company uses a proprietary algorithm to predict the sequence of siRNA that have the ability to turn off genes that can be best used against a gene target of interest. It uses high throughput assays to validate the target, and a third generation nanoparticle delivery scheme that features temporally and locally controlled delivery systems with infrared activated siRNA and photodynamic therapeutics. The company's therapeutic product pipeline for its multi-targeted "cocktail" technology includes skin scarless wound healing that has potential also for acne treatment, lung fibrosis, spinal cord injury, corneal scaling, and colon cancer surgery. Phase I trials will begin next year. Products for flu and ocular neovascularization will be reaching clinical trials in 2012, followed by products for glioblastoma, breast cancer, lung cancer, organ transplant, spinal cord injury, RSV infection, liver cancer, and Crohn's disease. Research collaborators include JHU, Duke, and Chinese pharmaceuticals companies. Funding has been received from MIPS, NIH/NIAID SBIR awards (glioblastoma and flu), NIH/NCI SBIR (lung cancer), the Chinese Minister of Health and others. It has licensed a nanoparticle technology from UMB School of Medicine.

Six million people (two million in the U.S.) will be employed and final products incorporating nanotechnology are expected to grow to $1 billion by 2015 and $3 billion by 2020. By the end of this decade, mass application of nanobiotechnology is expected to be seen; it will become a general-purpose enabling technology like electricity or computing, making it pervasive in virtually every aspect of the economy, even though its development may be in a formative stage.

Between 2010 and 2020, NNI and Dr. Roco have identified the following fundamental goals to attain and barriers to overcome in the realm of nanobiosystems and nanomedicine:

- **Characterization of nanoscale molecules** – evaluating characteristics such as particle size, size distribution, surface charge, surface properties, and particle interactions (such as aggregation) that may be relevant to dose, stability, or other characteristics significant to biological interaction or product quality. Techniques for tackling this basic challenge, which are not the same as those for larger molecules, are under development;

- Diagnostics, including low cost point of care diagnostics (nanodiagnostic tools are expected to become the backbone of clinical medicine), biological diagnostics (live cell imaging of cellular components), and non-invasive diagnostics using saliva and breath nanoscale detection;

- **Therapeutics**, including pharmacokinetics, biodistribution, targeting, tissue penetration; widespread adoption of nanomaterials for chemotherapy to reduce toxic side effects and improve effectiveness; to improve gene therapy; and enable inexpensive gene sequencing;

- **Tissue engineering**, including use of nanoarchitecture to engineer tissues for repair and creation of artificial organs and regeneration of spinal cord, cardiac, and other tissue;

- **Stem cells**, including use of nanobiotechnology to enhance understanding and control of stem cells for widespread medical application, multifunctional nanoparticle delivery systems for drug and siRNA delivery, and widespread use of nano-enabled stem cell-based therapies for spinal cord regeneration;

- **Synthetic biology** -- the design and construction of biological functions and systems not found in nature – in regenerative medicine, biotechnology, pharmaceuticals, and energy;

- **Manufacturing**, including controlled manufacturing methods for producing more complex nanostructures and nanosystems at scale and molecular printing techniques for single-molecule positioning of proteins on a surface and exquisite control of surface-stimulated processes such as stem cell differentiation, at large scales; and

- **Environment and safety**, including better understanding of the nano-bio interface, knowledge for managing risk; and high throughput screening for hazards and risk assessment, reduction of animal experimentation.

The currently approved and marketed "second generation" cancer nanodrugs consist of chemotherapeutic agents formulated with liposomes – prepared membrane-enclosed sacs that contain drugs and can bind to cancer cell membranes – or bound to the protein albumin that can deliver high concentrations of drugs to cancer cells and cause less damage to healthy cells than systemically administered drugs. Beyond lowered toxicity, drug development companies now seek to improve the targeting and efficacy of the nanoscale agents.[7]

These challenges and the commercialization of new nanodiscoveries and developments are being addressed by Maryland universities, federal laboratories, research institutes and private companies profiled in sections of this report.

[7] GENetic Engineering and Biotechnology News, Analysis & insight: Jul 19, 2010

CURRENT AND EMERGING MARKETS FOR NANOBIOTECHNOLOGY

Of all applications of nanotechnology, products incorporating nanotechnology in the chemicals industry account for the largest share, but those in pharmaceuticals and healthcare are the fastest growing. *(Global Business Analysts October 2010)* In 2006, chemical applications accounted for $80 billion in sales and sales of all other applications were negligible. By 2012, chemical applications are projected to have increased slightly, but pharma/healthcare will have surpassed them to $110 billion.

The analysis for Cientifica concludes that nano is, along with bio and info, **one of the platforms enabling 21st century technology**. *(Harper 2007)* One of the dangers in using projections of market size for nanobio, however, is that the estimates are for the value of products that contain minute amounts of nanomaterial, not the material itself.

If, as predicted, all products will become nanotechnology-enabled within the next 20 years, some claim that there is little value in predicting the market size of its applications. *(Berger 2007)* The market estimates, and there are many, bear out Berger's point. Freedonia Group's extensive analysis, "Nanotechnology in Health Care to 2014," projects that by 2019, nano-enabled products will account for 34 percent of all U.S. health sales, exhibiting explosive growth from the nine percent in 2004.

Increasingly over the next decade, nanomedicines will account for a larger and larger share of sales of nanotechnology medical products, up to 80 percent of the total $149 billion expected by 2019; nanodiagnostics and nanotechnology medical supplies and devices comprise the remainder. Growth in sales of all these products is projected to accelerate from 16 percent per year through 2014 and then grow to 17 percent annually through 2019.

Expenditures on cancer applications are projected to account for almost half of expenditures, but central nervous system applications (27 percent) and cardiovascular diseases (six percent) will grow faster for the first half of the decade.

Infectious disease applications make up a relatively small and slow-growing share of the total.

"Other" applications, which include other major ophthalmic, endocrine, gastrointestinal, and dermatological diseases; injuries; drug discovery; and medical research make up 14 percent of the total projected expenditures and are expected to grow 14 percent per year to 2019.

Freedonia Group estimates that six companies – Roche Holding (Genentech), Abbott Laboratories (Soliqs), Johnson & Johnson (Centocor Ortho Biotech), Amgen Inc., Teva Pharmaceuticals, and Siemens – now account for 75 percent of the nanomedicine market, largely the result of acquisitions. Teva and Amgen each have had one blockbuster product. *(Freedonia Group 2010)*

BCC Research's December 2010 update estimates that the global market for nanobiotechnology products in 2010 is $19.3 billion, growing at a compound annual growth rate of nine percent, on track to reach the forecast market size of $29.7 billion by 2015.

Even though corporate R&D spending – along with revenues – in the top 1000 innovative firms declined in 2009 for the first time in decades, R&D investment in health care industries grew 1.5 percent as revenues expanded by six percent, including Roche, Pfizer, Novartis, Johnson & Johnson, Sanofi-Aventis, and GlaxoSmithKline, all in the top 10 corporate investors in R&D globally. *(Booz 2010)*

The Food and Drug Administration (FDA) has presently approved several products that contain nanomaterials. The chart below provide real-life examples of first-generation life sciences products with therapeutic nanoparticles that have cleared its way through the FDA regulatory approval process to enter into the commercial marketplace.

Examples of FDA Approved Products Containing Nanomaterials[9]

Platforms	Trade Name	Indication	Approved Date
Liposome	Abelcet	Fungal infections	11/20/1995
	AmBisome	Fungal infections	8/11/1997
	Amphotec	Fungal infections	11/22/1996
	DaunoXome	Antineoplastic	4/8/1996
	DepoCyt	Lymphomatous meningitis	4/1/1999
	Doxil	Antineoplastic	11/17/1995
	Visudyne (verteporfin for injection)	Photodynamic therapy for age-related macular degeneration	4/12/2000
Micelle	Amphotec	Antifungal	11/22/1996
	Estrasorb	Vasomotor symptoms associated with menopause	10/9/2003
	Taxotere	Antineoplastic	5/14/1996
Nanocrystal	Emend	Antiemetic	3/27/2003
	Tricor	Hypercholesterolemia and hypertriglyceridemia	11/5/2004
	Triglide	Hypercholesterolemia and hypertriglyceridemia	5/7/2005
	Megace ES	Anorexia, cachexia or an unexplained significant weight loss in AIDS patients	7/5/2005
	Rapamune	Immunosuppressant; The prophylaxis of organ rejection in patients receiving renal transplants	8/25/2000
Nanoparticle	Abraxane	Metastatic breast cancer	1/7/2005
	Anthelios 20	Sunscreen	10/5/2006
	Helioblock SX Sunscreen Cream	Sunscreen	3/31/2008
Nanotube	Somatuline depot	Acromegaly	8/30/2007
Superparamagnetic iron oxide	Feraheme Injection	Treatment of iron deficiency anemia in patients with Chronic Kidney Disease (CKD)	6/30/2009
	Feridex	MRI contrast agent	8/30/1996
	GastroMARK	Imaging of abdominal structures	12/6/1996

[9] Nakissa Sadrieh, FDA, presentation to the Task Force on Nanobiotechnology, November 10, 2010.

MARYLAND NANOBIOTECHNOLOGY CAPABILITIES: UNIVERSITY & COLLEGE EXAMPLES[10]

The **Maryland NanoCenter at the University of Maryland** is pursuing a broad range of nano research in four key areas: fabrication, characterization, systems, and performance. The Maryland NanoCenter brings together world-class scientists from the School of Engineering, and the schools of computer science, mathematical, and natural sciences. The Center is supported by nanofabrication (FabLab), nanocharacterization (NispLab), and Nanosynthesis (KeckLab) physical infrastructure.

The major labs are shared user facilities, open to outside users and collaborators, and additional expertise and facilities may be accessed through partnerships. From 2006 to 2009, the Maryland Department of Business and Economic Development (DBED) provided significant assistance for building the laboratory infrastructure for the FabLab and NispLab ($3.6 million), and for strengthening research support in nanobiotechnology within the University System of Maryland ($6.2 million over three years), which attracted 22 new outstanding faculty in nanobiotechnology and 13 cutting-edge research projects.

Industry partners for the Maryland NanoCenter have included both federal contractor giants and smaller, newer companies. Federal government partners include NASA Goddard, NIH, FDA, and the Army Research Laboratory.

The Maryland NanoCenter provides research leadership in biomicrosystems, including microarray-based sensors, cell-based sensing, biomolecular functionalization, and metabolic engineering. Additional research capabilities include scanning nanoprobes, nanoparticle synthesis for analysis of environmental impact, nanoelectronics and systems, nanomaterials design-for-function, and 3D nano and micro fabrication. As noted by Dr. Mihail Roco in his look at the next decade, the promise of nanotechnology will only be realized through nanomanufactured systems such as biosensors, drug delivery vehicles, environmental sensors, and chem-bio detection systems for security. The Maryland NanoCenter is developing microfluidic systems as a vehicle for transporting and assembling nanostructures into small systems for important tasks.

Biomolecular engineering, a major component of Maryland NanoCenter, has broad applications to biomedical diagnostics and therapeutics, agriculture and environment, and ultrahigh selectivity approaches to nanosensors and nanoassembly. The faculty is exploiting complex biochemical reactions to tailor biomolecules for specific applications, such as revealing the fundamentals of metabolic processes in living systems, or developing new means to identify and control viruses.

Faculty researchers in the **FIschell Department of Bioengineering** in the University of Maryland School of Engineering are developing nanocomposites for orbital bone regeneration, nanofactories for next generation antimicrobials, and exploring the use of nanoscaffolds for mechanobiology, particularly in orthopaedics – in collaboration with the University of Maryland, Baltimore and the Department of Mechanical Engineering.

[10] Unless otherwise noted, all information from university websites or presentations to the Task Force on Nanobiotechnology

The **Maryland Center for Cancer Nanotechnology Excellence** at **University of Maryland Baltimore (UMB)** brings together faculty from the UMB schools of pharmacy, dentistry, and medicine and the departments of chemistry and bioengineering at University of Maryland College Park, Maryland nano industrial partners, and federal partners (NIST, NCI-NCL). Core projects include silicon nanotubes for image-guided targeted drug delivery, targeted delivery using surfactant nanovesicles, multiphoton imaging of functionalized gold nanorods, delivery of magnetic particles, and gold nanoparticle delivery and angiogenesis inhibitors. Three cores support the work – translational/imaging, bioinformatics and data sharing, and analytical and pharmacokinetics/pharmacodynamics. Its integrated capabilities include fabrication, bioconjugation, characterization, *in vitro* studies, animal pharmacokinetics (what the body does to drugs externally administered) and efficacy, imaging/radiology, intellectual property, clinical translation, and commercialization.

Led by the UMB School of Pharmacy, the **Center for Nanomedicine and Cellular Delivery** is a fully integrated and synergistic, cross-campus, interschool/college, interdepartmental organized research center that organizes research, education, outreach, and pilot programs. It is part of an international alliance with universities in Italy, Finland, and Netherlands. It embeds basic scientists and engineers with medical specialists to foster clinical translation science programs for the design, development, and use of nanosystems for therapeutic and diagnostic purposes, with a focus on the use of nanosystems in the targeted delivery of bioactive agents for diagnosis and therapy.

The Center for Nanomedicine and Cellular Delivery (CNCD) facilitates the translation of promising delivery systems to clinical research, fosters collaborative projects, recruits experts in nanomedicine research and enhances the infrastructure supporting it, and provides training in the emerging interdisciplinary field of nanomedicine. Research and translation into clinical research focuses on nanofabrication and characterization (nanotubes, nanoparticles, nanocomposites, colloids, polymers), delivery of bioactive agents (targeted delivery to solid tumors, targeting tumor antiogenesis, drug delivery with microfabricated devices, recombinant polymers for cancer gene therapy, dendrimers for oral drug delivery, delivery of radionuclides and contrast agents), and pharmacokinetics, transport, and subcellular fate (biopharmaceuticals and pharmacokinetics, transport across epithelial barriers and across blood-brain barriers, mucosal biology, membrane transporters, cell proliferation, growth regulation, and apoptosis).

Current research includes imaging of cancer tumor location and the effect of polymer-directed radiotherapy and the use of confocal microscopy to observe the uptake of a polymer-drug conjugate by cancer cells, the effect on the cells and drug release inside the cells. CNCD's strengths lie in materials science, fabrication facilities, characterization, GMP (Good Manufacturing Practice), pharmacokinetic analysis, and clinical trials.

Faculty in the Department of Chemistry and Biochemistry at the **University of Maryland Baltimore County** (UMBC) bioanalytical and environmental spectroscopy group involves the development of novel sensing tools and strategies for the monitoring of biological and environmental systems at the nanoscale. Nanoscale work includes implantable sensors capable of being inserted into individual cells and optically positioned for the monitoring of cellular response to various external stimuli.

The **Johns Hopkins Institute for NanoBioTechnology (INBT)** was launched in May 2006 with a $5 million federal grant and includes more than 200 affiliated faculty in 22 departments in the schools of arts and sciences, medicine, public health, and engineering in Baltimore, and the Applied Physics Laboratory in Laurel. The Institute's integrated approach has allowed it to win several federally-funded centers, the JHU Physical Sciences – Oncology Center (NIH), and the JHU Center for Cancer Nanotechnology Excellence (NIH).

The Johns Hopkins University Physical Sciences-Oncology Center was established in 2009 when INBT-affiliated faculty won a competition to receive $14 million from the National Cancer Institute (NCI) of the National Institutes of Health (NIH) to explore the mechanical forces in cancer that bolster the tumor metastatic cascade. Metastatic disease is the cause for the preponderance of deaths related to cancer. The Center brings together experts in cancer biology, molecular and cellular biophysics, applied mathematics, materials science, and physics to study and model cellular mobility and the assorted biophysical forces involved in the metastatic process. New knowledge generated by the Center will identify new pathways for therapies that prevent tumor cells from acquiring properties that allow them to enter the vascular system, kill tumor cells that are able to circulate through the vascular system, and prevent tumor cells from acquiring properties that allow them to leave the vascular system and penetrate a second site. State-of-the-art microfabrication facilities support this center. The principal investigator is a faculty member for the school of engineering and the senior scientific investigator is on the faculty of the school of medicine. Collaborators include the University of Connecticut Health Center, University of Florida, University of North Carolina, and Washington University-St. Louis.

In September, 2010, the Johns Hopkins Institute for NanoBioTechnology received a $13.6 million five-year grant from the National Cancer Institute to establish a Center of Cancer Nanotechnology Excellence. Once again led by a pair of faculty members from the schools of engineering and medicine, the new Johns Hopkins center brings together a multidisciplinary team of scientists, engineers and physicians to develop nanotechnology-based diagnostic platforms and therapeutic strategies for comprehensive cancer care. Seventeen faculty members will be involved initially, with pilot projects adding more participants later. The Center features a Validation Core, for assuring that the experimental products and results generated are on target and the intended biological effects measured.

The Center's four primary research projects are:

(1) Epigenetic markers: seeking methods to screen bodily fluids such as blood or urine for indicators of cancer found outside of the genetic code, indicators called epigenetic markers, using semiconductor nanocrystals, also known as quantum dots, and silica superparamagnetic particles to detect DNA methylation. Methylation adds a chemical group to the exterior of the DNA and is a biomarker frequently associated with cancer.

(2) Curcumin: a substance found in the traditional Indian spice turmeric; in preclinical studies, curcumin has demonstrated anti-cancer properties but, because of its physical size, it is not readily taken up into the bloodstream or into tissues. Engineered curcumin

nanoparticles, however, can more easily reach tumors arising in abdominal organs such as the pancreas. This team will try to determine whether nanocurcumin, combined with chemotherapeutic agents, could become a treatment for highly lethal cancers, such as pancreatic cancer.

(3) Vaccines: seeking to use a noninvasive method to monitor the effectiveness of vaccines for cancer and infectious diseases.

(4) Lung cancer: building on the work of professors at the school of medicine involving the delivery of therapies directly to small cell lung cancer tissue via mucus-penetrating nanoparticles.

The Institute marries basic engineering science related to nanoscience and nanotechnology – nanoparticles, microfluidic devices, -- and basic biological science related to cellular and molecular dynamics – particle tracking, bioanalytical assays, biosensors to tackle therapeutic and diagnostic challenges in clinical science and public health challenges to both humans and the environment. A nanoparticle engineering core, which makes and characterizes a variety of nanomaterials, and a bioinformatics and data sharing core support all investigations.

INBT builds market integration into the research process. A group of marketing, licensing, intellectual property, and venture capitalists meet quarterly with research teams working in cancer nanomedicine to actively manage the translation from laboratory to bedside. Through its corporate partnership program, companies provide undergraduate summer internships, graduate internships, consult a student resume database of students in the nanobio training program, sponsor graduate fellowships, collaborate on research, sponsor university/industry post-doctoral fellowships, and offer their research employees "sabbaticals" at Hopkins in an INBT lab. The exchange of new knowledge, potential employees, new tools and techniques, and expertise has proven useful for both academic and industry partners.

INBT has created a unique model for training researchers at the interface between nanoscience and medicine. See "education" section below. The Institute also offers an undergraduate minor: Nanotechnology Risk Assessment and Public Policy; its fourth annual symposium, held in April of this year, included a workshop, "Health and the Environment."

A $7 million grant from NIH's National Center for Research Resources with funding from American Recovery and Reinvestment Act in May 2010 is allowing the renovation of the **Center for Translational Molecular Imaging (CTMI)** on the campus of Johns Hopkins Bayview Medical Center. The renovations will permit generation of imaging agents in an environment that meets the requirements for a Good Manufacturing Practice (GMP). These in turn will be used by researchers throughout Johns Hopkins to validate the new therapeutic targets, reagents, and biomarkers for cancer, central nervous system disease, cardiovascular disease, and other disorders. The CTMI's work will include first-in-man studies to bring these imaging agents to patients faster to provide early diagnosis and support emerging cancer therapies. One of the INBT's affiliated faculty is leading the development of the CTMI.

Johns Hopkins Institute for Basic Biomedical Sciences (IBBS) is an experiment in collaborative research that promotes fundamental research that drives advances in medicine in a collaborative environment that bridges basic science and clinical research. The 116 primary faculty (of a total of 2,448 full time) from the departments of biological chemistry, biomedical engineering, biophysics and biophysical chemistry, molecular and comparative pathobiology, cell biology, molecular biology and genetics, neuroscience, and pharmacology and molecular sciences include 12 Howard Hughes Medical Institute investigators and four Nobel laureates. Over one hundred hold joint appointments in clinical departments. The faculty also participates in education and training of young researchers (see Education section below).

Organized in eight interdisciplinary centers focused on fundamental problems in biology and medicine, the Institute features an interdepartmental, dynamic partnership of basic and clinical faculty in interactive clusters of laboratories that have been attractive to the most innovative young scientists. The eight centers, high throughput biology, sensory biology, cell dynamics, metabolism and obesity research, epigenetics, chemoprotection, drug abuse, and membrane transport, also draw on the clinical departments of medicine, pediatrics, otolaryngology, psychiatry, surgery, oncology, neurology, and pathology, as well as three other Johns Hopkins schools: epidemiology and biostatistics at public health, biology and biophysics at arts and sciences, and biomedical engineering at engineering. Approximately 80 percent of the $100+ million in external support comes from the National Institutes of Health.

Nanobiotechnology is being used at IBBS for basic research, development of diagnostics and therapeutics, and environmental science in a range of centers. Mechanical engineers are developing tools for nanoscale measurement of DNA activity that may serve as a marker for cancer and, more importantly, exploring ways to automate these functions to reduce processing time and cost while improving sensitivity and specificity. Others are using quantum dots (semiconducting nanoscale crystals) as probes and triggers for studying immunity and autoimmunity, using magnetic nanoparticles to track cells, creating tissue blueprints for tissue repair, using nanoparticles to enable the oral delivery of water-insoluble drugs or drugs for cystic fibrosis, and electrochemically programming the release of biomaterials.

With a generous gift from an anonymous donor, **The Johns Hopkins University School of Medicine** launched the **Institute for Cell Engineering** (ICE) to focus on selecting, modifying and reprogramming cells to answer fundamental questions in biology. These answers may one day lead to treatments or therapeutic transplants for conditions ranging from Parkinson's, ALS and diabetes to heart failure, stroke and spinal cord injury. ICE supports and houses scientists working to understand how cells' fates are determined and to harness that information in order to select, modify and reprogram human cells.

While basic research is the hallmark of ICE science, the ultimate goal is to mold engineered human cells into therapeutic transplants for a wide range of currently devastating diseases, including Parkinson's disease, Lou Gehrig's disease or amyotrophic lateral sclerosis (ALS), diabetes and heart failure. Taking the next steps in stem cell biology, researchers are studying how human pluripotent stem cells capable of becoming virtually any of the cell types found in the body "decide" what to become, a key step in capturing their potential to rebuild tissues lost to disease. ICE's interdisciplinary researchers are studying many types of cells for clues to

differentiation -- how cells specialize -- and insight into how organisms as complex as mice and humans develop so precisely. ICE houses a $10 million project grant to study immune activation.

Among ICE's current activities is a collaborative effort to establish a premier proteomics facility at Johns Hopkins. On Sept. 30, 2002, Johns Hopkins received more than $18 million from the National Heart, Lung and Blood Institute (NHLBI) to establish the Johns Hopkins NHLBI Proteomics Center, one of 10 such centers nationwide. ICE has provided $2 million to the new center, matching the "infrastructure" funds from the NHLBI contract.

MARYLAND NANOBIOTECHNOLOGY CAPABILITIES: FEDERAL AND OTHER SUPPORT EXAMPLES

FEDERAL RESEARCH INSTITUTIONS[11]

The vast majority of university nanobiotechnology research in Maryland is underwritten by federal agencies, particularly the National Institutes of Health and the National Science Foundation.

The President's proposed Fiscal Year 2011 federal budget for the National Nanotechnology Initiative (NNI) includes investments in eight program areas across 15 federal agencies (see the chart numbered on the following page). Federal nanotechnology investments are concentrated in basic research in program component areas such as: (1) fundamental phenomena and processes and foundational applied research on (3) nanoscale devices & systems, (2) nanomaterials, and (6) research infrastructure.

Basic research investment is increasing, as is **nanomanufacturing**, research infrastructure, and environment, health and safety. The Department of Energy has overtaken the Department of Defense to garner the highest level of investment – largely due to the construction of five Nanoscale Science Research Centers at DOE laboratories – followed by the National Science Foundation, HHS/National Institutes of Health, and DoD. Reflecting an increased focus on not only the risks of nanoparticles in the human and physical environment but also their potential for environmental remediation, modest budgets for the Environmental Protection Agency, the Food and Drug Administration, the National Institute for Occupational Safety and Health (HHS), and the Consumer Product Safety Commission have grown fastest. In December, 2010, NSF announced the availability of $4.9 million for research on the environmental effects of nanotechnology.

Looking back at the first 10 years of the National Nanotechnology Initiative, which includes all applications of nanotechnology, the 2011 NNI supplement to the President's budget concludes that "[t]he extensive network – the National Nanotechnology Infrastructure Network (NNIN)[12] – of research centers, user facilities, and other infrastructures for nanotechnology research, which was a key element of the original NNI strategy, is now largely complete." *(p. 36)*

[11] Many of the agency description passages are taken from the Supplement to the President's 2011 Budget, National Nanotechnology Initiative. The remainder is from agency websites and Task Force presentations as noted.

[12] The Cornell NanoScale Science & Technology Facility at Cornell University; The Stanford Nanofabrication Facility at Stanford University; The Lurie Nanofabrication Facility at the University of Michigan; The Nanotechnology Research Center at the Georgia Institute of Technology; The Center for Nanotechnology at the University of Washington; The Penn State Nanofabrication Facility at the Pennsylvania State University; Nanotech at the University of California at Santa Barbara; The Nanofabrication Center at the University of Minnesota; The Microelectronics Research Center at University of Texas at Austin; The Center for Nanoscale Systems at Harvard University; The Howard Nanoscale Science and Engineering Facility at Howard University; The Colorado Nanofabrication Lab at University of Colorado; Nanofab at the Arizona State University; The Nano Research Facility at Washington University in St. Louis

PROPOSED 2011 AGENCY INVESTMENTS BY PROGRAM COMPONENT AREA ($million)

	1.Fundamental Phenomena & Processes	2.Nanomateirals	3.Nanoscale Devices & Systems	4. Instrument Research, Metrology, & Standards	5. Nano-manufacturing	6. Major Research Facilities & Instr. Acquisition	7. Environment, Health & Safety	8. Education & Societal Dimensions	*NNI Total*	*Change 2009 actual – 2011 Proposed**
DOE	117.2	121.7	30.4	19.3	20.9	111.3	2.6	0.5	**423.9**	**+**
NSF	140.1	74.3	40.7	16.6	32.2	35.3	33.0	29.0	**401.3**	**-**
HHS/NIH	50.3	80.0	193.8	18.6	2.3	14.4	18.3	4.7	**382.4**	**+**
DOD	151.5	39.3	99.0	2.5	25.1	30.7	0.5	0.0	**348.5**	**-**
DOC/NIST	22.4	8.2	20.2	18.5	20.2	11.2	7.3	0.0	**108.0**	**-**
EPA	0.2	0.1	0.2	0.0	0.0	0.0	19.5	0.0	**20.0**	**+**
HHS/NIOSH	0.0	0.0	0.0	0.0	0.0	0.0	16.5	0.0	**16.5**	**+**
NASA	0.0	8.4	7.4	0.0	0.0	0.0	0.0	0.0	**15.8**	**+**
HHS/FDA	0.0	0.0	0.0	0.0	0.0	0.0	15.0	0.0	**15.0**	**+**
DHS	0.0	6.5	4.9	0.0	0.3	0.0	0.0	0.0	**11.7**	**o**
USDA/NIFA	0.7	1.4	3.8	0.3	0.2	0.0	2.0	0.5	**8.9**	**-**
USDA/FS	2.0	1.4	0.7	1.1	0.2	0.0	0.0	0.0	**5.4**	**o**
CPSC	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	**2.2**	**+**
DOT/FHWA	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	**2.0**	**-**
DOJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**o**
TOTAL	**484.4**	**342.3**	**402.0**	**76.9**	**101.4**	**203.0**	**116.9**	**34.8**	**1761.6**	

* Increase (+), decrease (-), or no change (O) from actual spending in FFY09 and the proposed budget for FFY11.

SOURCE: Table 6, page 10, National Nanotechnology Initiative Supplement to the President's 2011 Budget

National Institutes of Health

The **National Institutes of Health**[13] (Bethesda) and its **National Cancer Institute** (with a major center in Frederick) lead the federal government's focus on the uses of nanotechnology for biological research, medical diagnosis, and treatment. ***NIH funding supports a large share of the nanoscale life sciences inquiry at Maryland's research universities and 15 of the State's two dozen nanobiotechnology companies have received NIH funding.***

[13] This section was enriched by a presentation made by Michael Weinrich, M.D., Director of the National Center for Medical Rehabilitation Research, to the Task Force on Nanobiotechnology, November 10, 2010.

According to the NNI supplement to the President's 2011 budget:

"The emergence of nanotechnology has opened a new era of design-driven research into the development of unique 3D nanomaterials and nanostructures with the potential for significant clinical impact across a range of diseases and disorders. The NIH continues to expand its support for nanoscale engineering of multifunctional systems for drug and gene therapy, nanostructures for tissue engineering, and a variety of other biomedical applications, in addition to research tools that aid in understanding the underlying causes of diseases.

Progress continues in development of sensors that are both selective and highly sensitive for early diagnosis of disease (when disease is easier to treat). Some of these sensors involve imaging techniques that pinpoint chemical and biochemical processes that are characteristic of specific diseases; these exams complement current anatomical imaging to provide essential information for early diagnosis. Others may be used as lab tests that identify early markers of diseases such as cancer or heart disease from a small drop of blood or saliva.

Multifunctional nanoparticles are being developed to deliver conventional or novel therapeutics directly to the specific tissues or cells in the body that are affected by disease, sparing healthy cells from drug side-effects. Some of these particles may help doctors to detect how much medicine is needed at a particular time, and to dispense only that dose at the time and location in the body where it is needed.

Nanotechnology-based research tools are being used to better understand the causes and course of diseases, and the effects of genetics and environment on individual patients. NIH plays a substantial role in developing understanding of how to design nanoparticles so that they can be safe to use both for manufacturing and for medical treatments. …

Commercialization is facilitated through funding of SBIR/STTR grants and programs at the various NIH institutes that encourage universities and companies to collaborate, and by providing resources and expertise to test novel formulations for safety and biological activity."*(pp. 21-22)*

NIH investments, 90 percent of which go to external research and practice grantees, focus on (1) detecting disease before health has deteriorated using sensors and imaging, (2) tissue engineering to repair or replace worn or damaged body parts by controlling interactions of synthetic and inorganic materials with the body for effective integration, delivery of therapeutics through work on particle size, materials properties, and (3) developing research tools to accomplish all of the above.

The agency embarked on an ambitious Nanomedicine Roadmap Initiative across all institutes in 2006 , a translational effort to characterize quantitatively the physical and chemical properties of molecules and nanomachinery in cells; gain an understanding of the engineering principles used in living cells to "build" molecules, molecular complexes, organelles, cells, and tissues; and use this knowledge of properties and design principles to develop new technologies and engineer devices and hybrid structures for repairing tissues and for preventing and curing disease.

INDUSTRY SPOTLIGHT

Science Applications International Corp. (SAIC) is a California-based, employee owned FORTUNE 500® scientific, engineering, and technology applications company. Over 1,600 of the Company's 45,000 employees work in Frederick County. SAIC-Frederick, Inc. is a wholly owned subsidiary of Science Applications International Corporation and operates exclusively under a single, long-term contract to the National Cancer Institute (NIH). It develops and applies advanced technologies, including nanobiotechnology, to accelerate the delivery of new treatments to patients with cancer and AIDS. The company supports the operation of the Nanotechnology Characterization Laboratory.

The vehicles for NIH support of nanobiotechnology include BECON (Bioengineering Consortium) which has grown to a trans-NIH Nano Task Force that is the locus of interaction with outside groups; nanoscience and nanotechnology programs in the component institutes of NIH, including the **National Cancer Institute's Alliance for Nanotechnology in Cancer**.

In 2005, NCI announced the award of five-year grants totaling $26.3 million to establish seven[14] **Centers of Cancer Nanotechnology Excellence (CCNEs**). NCI's Alliance for Nanotechnology in Cancer encompasses four major program components, including the CCNEs.

CCNEs are multi-institutional hubs that focus on integrating nanotechnology into basic and applied cancer research and provide new solutions for the diagnosis and treatment of cancer. Each of the CCNE awardees is associated with one or more NCI-designated Cancer Centers, affiliated with schools of engineering and physical sciences, and partnered with not-for-profit organizations and/or private sector firms, with the specific intent of advancing the technologies being developed. Johns Hopkins' Institute for Nanobiotechnology became a CCNE in 2010 when a second round of funding was made available.

The **National Heart Lung and Blood Institute's (NHLBI) PENS** (Programs of Excellence in Nanotechnology) multi-university projects is aimed at developing and applying nanotechnology solutions to the diagnosis and treatment of heart, lung, blood, and sleep disorders; and the NIEHS (**National Institute of Environmental Health Sciences**) participates in the interagency

[14] Current CCNEs are: AWARDED in 2010: Center for Cancer Nanotechnology Excellence at Johns Hopkins (*Principal Investigators:* Peter Searson, Ph.D. and Martin Pomper, M.D., Ph.D., *Scientific Focus:* Develop and integrate nanotechnology-based *in vitro* assays, targeted chemotherapy and immunotherapy for diagnosis, therapy and post-therapy monitoring of lung and pancreatic cancer); Center for Translational Cancer Nanomedicine, Northeastern University; Dartmouth Center for Cancer Nanotechnology Excellence, Dartmouth College; Texas Center for Cancer Nanomedicine, The University of Texas Health Science Center; Center for Cancer Nanotechnology Excellence and Translation, Stanford University; ORIGINAL grantees renewed in 2010: Carolina Center of Cancer Nanotechnology Excellence, University of North Carolina, Chapel Hill; MIT-Harvard Center of Cancer Nanotechnology Excellence; Nanomaterials for Cancer Diagnostics and Therapeutics, Northwestern University; Nanosystems Biology Cancer Center, California Institute of Technology

National Toxicology Program, joint solicitations, and the NanoHealth Enterprise – an integrated, interdisciplinary program that draws upon the expertise and interests of the NIH institutes and centers, in partnership with private industry, to address critical research needs for the safe development of nanoscale materials and devices.

NIH's National Cancer Institute (NCI) in Frederick hosts the national Nanotechnology Characterization Laboratory (NCL), a collaboration of NCI with the National Institute of Standards and Technology (NIST) and the U.S. Food and Drug Administration (FDA), both based in Maryland. NCL performs and standardizes the pre-clinical characterization of nanomaterials intended for cancer therapeutics that have been developed by government, academic, and industry researchers. NCL has the capacity to characterize the nanoparticles' physical attributes, *in vitro* biological properties, and *in vivo* compatibility using animal models. If accepted for characterization, NCL's services are provided at no cost to the investigator. The Nanobiology Program at the NIH Center for Cancer Research at Frederick brings together the NCI Alliance for Nanotechnology, the University of Maryland (a participant in the Cancer Nanotechnology Training Center), the Bill and Melinda Gates Foundation (vaccines), and NIST.

National Institute of Standards and Technology

The **National Institute of Standards and Technology**[15] (NIST), headquartered in Gaithersburg, is a component of the U.S. Commerce Department, and therefore focused on U.S. innovation and industrial competitiveness. NIST plays a leading role in nanoscale measurement science, standards, and nanotechnology development. The nanotechnology-related research conducted in NIST's laboratories provides measurements, standards, data, and standard reference materials that are crucial to industry as well as other federal agencies that need to accurately quantify and measure the presence of nanomaterials in the environment. Its impact measurements extend throughout the life cycle of the nanomaterial being studied.

NIST supports U.S. nanotechnology enterprises from discovery through production through its **Center for Nanoscale Science and Technology** (CNST), which includes a shared-use nanofabrication facility, the Nanofab, a national, state-of-the-art, shared resource for the fabrication and measurement of nanostructures. It includes 60,000 ft^2 (5600 m^2) of labs and clean room; a 19,000 ft^2 (1800 m^2) clean room; 8,000 ft^2 (750 m^2) at class 100; over 65 tools (~$30M), including advanced lithography and microscopy; talented staff to train users or operate the tools (230+ staff-years of process development experience); and links to extensive measurement resources in the NIST Laboratories and Centers. Nanofab leverages the expensive tools needed for nanotechnology through cost sharing.

To date, a few Maryland life sciences companies have used the Nanofab, but the number is growing. Martin Woodle of AparnaBio, has signed a Cooperative Research and Development Agreement (CRADA) with NIST for work at the CNST laboratories on the company's platform nanotechnology systems for the targeted delivery of powerful RNAi[16] therapies. Proximity has

[15] This section was enriched by a presentation made by Lloyd Whitman, Deputy Director of CNST, to the Task Force on Nanobiotechnology, November 10, 2010.

[16] Gene products (RNA) that can bind to and "interfere" with – increase or decrease the activity of – other RNA, for example viruses.

value -- 397 (48%) of the participants in the CNST have been Maryland entities – mostly from within NIST, 14 of the 49 companies were Maryland-based, as were three of the 114 university users.

Other Maryland companies are working informally with NIST collaborators through short-term visits to the labs and sharing of research methods. Intramural labs at NIST often partner with industry; in a recent project, Montgomery County-based Army Medical Research contractor Translabion and others worked with NIST's Material Measurement Laboratory to bond an antibody for *HER2* genes associated with breast cancer to a short nanotube in order to detect and destroy 100 percent of the cancer cells while nearby normal cells were unharmed. The next step is to move from laboratory cell cultures to animal testing.[17] NIST's Image Analysis Laboratory, in collaboration with its Advanced Biomedical Computing Center (funded by NIH-NCI), has developed and is sharing several algorithms that facilitate the measurement of fluorescence-labeled molecules in individual cells of both intact tissue and cell culture samples.

NIST is a partner in the National Characterization Lab (see NIH/NCI above) and its **Technology Innovation Program** (TIP) is investing in private sector projects that advance transformational technologies required for large-scale manufacture of nanomaterials. TIP's 2010 competition focused on "Manufacturing and Biomanufacturing: Materials Advances and Critical Processes," in 2009 on "Critical National Needs in Manufacturing and Civil Infrastructure," and in 2008 on Critical National Needs in Manufacturing and Civil Infrastructure." A Maryland company, Pixelligent Technologies, LLC (College Park) won an award in 2009 its nanocomposite project, which is destined for industrial applications. A 2009 award was also made to a Durham, NC company for a novel manufacturing process that produces engineered nanoparticles for therapeutic applications.

National Science Foundation

Headquartered in Arlington, Virginia, the **National Science Foundation** funds 20 percent of all federally supported basic research conducted by America's colleges and universities. In many fields such as mathematics, computer science and the social sciences, NSF is the major source of federal backing and is the only federal agency whose mission includes support for all fields of fundamental science and engineering, except for medical sciences. ***NSF supports a large share of physical and fundamental nanoscale research and education at Maryland's research universities.***

NSF dominates NII funding for research on the fundamental phenomena and processes of nanotechnology and its mission also explicitly includes ***research infrastructure*** and education; its budget contains 83 percent of all NII proposed FFY11 investments in ***education*** and the societal dimensions of nanotechnology. It also supports translational research in partnership with industry and States as well as an active investigator-initiated SBIR/STTR program, with $20 million allocated specifically for nanotechnology-related proposals.

[17] NIST news, "Combining Nanotubes and Antibodies for Breast Cancer Search and Destroy' Missions, December 1, 2009.

NSF's traditional approach to funding teams and centers is particularly appropriate to the inherently interdisciplinary nature of nanotechnology. NSF participates with other federal agencies in the National ***Nanomanufacturing*** Network's four Nanoscale Science and Engineering Centers,[18] which include industry partners as well as federal laboratories and universities. ***Environmental, health, and safety*** implications of nanotechnology, including the predictive toxicity of nanomaterials are to be investigated in three dedicated multidisciplinary centers and over 60 other smaller groups.

NSF's **Biotechnology, Biochemical, and Biomass Engineering** (BBBE) program supports fundamental engineering research that advances the understanding of cellular and biomolecular processes (*in vivo*, *in vitro*, and/or *ex vivo*) and eventually leads to the development of enabling technology and/or applications in support of the biopharmaceutical, biotechnology, and bioenergy industries, or with applications in health or the environment. Quantitative assessments of bioprocesses are considered vital to successful research projects in the BBBE program.

Fundamental to many research projects in this area is the understanding of how biomolecules and cells interact in their environment, and how those molecular level interactions lead to changes in structure, function, phenotype, and/or behavior. The program encourages proposals that address emerging research areas and technologies that effectively integrate knowledge and practices from different disciplines, and effectively incorporate ongoing research into educational activities. Research projects of particular interest in BBBE include nanobiotechnology.

Department of Energy

While headquartered in Washington, DC, the Department of Energy's nanotechnology activities are concentrated at its national laboratories. The Thomas Jefferson Lab in Newport News, VA, the closest to Maryland, includes medical imaging as one of its research foci, primarily focused on resolutions above the nanoscale. Within the Biological and Nanoscale Systems Group at Oak Ridge National Laboratory (ORNL) in Oak RIdge, TN, researchers are focused on characterizing and understanding how natural systems are organized at the nanoscale and how this organization contributes to biological function. Oak Ridge houses one of five Nanoscale Science Research Centers, DOE's premier user centers for interdisciplinary research at the nanoscale. ORNL is managed by Battelle.

DOE's SBIR/STTR program management is located in Germantown. Although the SBIR/STTR program is national, Maryland companies have been recipients of these grants. For 2011, DOE has created several solicitations for possible SBIR/STTR grants. The goal is to enable both the public and private sectors to apply genome knowledge to the bio-production of energy, promote environmental applications such as bioremediation and carbon sequestration, promote

[18] 1) Center for Hierarchical Manufacturing (CHM) – UMass-Amherst; 2) Center for High-Rate Nanomanufacturing (CHN) – Northeastern Univ with UMass-Lowell and Univ of NH; the 3) Center for Scalable and Integrated NanoManufacturing (SINAM) – UCLA, UC Berkeley, UNC-Charlotte, Northwestern Univ, MIT and Hewlett-Packard Laboratories; and 4) Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (Nano-CEMMS) – Univ. of Ill-Urbana-Champaign as well as Stanford University, North Carolina Agricultural and Technological State University, University of California - Irvine, University of Notre Dame, and Northwestern University.

cleaner industrial processes, and enable increasingly effective computational models of the microbial cell.

Nanobio-relevant topics in DOE's 2011 SBIR/STTR solicitation include: electron and scanning probe microscopy for the characterization of materials; radiochemistry and radionuclide imaging research into the real-time visualization of dynamic biological processes in energy and environmentally-relevant contexts, particularly those that could be beneficial for metabolic imaging in living systems, including plants and microbial-communities that are relevant to biofuel production and bioremediation, and that are transferable for use in nuclear medicine research and in applications by NIH and industry; and genomic science and related biotechnologies research aimed at developing a detailed understanding of the molecular machines of energy relevant plants, relevant microbes and their networking in living cells and microbial communities.

Department of Defense

Fort Detrick's 8,460 employees include workers at the **U.S. Army Medical Research Institute of Infectious Diseases** (USAMRIID) that is part of the **U.S. Army Medical Research and Materiel Command** (USAMRMC), also headquartered at the Frederick County base.

Fort Detrick USAMRIID is supporting research in partnership with an innovative company into optofluidic-nanoplasmonic biosensors that can directly detect live viruses from biological media at medically relevant concentrations with little to no sample preparation, which makes it easily adaptable for low cost point-of-care diagnostics in clinics, defense and homeland security as well as in civilian settings such as airports or other public spaces. USAMRIID's capabilities allow companies to test new anti-viral nano solutions using Material Transfer Agreements.

INDUSTRY SPOTLIGHT

Allegiance NanoSolutions, located in the Emerging Technology Center incubator in the Baltimore City, is an analytical testing, consulting, research & development, and contract manufacturing organization serving Nanotechnology focused companies. Its services include characterization of nanomaterials and the synthesis of a wide spectrum of nanomaterials such as nanoparticles, quantum dots, nanoporous materials, as well as nanowires, nanotubes and nanostructural polymers.

Collaboration with AVI BioPharma, a Washington-based biotechnology firm, has led to the development of novel 'antisense' therapies that protect primates from lethal Ebola and Marburg viruses. The therapy is effective even when administered hours after infection.

Other Maryland Army medical research commands include the U.S. Army Medical Research Institute of Chemical Defense (Edgewood), U.S. Army Center for Environmental Health Research (Edgewood), and Walter Reed Army Research Institute (Silver Spring).

INDUSTRY SPOTLIGHT

*AparnaBio, founded in 2007 by serial entrepreneurs to develop biomedical nanoparticles, is a tenant in the Shady Grove incubator. Its NanoElectroPlex™ reagent system can be used to deliver various "payloads" of antibodies and peptides to various targets, including tumors and immune response cells. It is a self-assembling nanoparticle with specific targeting capabilities. Uses for the reagent family InVivo*Plex® *for gene function research, cancer therapeutics, and invasive infections. In collaboration with Sirnaomics, Aparna is exploring the potential for combining siRNA and drug delivery.*

The company has benefited from collaboration with multiple regional federal labs, UMD, JHU and has received NIH, MIPS, TEDCO, and DBED funding.

Also at Ft. Detrick is the **U.S. Army Medical Research Acquisition Activity** (USAMRAA), the contracting element of USAMRMC; it provides support to the Command headquarters and its worldwide network of laboratories and medical logistics organizations. In addition to solicitations for specific services, USAMRAA issues Broad Area Announcements (BAAs) to solicit proposals for research. USAMRAA also supports the Fort Detrick Garrison and its military tenant activities, Army-wide projects sponsored by the Army Surgeon General, and numerous Congressionally mandated programs.

USAMRMC's **Clinical and Rehabilitative Medicine Research Program** supports nanoresearch aimed at burn repair (engineered skin products, bio-printing of skin in the field); wound healing; limb reconstruction, regeneration or transplantation; drugs to control transplant rejection; and treatment of eye injuries. The Walkersville, MD location of $2.7 billion Swiss-based Lonza recently won $16 million from DoD for clinical trials for its eye injury nano-enabled product.

The USAMRMC hosts and supports the **Armed Forces Institute of Regenerative Medicine**, with contributions from the Navy and Air Force. The Project Manager is based at Fort Detrick, while the U.S. Army Institute of Surgical Research at Ft. Sam Houston in Texas provides day-to-day management that includes two consortia hosted respectively by Rutgers/Cleveland Clinic and Wake Forest/Pittsburgh. No Maryland universities are members of these consortia.

Fort Detrick also hosts the **U.S. Army Medical Command** (USAMC), responsible for service-wide health care; the Army's Surgeon General serves as the Commanding General of the USAMC. Within USAMC and also at Ft. Detrick, the **U.S. Army Medical Materiel Agency** (USAMMA)'s responsibilities include acquisition. Both the medical research and health care commands' acquisition arms include robust support for small business contracting.

The **Department of Defense's Chemical Biological Defense (CBD) Program**, headquartered in Northern Virginia, has undertaken a cross-cutting Transformational Countermeasure Technologies Initiative (TCTI) that is integrating basic science advantages in nano-catalytic self-constructing decontamination material, bio-engineered countermeasures, nano-enabled meta-data information interfaces, and nano-scale protective coatings and fabrics into a Nanotechnology-Biotechnology-Information Technology-Cognitive Sciences (NBIC) platform that has broad spectrum applications in combat systems and consequences management that are invisible to the user.

The **Army Research Laboratory** (ARL) at Adelphi's 10,000 Gross Square Feet (GSF) Class 100 and 5,000 GSF Class 10 Specialty Electronic Materials and Sensors Clean room (SEMASC) Facility, managed by ARL's Sensors and Electron Devices Directorate, provides state-of-the-art materials growth, fabrication, analysis and packaging facilities for research and prototype development of nano and micro scale electronic devices. Its micro-electro-mechanical system (MEMS) and nanotechnology research facility features a complete equipment set for innovative materials processing which includes lithography, metal and dielectric deposition, wet and dry etching, thermal processing, wafer bonding and characterizations. Research areas of the SEMASC facility include MEMS sensors and actuators, advanced Radio Frequency (RF) devices, wide bandgap electronics, MEMS power, nano devices, electro-optic and photonic devices, detector materials and devices.

The **Naval Research Laboratory** (NRL), located on the Potomac in southwestern DC adjacent to Bolling AFB, is the Navy's corporate laboratory. Its bio/molecular science and engineering interests – as expressed in current Broad Area Announcements – include: (1) Biophysical chemistry of membranes, proteins, DNA, and RNA; (2) research into biosensors including construction of novel devices, accessories for automated reagent delivery, production of biomolecular recognition elements or configuration of bioassays for integration into the sensor - targets of detection include explosives, pollutants, pathogens, toxic agents, and hazardous chemicals; (3) genetic and tissue engineering of biomaterials; (4) synthesis, fabrication, and physical characterization of self assembled thin films and surfaces for material development; (5) microwave devices, ultramicroelectrodes and electron emitters based on metallized composites and microwave materials based on nanodimension powders and metallized composites; (6) self-assembly of microstructures for advanced materials, including tubules, advanced ceramics and ceramic solgels, and the assessment of potential applications including: controlled release, advanced composites for electronic, structural, and thermal applications, and environmental applications; (7) fabrication and integration of microfluidic components for sample processing and analysis; (8) design, development, and characterization of multifunctional, multilayered assemblies for advanced applications in the areas of environmental protection and general purpose detection, and in the development of non-conventional bioreactors for performing multistep chemistries in single operation; (9) development of novel lithographic, patterning for fabrication or advanced biosensors processes for high resolution imaging, fabrication of advanced microelectronic or nanoelectronic devices, displays, biosensors, multilayers, or three dimensionally structured materials; (10) advanced materials using liquid crystals and ordered polymers, relation between molecular structure and material properties, assessment of their properties for potential applications in the areas of real time holography, ferroelectric phenomena, high resolution display, pryoelectric sensors, and piezoelectric materials, electro-optic materials, non-linear optics, and optical wave guiding; (11) self-assembly of nano-scale structures such as bicontinuous cubic phase and assessment of their use for technological applications in the areas of controlled release, encapsulation, and nanocomposites; (12) remediation of oily and contaminated water using physical or phase-separation processes; (13) bio-based energy harvesting and production for marine, underwater, and naval applications; and (14) development of bioprotocols and subsequent bioinformatic analysis of DNA chip arrays.

Department of Agriculture

At the **U. S. Department of Agriculture's National Institute of Food and Agriculture** (USDA/NIFA), research focuses on (1) nanosensors for detection of pathogens, contaminants, nutrients, environmental characteristics (light/dark, hot/cold, wet/dry), heavy metals, particulates, and allergens; (2) identity preservation and historical tracking of pesticides, fertilizers, and other biological events in the life history of agricultural commodities, using nanoscale devices and data loggers; (3) smart treatment of delivery systems to improve digestibility and flavor of food, nutrient application, and implantable self-regulating drug delivery systems that can be activated to combat disease long before symptoms appear and to allow real-time monitoring and regulation of delivery of needed constituents (bioactive compounds, nutraceuticals, nutrients, drug, insecticides, pesticides, fertilizers, vaccines, etc.) to people, animals, plants, insects, microorganisms, soils, and the environment; (4) novel tools, including nano-filtration devices and a nano-bioreactor critical for the study of enzymatic processes, microbial ecology, and kinetics in communities such as compost systems as well as nanodevices and materials for enhanced gene insertion and gene therapy for veterinary medicine; (5) nanomaterials, including self-healing nanomaterials, bio-selective surfaces development, fundamental nanomaterials science research, modeling of the processes of self assembly in biological systems, and nanoparticles in soil and air that are critical to the future of agricultural and biological production; (6) environmental issues and agricultural waste challenges that may be addressed with nanotechnological concepts, such as the extraction of biopolymers from agricultural byproducts and the design of nanocatalysts for waste bioprocessing into food, feed, industrial chemicals, biofuels, and energy; (7) educating the public and the future workforce through NIFA and land-grant universities traditional partnership, including support for graduate research programs and the use of the interesting, highly visible aspects of nanotechnology to excite young students and the public about agricultural science, food science and technology, and agricultural and biological engineering careers.

The **U.S. Department of Agriculture, Forest Service** (USDA/FS) seeks to use nanotechnology to efficiently and effectively capitalize on a major strategic national asset to make forest-derived materials "the materials of choice for the 21st century." Wood from trees is made up of nanodimensional building blocks that: (1) have strength properties greater than Kevlar® and piezoelectric[19] properties equivalent to quartz, (2) can be manipulated to produce photonic structures, (3) are remarkably uniform in size and shape, (4) possess self-assembly properties, and (5) can be renewably produced in quantities of tens of millions of tons. Through partnership with the U.S. forest products industry – the American Forest & Paper Association Agenda 2020 Technology Alliance – opportunities for using nanotechnology in existing processes and creating new high-performance consumer products from lignocellulosic-based materials in a safe and sustainable manner are being identified. Use of these nano-dimensional cellulose in nanocomposites will allow the production of much lighter weight, hyper-strength, multi-functional materials to replace metals and plastics in many industries.

[19] The internal generation of electrical charge resulting from an applied mechanical force as well as the reverse piezoelectric effect the internal generation of a mechanical force resulting from an applied electrical field

Other potential applications include electronic displays and microelectronic devices, clear armor, self-sterilizing and self-healing surfaces, pharmaceutical products, and intelligent wood- and paper-based products that sense forces, loads, moisture levels, temperature, pressure, chemical emissions, and attack by mold and wood-destroying fungi. In partnership with government and academia, industry leaders have identified three priority focus areas:

- Creating new revenue streams from production of new generations of high-value, high-performance innovative nanotechnology-enabled products and forest-derived nanomaterials;
- Improving the strength/weight performance of traditional paper- and wood-based structural materials; and
- Developing new value-added, multifunctional features for paper and forest products.

USDA/FS is based in Washington, DC; however, its nanotechnology research agenda is centered at the Forest Products Laboratory in Madison, WI.

Food and Drug Administration

The Silver Spring-based **Food and Drug Administration** concentrates on the toxicologic, safety, and effectiveness assessments of nanoscale materials, which often have chemical, physical, catalytic, or biological properties that are different from the same materials in bulk scale. Such differences may include altered magnetic, electrical, optical properties, structural integrity, and chemical or biological activity.

FDA investments support the responsible development of nanotechnology by enabling the agency to characterize nanotechnology-based products, developing models for safety and efficacy assessment, and studying the behavior of nanomaterials in biological systems and their effects on human health. The FDA collaborates with other regulatory agencies in the U.S. and internationally as well as health care professionals, industry, consumers, and other organizations to exchange information and identify interdisciplinary research needs.

The Supplement to the President's 2011 Budget reports that the FDA plans to increase nanotechnology laboratory testing capacity at its Maryland campus. *(p.36)* Research of interest to the FDA in 2010 includes:

- Risk characterization information to determine and classify nanomaterials based on physical and chemical properties;
- In vitro and in vivo assays/models to predict in vivo human responses to nanomaterials exposure;
- Methods to quantify and characterize exposure to nanomaterials and characterize nanomaterials in biological matrices;
- Absorption and transport in the body; and
- Relationships between properties of nanomaterials and how they affect uptake via lungs, skin, GI tract, assess body burden.

A review of science literature by the **FDA's Task Force on Nanotechnology** concluded in 2007 that "[I]dentifying precisely what qualifies as a nanoscale material is difficult and currently a subject of substantial discussion in the scientific, regulatory, and standards communities. As a result, developing a comprehensive description of products that are currently produced with nanotechnology, or may be produced with this technology in the future, would be difficult at best, and likely infeasible. Instead this report considers examples based on what is currently known about use of this technology… [A]vailable information does not suggest that all materials with nanoscale dimensions will be hazardous. Furthermore, if all nanoscale materials are compared to all non-nanoscale materials, whether larger or smaller, it is not apparent that the nanoscale materials as a group would have more inherent hazard. However, consideration of the basic science of how materials interact with biological systems does indicate that a material's properties can change when size is increased or decreased into, or varied within, the nanoscale range."

The FDA Task Force on Nanotechnology concluded that "these nanoscale materials will present regulatory challenges that are similar to those posed by other new technologies the FDA has dealt with in the past, such as biotechnology products, but also some potentially new challenges… The very nature of nanoscale materials – their dynamic quality as the size of nanoscale features change, for example, and their potential for diverse applications – may permit the development of highly integrated combinations of drugs, biological products, and/or devices, having multiple types of uses, such as combined diagnostic and therapeutic intended uses. As a consequence, the adequacy of the current paradigm for selecting regulatory pathways for 'combination products' may need to be assessed to ensure predictable determinations of the most appropriate pathway for such highly integrated combination products… [T]he Task Force believes communication between regulated entities and the agency early in the product development process, particularly with regard to highly integrated combination products, will help ensure timely consideration of any potentially novel issues raised by products using nanoscale materials. In addition, to assist the agency to be well-positioned to enable the development and premarket review of such highly integrated combination products, the Task Force recommends that the FDA seek public input on the adequacy of agency policies and procedures…" *(FDA 2007)*

In August 2008, the FDA formally sought industry views on "*the information and data that may be needed to demonstrate the safety and effectiveness of FDA-regulated products containing nanoscale materials and the circumstances under which a product's regulatory status might change due to the presence or use of nanoscale materials*" and in March 2009, the agency announced a collaboration with the Alliance for NanoHealth (ANH) and its members. According to the FDA, the collaboration is intended to "help speed development of safe and effective medical products in the emerging field of nanotechnology."

Under a memorandum of understanding, the FDA and ANH will work to increase the knowledge of how nanoparticles behave and affect biologic systems, and to facilitate the development of tests and processes that could mitigate the risks associated with nanoengineered products. The FDA states that all outcomes "will be placed in the public domain for the benefit of all stakeholders." The ANH member institutions include Baylor College of Medicine; the University of Texas' M.D. Anderson Cancer Center; Rice University; the University

of Houston; the University of Texas Health Science Center at Houston; Texas A & M Health Science Center; the University of Texas Medical Branch at Galveston; and the Methodist Hospital Research Institute.

The FDA plans in 2011 to strengthen its staff's nanotechnology scientific training and expertise, including cooperative training of review staff at research facilities. *(National Nanotechnology Initiative 2010)* Legislation was also introduced in the 111th Congress to address this need. In January 2010, U.S. Senators Mark Pryor and Benjamin Cardin introduced the Nanotechnology Safety Act of 2010. This legislation would amend the Federal Food, Drug and Cosmetic Act to establish a nanotechnology program at the FDA. It would authorize funding of $25 million per year from 2011 to 2015 for the FDA to assess the health and safety implications of nanotechnology in everyday products and develop best practices for companies using the technology. The FDA would use this funding to perform nanotechnology toxicology studies, develop analytical tools to quantify nanomaterials in complex matrices and create procedures for characterizing the technology in regulated products. *(Nanotech Now 2010)*

Relevant Activities at Other Federal and Maryland Research Institutions

Also in the environment, health, and safety realm, the **National Institute for Occupational Safety and Health** (NIOSH), based in Washington, D.C., is responsible for evaluating potential hazards of select nanomaterials, assessing human exposure in the workplace and potential health risk, evaluating controls and risk management practices for safe handling of nanomaterials, and developing guidance on medical screening and evaluation of workers. The research agenda of the agency, which is part of HHS's Centers for Disease Control, includes toxicology studies of the growing portfolio of nano materials, the efficacy and specificity of engineering and work-practice control measures in order to develop better guidance, and exploration of the use of nanotechnology to improve worker protection, through development of sensors, more efficient filters, and better protective materials. NIOSH also represents the U.S. in international efforts to assure nanotechnology safety.

The **Consumer Product Safety Commission** in Bethesda will formally join the NNI budget crosscut in 2011. It will work with other agencies to examine safety aspects of nanomaterials used in consumer products. The work plan includes developing protocols to assess the potential release of airborne nanoparticles from various consumer products and to determine their contributions to human exposure, determining whether nanoparticles can be used for performance improvements in sports safety equipment such as helmets and kneepads without creating other health hazards, expanding consumer product testing using scientifically credible protocols to examine the exposure (particularly of children) potential from nanosilver in consumer products, and working across agencies to assure that shared common public health concerns are met in research studies to determine potential impacts on the public health of nanomaterial use in consumer products.

The **Environmental Protection Agency** (EPA) 's Nanomaterial Research Strategy guides its research, which seeks to generate decision-support information to promote the safe development, use, and disposal/recycling of products that contain manufactured nanoscale materials. Through its Science to Achieve Results (STAR) grant program and SBIR/STTR, it has developed a growing cadre of highly skilled environmental nanotechnology researchers and engineers. EPA's researchers have joined an international testing program under the auspices of OECD, and it has issued join grant solicitations with other governments. EPA's headquarters are in Washington DC; its Environmental Science Center is located at Ft. Meade. University of Maryland Biotechnology Institute was a partner in the Center's Microarray Research Laboratory.

The **U.S. Patent and Trademark Office** (USPTO) plays a critical role in the commercialization of nanobiotechnology innovations. Without control over intellectual property, innovators cannot satisfy investors or business partners that they have a market advantage. This is particularly important when the product or process development timeline is long and research intensive, as it is in the nascent field of nanobiotechnology.

Stanford Law School researcher Mark Lemley said in a 2005 study entitled "Patenting Nanotechnology" that "…patents will cast a larger shadow over nanotech than they have over any other modern science at a comparable stage of development." Lemley notes that in this new field, unlike others before it, patenting has started at the most basic building block level. Because of its interdisciplinary character and wide applicability across industries, those who develop and patent the technology will not likely be taking it to market, the patent holders will potentially own rights in any of the industries in which the invention is used, and will make decisions about when and where to license them. Similarly, many of the early patents are held by universities, which will also be in a position to stimulate or delay early adoption that can give rise to building-block inventions. *(Lemley 2005)*

Of great concern to many in industry, public interest groups, and academics has been the proliferation of patents issued and the broad scope of many of them. A thicket of overlapping patent claims has ensued. Using the NNI definition of nanotechnology that includes, "Nanotechnology is the understanding and control of matter at the dimensions of roughly 1 to 100 nanometers where *unique phenomena enable novel applications*…." and applying it strictly, the USPTO has approved very few pure nanotechnology invention claims.

To enable patent examiners and the public to stay current with current developments, however, in 2006 the agency introduced a new class, #977, "Nanotechnology," as a secondary or cross-reference class to any invention that includes nontech-related terms in the disclosure. Using this search tool, over 5,800 patent grants that reference nanotechnology have been approved, growing over the past two decades from 40 per year to over 500 last year (USPTO 2010). As of July, 2010, 16 percent of the Class 977 patent awards were in biotechnology and organic chemistry, down from 20 percent in 2006. Globally in 2008, U.S.-based first-occurring nanotech-related patent publications accounted for 30 percent of the world total, China for almost 25 percent, Japan for nearly 15 percent, Korea for slightly more than 15 percent and Germany for five percent. However, U.S.-based patent holders on the same invention in three or more countries accounted for 38 percent of the world total, Japan for 18 percent, Germany and Korea for nine percent each, and France for four percent. *(Kisliuk 2010)*

The challenges to USPTO and its counterparts in other countries include patent applicability; because properties of matter and other fundamental scientific discoveries are not patentable. Applicants must claim to have achieved previously unattainable size, structure, composition, organization, methods of measurement, and methods of changing the properties of materials or applications of new properties. Balancing the freedom to innovate against excluding others from innovating has been a particularly thorny issue in this field where universities and other research organizations are patenting their innovations so that by the time an entrepreneur seeks to take a discovery to market, licenses from multiple patent holders may be required. USPTO's major challenge is the deluge of nano-related applications, which now make up 10 percent of submissions. It is unclear whether the agency has the human and financial resources to handle exponential increases in the numbers of these cross-cutting patent applications, especially in national and regional patent offices where examiners are generally assigned to examine a single class or related classes of technology. *(Tullis 2004)*

As in any field, academic publication, the *sine qua non* of the global community of scholars that builds upon one another's work, is a particular risk for patent strategists and university patent offices, as are procedures for technology transfer, and safeguarding intellectual property rights at each relevant stage of the research process. Premature disclosure may inadvertently occur in reporting to government agencies that have funded nanobiotechnology research. Private sector partners in many nanobiotechnology research centers also complicate the intellectual property picture.

The $14.8 billion **Howard Hughes Medical Institute (HHMI)**, headquartered in Chevy Chase, currently supports 350 investigators through its flagship program, 12 of whom are at Johns Hopkins, one at University of Maryland Baltimore County, and one at University of Maryland Baltimore School of Medicine. Awards underwrite the research portfolio of selected investigators rather than a specific project. HHMI is guided by the principle of "people, not projects." Investigators have the freedom to explore and, if necessary, to change direction in their research. They have support to follow their ideas through to fruition—even if that process takes a very long time. HHMI also provides funding for graduate and post-doctoral students as well as early career scientists and science education.

A PRESENCE OF NANOBIOTECHNOLOGY COMPANIES IN MARYLAND

Almost all of Maryland's 500 bioscience companies – for example large employers like BD Diagnostic Systems and Human Genome Sciences – are utilizing nano-sized molecules in their drug development, diagnostics, or devices. There are about two dozen Maryland firms that are singularly focused on using nanobiotechnology methods. However, as the road map presented above suggests, nanobiotechnology, like information technology, will rapidly become part of the infrastructure of many industries in the biology, medicine, and environmental sectors and in other industries that are exploring approaches that seek to mimic biological processes at the molecular level to generate energy and manufacture high value goods.[22]

COMPANY	COUNTY	INCUBATOR ?
Advanced Biomimetic Sensors	Montgomery	Y
Aeras Global	Montgomery	
Affinigen	Frederick	Y
Allegiance NanoSolutions	Baltimore City	Y
Aparna	Montgomery	Y
Applied Sensor Research & Development Corp.	Anne Arundel	Y
AriaVax	Montgomery	
Avanti NanoSciences	Baltimore County	
BioActive Surgical	Howard	
BioAssay Works	Frederick	
BriJen Biotech	Baltimore City	
Champions Biotechnology	Baltimore City	
Chikujee Therapeutics	Montgomery	
Columbia Biosciences	Howard	
Creatv Microtech	Montgomery	
CytImmune Sciences	Montgomery	Y*
General Research Laboratory	Montgomery	
Intelligent Substrates	Baltimore City	
Izon Science	Frederick	
NanoRods	Montgomery	Y
Noxilizer	Baltimore County	
Rexahn Pharmaceuticals	Montgomery	Y
SAIC-Frederick	Frederick	
Sirnaomics	Montgomery	
Valens Therapeutics	Baltimore County	

**incubator graduate*

SOURCE: Maryland Biotechnology Center, December 2010

[22] Biomimetic applications outside life sciences are not included in this report.

Sixteen of the State's two dozen nanobiotechnology companies have successfully competed for research funding from the National Institutes of Health and used this support to advance their core technologies, once again demonstrating the value of propinquity due to the catalytic proximity of being near NIH. Much of the NIH funding came through Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) awards. Seven of the companies are current tenants of State-supported incubators, and one is a graduate. A list of Maryland nanobiotechnology companies is included in the Appendices.

THE IMPORTANCE OF EDUCATION/WORKFORCE FOR NANOBIOTECHNOLOGY COMPANIES

The 2007 National Nanotechnology Initiative (NNI) Strategic Plan legislation included four goals against which progress is to be reported annually: (1) R&D; (2) commercialization; (3) **education, workforce**, and technology development infrastructure; and (4) responsible development of nanotechnology. Since nanotechnology is a multidisciplinary field of discovery, scientists working in physics, chemistry, biology, engineering, information technology, metrology, and other fields are contributing to today's research breakthroughs. The ***worldwide workforce necessary to support the field of nanotechnology is estimated at two million employees by 2015.***

The **workforce pipeline development** requires enrichment of professional training of all kinds. As Dr. Roco reminded in the NNI2 report, "new jobs are likely to be created in enterprises of any size that are able to identify and exploit the commercial opportunities that nanotechnology presents. In this context, access to workers who are able to develop, acquire, produce, and manage nanotechnology-enabled innovations will be vitally important. It is important to ensure that those who will develop, manage, and oversee innovations in nanotechnology are not only technically well-trained but also well prepared to anticipate and address broader implications. Employees in corporate public, legal, and regulatory affairs and areas other than R&D will need increased knowledge of nanotechnologies as well." *(Roco, 2010)* The State's business and law schools have a role to play in preparing new managers and lawyers, and in adding these competencies to the portfolios of existing professionals.

State and local government responsibility for education and workforce training will once again be tested as a new technology, potentially as ubiquitous as information technology, spreads through the economy. The Maryland State Department of Education, particularly its science, technology, engineering and math (STEM) efforts, the Maryland Higher Education Commission, the University System of Maryland and other higher education institutions, and the Department of Labor, Licensing and Regulation have critical roles to play in the preparation, retooling, and retention of the nanobiotechnology-related workforce, which will in turn determine the relative attractiveness of the State to industry and researchers.

NNI-funded research and development is intended not only to expand knowledge and its applications, but also to educate the next generation of young researchers participating in these projects. NNI research centers, user facilities, and university-based research projects are designed and developed to foster multidisciplinary education, offer opportunities for teacher training, and stimulate the development of curricula and instructional materials.

The NNI also provides hands-on training of technicians, undergraduates, graduate students, and postdoctoral researchers at universities, federal laboratories, and other institutions. For example, NIH used administrative budget supplements available through ARRA to maintain and enhance the student and post-doctoral workforce within its Cancer Nanotechnology Centers of Excellence. A five-year goal of the NNI is to ensure that 50 percent of US research institutions' faculty and students have access to the full range of nanoscale

research facilities, and student access to education in nanoscale science and engineering is enabled in at least 25 percent of the research universities. NNI supports five nationwide education networks that include universities, colleges, community colleges, regional museums and science centers, and historically black colleges and universities.

The NSF's education investments, concentrated at the beginning of the decade on curriculum development for graduate education programs, now include undergraduate, high school, and K-12 and informal (museum/science center) components. "Specific programs targeted at K-16 education, educating the public about nanotechnology, and improving nanotechnology in U.S. schools and universities have been initiated and are growing in scale and reach," reports the 2011 Supplement to the President's Budget.

How does the U.S. educational system train these workers and how do students choose the appropriate educational path for their interests? As in other fields, a passion for science is developed while students are young and an introduction to the many facets of nanotechnology will provide the basis for future educational opportunities. Curricula development is beginning and is available for K-12 and undergraduate education. Right now, however, only few degree programs in the field are available nationwide (and worldwide).

Help for teachers looking for nanoscience and technology curriculum can be found on the NanoEd Resource Portal, a "one-click resource" site for finding educational resources and to showcase work to facilitate collaborations within the Nanoscale Science and Engineering Education (NSEE) community. The site, sponsored by the NSF-funded **National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT)**, based at Northwestern University,[23] offers educational resources to help teachers with nanotechnology-related concepts, simulations, and activities for the classroom, including educational materials for science teachers and students in grades 7-12, college and university students and faculty, researchers, and post doc students; seminars to advance education initiatives; Learning Research and Methods, a collection of papers, presentations and resources to promote the best teaching practices and methodologies; Nanoconcepts and Applications, instructional materials focusing on the key ideas in nanoscale science and engineering; NSEE resources and calendar of events for nanoscale science and engineering education; NSEE News and network and a glossary.

The National Science Digital Library (NSDL) is the National Science Foundation's online library of resources for science, technology, engineering, and mathematics education. It maintains a collection of lessons and web resources aimed at classroom teachers, their students, and students' families at www.nsdl.org. The NNI-supported Nanobiotechnology Center (NBTC) at Cornell University has a traveling exhibit for children ages 5-8 years old called It's a Nano World, a club for middle school, Tri-Sci Club for Girls, and high school summer internships in nanotechnology. There are also many opportunities for undergraduate and graduate students to pursue independent research and to participate in the K-12 educational programs of the NBTC.

[23] In collaboration with scientists at: Purdue University, University of Illinois at Chicago, University of Illinois at Urbana-Champaign, Argonne National Laboratory, Alabama A&M University, Fisk University, Hampton University, Morehouse College, and University of Texas at El Paso.

The presence of the **NCLT at Pennsylvania State University** has permitted the university to serve as a nanotechnology education hub and provider of capstone coursework for all Pennsylvania community colleges as well as **Allegany College** in Western Maryland. The curriculum embodies the hiring philosophy of the director of quantum science research at Hewlett Packard, "I want people who are very deep in their discipline and can talk to each other."[24] Associate degree nanotechnology students follow a prescribed sequence of courses at their home colleges for three semesters, including chemistry, mathematics, physics, biological science, computer science, medical laboratory techniques, and statistics and also English, psychology, speech communications, business and technical communication, and interdisciplinary leadership. For the fourth semester at Penn State, they are introduced to nanotechnology material safety and equipment, and study basic nanotechnology processes, materials and materials modification in nanotechnology, patterning for nanotechnology, and characterization and testing of nanofabricated structures and materials.

Frostburg State University received a grant from the Appalachian Regional Commission in July, 2010, to enhance its nanotechnology laboratory. The laboratory is used for college science programs in engineering, physics, chemistry, and biology as well as extracurricular activities for K-12 students, continuing education, and providing nanotechnology expertise to tenants in the AlleganyBusinessCenter. The funding is being used for new equipment, hiring trained instructors, and developing outreach programs in order to serve 450 college students annually, and 700 other visitors and pre-college students.

As noted above, the **National Science Foundation** funds education at all levels and to the public schools, including K-12, community colleges, vocational schools, and major research universities. NSF's Research Experience for Teachers and Research Experience for Undergraduates reach thousands of students and educators annually.

NSF's Nanoscale Science and Engineering Education (NSEE), including Nanotechnology Undergraduate Education (NUE) awards supporting course development. In the coming year, it plans to expand the outreach by its grantee, the National Center for Nanotechnology Applications and Career Knowledge (NACK) at Pennsylvania State University to other educational clusters and States in the U.S.

NSF's Nanoscale Informal (museums, science centers) Science Education (CISE) network[25] will share knowledge, resources, and networking for educational activities with DoD and DOE, and NSF, DOE (Sandia), NIST, DoD, and NIH are coordinating join student fellowship programs in various areas of nanotechnology. **NIH** participates in webinars on medical nanotechnology sponsored by the University of California, San Diego for academics, physicians, and industrial researchers globally. Using fellowships funded by ARRA, **NIST** will be providing opportunities for students, faculty, and industrial researchers to interact with NIST scientists and conduct nanotechnology research in NIST laboratories.

[24] Stan Williams, Director, Quantum Science Research, Hewlett Packard, quoted on NNI's education website: http://www.nano.gov/html/edu/eduunder.html

[25] Museum of Science, Boston, the Exploratorium in San Francisco, the Science Museum of Minnesota

The **Johns Hopkins Institute for NanoBio Technology** (INBT) has launched a new model for training the interdisciplinary researchers the field requires. It involves lecture courses, laboratory courses, professional development seminars (including technology commercialization), peer-to-peer teaching, and communications workshops. All students are co-advised by faculty from both the physical sciences/engineering and the biological sciences/medicine realms. INBT offers postdoctoral fellowships in Nanotechnology for Cancer Medicine and Physics of Cancer. The NSF-funded Integrative Graduate Education and Research Traineeship trains graduate students in biology, engineering, and materials synthesis to create probes to study biological events. Accepted students receive a yearly stipend and full tuition support. The Research Experience for Undergraduates (REU) program offers undergraduate students from colleges and universities around the country a chance to participate in research projects in nanobiotechnology.

INBT also has funding to support four summer research internships at the NSF-funded Inter-University MicroElectronics Centre (IMEC) in Leuven, Belgium. Students work at IMEC's world-class microfabrication facility and learn to design, fabricate and test a wide range of biomedical devices. INBT also offers an independent study course, Animation in Nanotechnology & Medicine, which revolves around the production of animations that depict processes at nanoscale. Communicating Science for Scientists and Engineers is taught during intersession in January.

Johns Hopkins Institute for Basic Biomedical Sciences trains 250 postdoctoral fellows and more than 500 graduate students. Its undergraduate "Build-a-Genome" Course addresses the challenge of keeping undergraduate biology education up to date with the rapidly advancing field. This undergraduate synthetic biology course operates within the context of the Synthetic Yeast Genome Project (http://www.syntheticyeast.org) in INBT laboratories. Although the goal of the project is to design and synthesize the total genome of Saccharomyces cerevisiae, the immediate goal was the synthesis of the starting materials for chromosome III in an undergraduate laboratory setting. Students are introduced to the field of synthetic biology through a series of lectures and laboratory sessions. After completion of the initial training segment, students work in an open-access lab to assemble designed segments of chromosome III in the form of 750-bp DNA building blocks. Assembly of these building blocks into larger 10-kb chunks in future semesters will be an important milestone in the fabrication of a complete synthetic eukaryotic genome. The Build-a-Genome course began as a pilot program in the summer of 2007 with nine students. In the Fall 2007 and Spring 2008 semesters, 18 and 20 students, respectively, participated in both Build-a-Genome and Build-a-Genome Mentor, a class offered to returning students who have satisfactorily completed the Build-a-Genome course. *(Dymond et. al. 2009)*

UMB's Center for Nanomedicine and Cellular Delivery and **UMD's Department of Bioengineering** offer a joint graduate research track in nanomedicine which instructs students in the areas of nanoscience and engineering with a focus on translational clinical research.

The University of Maryland through the **Maryland NanoCenter** offers facilities and faculty to expand educational offerings. A freshman year one-credit course "Introductions to Nanotechnology: the Future of Engineering" covers the roles of various engineering and science

disciplines in nanotechnology. For upperclassmen, a new nano minor (officially the Interdisciplinary Minor Program in Nanoscale Science and Technology) draw courses and faculty from the school of engineering and the colleges of computer, math and physical sciences and of chemical and life sciences. Any student majoring in engineering, physics or chemistry may elect this minor. Other universities, colleges, and community colleges in Maryland offer courses in nanotechnology.

Additionally, a number of the federal laboratories located in Maryland sponsor programs that bring students – not solely from Maryland or singularly focused on nanotechnology – into their laboratories. Examples include the Summer Undergraduate Research Fellowship (SURF) Program, through which students majoring in science, mathematics, and engineering are invited to apply to spend a summer working at NIST.

Education collaborations include an agreement between Johns Hopkins University and the U.S. Army to work together to train scientists to develop vaccines and medicines to defend against biological attacks. Students accepted into the program study part-time to earn Johns Hopkins Master of Science in Biotechnology degrees with concentrations in biodefense. Simultaneously, the students work for the U.S. Army Medical Research Institute of Infectious Diseases (USAMRIID), located at Fort Detrick. Also, under a five-year agreement between Johns Hopkins' Advanced Biotechnology Studies Program and USAMRIID, graduate students are employed under the Army's Student Career Experience Program and are eligible for Army reimbursement of their Johns Hopkins tuition.

In addition to support for educating a pipeline of nanotechnology workers, NNI's workforce agenda includes partnerships aimed at providing access to training programs for careers in nanotechnology-related industrial sectors. Examples include using career centers funded by the Department of Labor and other appropriate public venues to distribute information on nanotechnology and the career opportunities this field offers; developing training programs that encourage workers to pursue nanotechnology-related career opportunities; providing information on nanotechnology-related training opportunities on the NNI website; and assessing human resource issues, including workforce training, by comparisons with other countries through international benchmarking exercises.

MARYLAND'S COMPETITIVE STANDING IN NANOBIOTECHNOLOGY

In a field that is still seeking understanding of fundamental biological processes and means to control them with atomic precision, research strength trumps all other factors. The University of Maryland, College Park has been ranked among the top 10 universities in ***nanotechnology*** research. *(Small Times 2009)* This superlative ranking was due in part to its strong physical sciences, engineering capabilities, and State support.

The University System of Maryland's (USM) strengths lie at the interface between nanobiotechnology and microdevices – e.g. bioMEMS for metabolic engineering and biological signaling – and in biofabrication, and possibly in next-generation nanoparticle cancer therapy (drug delivery and disease imaging, beyond heatable gold nanoparticles targeted to tumors); and virus approaches to energy. Also, USM has a broad program in nanotechnology, with multiple areas of excellence including nanoparticle synthesis, nanostructure fabrication, in-situ and real-time nanoscale imaging, nanotubes and nanowires for electronics, energy, and biotech sensing, and multifunctional nanomaterials both inorganic and organic. The system's leader in nanobiotechnology is the School of Pharmacy at UMB, which is the hub of several cross-system initiatives.

Johns Hopkins is one of an elite group of universities in the U.S. that has been successful in competitive large-scale funding for ***nanobiotechnology***, including awards by the NIH National Cancer Institute for the 1) Physical Sciences – Oncology Center, 2) Center of Cancer Nanotechnology Excellence, and 3) Cancer Nanotechnology Training Center; by NIH for a Cancer Nanomedicine Post-Doctoral Training Program; and by the National Sciences Foundation for a Nanobiotechnology Training Program (IGERT). The university's expertise in everything from the basic sciences to clinical medicine and bioengineering, chemistry, and physics has enabled it to integrate across the institution the kinds of centers that in other places require multi-university collaboratives.

Primary JHU competitors include Stanford, Harvard, MIT, and Northwestern. Others would add Cornell, Utah, University of Washington Seattle, Rice, California Institute of Technology and University of Pennsylvania. It has been noted that University of Delaware is hiring many new faculty (and raiding other universities such as Cornell, Northwestern, and UC Riverside for full professors with large start-up packages and huge salaries) in their biotechnology institute during times of budgetary hardship elsewhere.

Commercialization of nanotechnology is in very early stages. Accordingly, measures such as revenues, market share, and employment that are often used to assess and track competitiveness in other more mature technologies and industries are not available for assessing the relative position in nanotechnology of any State or of the U.S. internationally. *(Sargent 2010)* Further investigation will be required to develop a full competitive analysis.

DEVELOPING A STATE ROLE IN PROMOTING NANOBIOTECHNOLOGY

Key issues that, if not addressed, may hinder the growth of the industry in Maryland, include research resources, developing nanoscale manufacturing capabilities, intellectual property, commercialization hurdles such as business development and financing, workforce pipeline, public understanding, regulation of nanomaterials, and failure to adopt and implement a focused State strategy, integrated with other competing emerging technology areas.

In the case of intellectual property and, to some extent, regulation, the potential barriers relate to **federal policy**. The State role in these cases becomes one of continuous dialogue and collaboration with Maryland's Congressional delegation and conveniently located federal officials. Technology business advocates and cross-sector leadership organizations like the Maryland Life Sciences Advisory Board bring important "real life" examples to these discussions. Lending the State's voice to university efforts to sustain flows of competitive federal research funding will also help ensure the flow of critical discovery inputs.

The remaining issues need to be addressed by the States directly. For example, while the federal government will remain the dominant funder of research that is the life blood for the nanobiotechnology enterprise, other States have become much more active in the last decade in funding research that is viewed as critical to their States' economies. Unlike federal underwriters, however, States have traditionally coupled **research** funding with **commercialization** requirements and support.

Support for Cutting-Edge Research and Critical Infrastructure

State funding of capital equipment for research activities provides ongoing infrastructure that enables discovery and makes Maryland institutions more competitive for federal funding. For example, University of Maryland's leadership in nanotechnology was built on Sunny Day funds for equipment that would have taken 10 to 30 years through normal federal channels of incremental research facility funding to achieve. Many high impact publications and wins of several funding competitions have resulted. Success in attracting a major $14 million grant from the Department of Energy would not have been possible without the Sunny Day-funded facilities and the Maryland NanoCenter organization.

There was discussion among the Task Force that to exploit Maryland's unique position, with a broad array of resources and capabilities, the State would need to prioritize around a synergistic development of two core components:

(1) The development of a broad-based infrastructure for promoting and enabling developments in nanobiotechnology across industry and academia through integration of research, education, and technology development. The goal will be to engage, as broadly as possible, companies, educational institutions, schools, national laboratories, incubators, and State government in developing nanobiotechnology in Maryland. This infrastructure will provide core activities for Maryland to compete nationally; and

(2) The development of national and internationally recognized leaders in industry and academia. To achieve a pre-eminent position in nanobiotechnology, Maryland must be successful and highly visible in industry and academia.

These two core components could serve to establish a pre-eminent position for the State in nanobiotechnology. The first component will broadly engage multiple constituencies in the development of nanobiotechnology. The second component emphasizes selective excellence in establishing nationally and internationally recognized academic and industrial pillars of excellence. Both components could be integrated into a Maryland nanobiotechnology roadmap.

Comparative Programs in Other States

Texas created the **Texas Emerging Technology Fund** in 2004 to support statewide nanotech commercialization and research efforts. Fifteen percent of the funding, $185 million total per year, is devoted to research, 70 percent to commercialization, and 10 percent to matching grants. Commercialization applicants must identify university partners, resulting in more teaming. A new Proof-of-Concept fund will provide funder-of-last-resort gap financing in relatively small amounts for first commercialization steps. Private financiers and Regional Centers of Innovation and Commercialization provide mentoring and guidance. Volunteers from throughout the State serve on review committees and help selected companies succeed. A pre-seed fund was recently added to the program, which has found that nanotechnology had the potential to advance each of the six target clusters of the Texas' economic development efforts – advanced technology and manufacturing, aerospace and defense, information technology, biotechnology and life sciences, petroleum refining, and energy. *(Trybula 2009)*

The **Georgia Research Alliance** (GRA), a model public-private partnership between Georgia research universities, business and State government, helps build Georgia's technology-rich economy in three major ways: through attracting Eminent Scholars® to Georgia's research universities, through helping create centers of research excellence, and through converting research into products, services and jobs that drive the economy. The Georgia Research Alliance (GRA) provided matching funds and funding for recruitment of two Eminent Scholars® in support of the Emory-Georgia Tech Nanotechnology Center for Personalized and Predictive Oncology's successful application to become an NCI Center for Cancer Nanotechnology Excellence. GRA provided $3 million to co-fund an NIH Nanomedicine Development Center at Georgia Institute of Technology, Emory University, and Medical College of Georgia (MCG) that will focus on DNA damage repair. With up to $10 million in funding, the center will be Georgia Tech and Emory's third NIH-funded nanomedicine/nanotechnology center in less than two years.

GRA provided a $100,000 grant for a collaborative research project, led by Mercer University professor Dr. Martin D'Souza, to explore using nanotechnology to deliver a pneumonia vaccine. Dr. D'Souza, professor in the College of Pharmacy and Health Sciences, will collaborate with researchers from Emory University and the Centers for Disease Control and Prevention. The grant is part of GRA's Next-Generation Vaccines and Therapeutics Initiative, which funds collaborative planning grants for projects among the eight universities in the State doing significant research. The program supports joint university-based research and

development projects related to next-generation vaccines and therapeutics that have the potential to attract significant non-State funding. The goal of the program is to attract national research and development centers and other high-level research and development awards to make Georgia a destination in the area of next-generation vaccines and therapeutics, one of the Alliance's targets. The program aims to create long-term, productive research and development partnerships among researchers in Georgia and develop new technologies that will accelerate the growth of the life sciences industry in the State.

Primarily through its award-winning VentureLab program, GRA also supports commercialization. Since 2002, GRA (through VentureLab) has evaluated the commercial potential of more than 300 inventions or discoveries at universities. The most promising of these were awarded VentureLab grants to help fund the technology research necessary to further develop the invention or discovery. This process has led to the formation of more than 80 early-stage companies that employ more than 450 people and have attracted $300 million in private equity investment. GRA also works with established Georgia companies through its Technology Partnerships program, which provides grants to university researchers conducting collaborative research with a Georgia company that will help the company to develop or refine its products and processes. The company matches the grants dollar-for-dollar.

Proposition 301, approved by **Arizona** voters, added 0.6 cents to the State sales tax, providing funding for the Technology Research Initiative Fund (TRIF) as well as K-12 education. The TRIF portion of the Proposition 301 revenues are administered by the Arizona Board of Regents and given to the State's public universities for creative research efforts in critical high-technology areas, translation of research results to clinical or commercial application, and education of a workforce prepared for the knowledge-based economy of the 21st Century. Funds also support specialized research facilities, enhancement of technology transfer, and distance-learning activities. Arizona State University (ASU) used these funds to establish the Biodesign Institute in 2003. To date, the Biodesign Institute has received $82 million from the TRIF and attracted more than $300 million in external funding, including competitive grant awards and support from philanthropic sources. ASU's innovation pipeline has been increased dramatically, disclosing 279 inventions, generating 178 provisional patents and 57 patent filings. To date, 18 patents have been issued. The Institute also educates future scientists, developing a home-grown workforce through hands-on laboratory training – to date, 188 postdoctoral researchers and 301 graduate students have been employed/trained; more than 170 have entered the workforce to date. Research experiences for 403 undergraduates, 95 high school students and 36 high school teachers have also been provided.

A 2008 student analysis in Georgia Tech's program in Science, Technology, and Innovation Policy (STIP) of State-level nanotechnology policy initiatives *(McKeon 2008)* found that the initiatives he examined were variations on four themes – consortium-led, industry-led, university-led, and agency led. Early-stage activities tended to be the consortium model, with loose structure and a focus on collaborations, shared information about nano-related activities, and advocacy for investment in nanotechnology. Examples include the Arizona Nanotechnology Center and the Michigan Small Tech Association.

Another decentralized model featured a core of industries with university partners, such as the California NanoSystems Institute, the New Jersey Nanotechnology Consortium, and New York Loves Nanotech. The university model, exemplified in the Illinois Coalition and the Oregon Nanoscience and Microtechnologies Institute, was decentralized and included groups of universities and other laboratories. The highly developed agency model featured centralized authority in a nonprofit public agency, such as the Massachusetts Nanotechnology Initiative and the Pennsylvania Initiative for Technology. Four states, Colorado, Minnesota, North Carolina, and Washington, have developed road maps, and other nano leaders do not have coordinated statewide policy initiatives, notably Georgia, New Mexico, Tennessee, and Wisconsin.

Patterns and lessons observed by McKeon in up-stream research activities included the use of alliances with other universities and federal laboratories to attract infrastructure support (IL, MN, OR, VA), the alignment of university research with local industry needs to foster private sector collaboration (NJ, NY, OR), and the attraction of prominent researchers to anchor university centers (WA). Down-stream activities included local industry projects (CA, NJ), university technology transfer offices (CO, IL, OR, VA), and were part of regional clusters for specialized innovation (PA, TX). Workforce and public education activities included workforce development at two-year colleges (PA,VA), nano-specific education programs (CA, IL, NY, WA), and public information campaigns (OR, PA).

ACCESS TO CAPITAL AND SUPPORT FOR NANOBIOTECHNOLOGY COMMERCIALIZATION

Nanobiotechnology commercialization challenges include a particularly acute need to demonstrate proof-of-principle or develop prototype devices, often before a company is formed. The applications for use in humans face a long and costly path to obtain FDA approval, which means that entrepreneurs and investors must have confidence in the technical feasibility of the innovation.

As the field progresses from the arenas in which incremental improvements in existing practice are being made possible to never-before-seen applications that require market-making, practitioner and public attitudes become critical. Of course, financing will always pose a hurdle, starting with support for R&D – often in collaboration with research institutions – and progressing to pre-seed capital for early market-entry expenses, and finally investments for scale-up to meet market demand.

Irrespective of the budgetary funding allowances, Maryland possesses a set of financing tools that could meet these needs. All existing programs in the State that involve funding of biocompanies and bioprojects are inclusive of nanobiotechnology.

There are also potential future funding vehicles that could benefit nanobiotechnology, such as the proposed Governor's InvestMaryland initiative to be considered by the 2011 General Assembly. InvestMaryland is a proposal for legislation creating a $100 million fund that would provide critical funding for the Maryland Venture Fund as well as separate private venture capital funding, with a portion dedicated to small and minority enterprises financed through the Maryland Small Business Financing Authority.

As has been seen in the past, many programs have not been funded to meet the growing demand and potential of promising technologies. For example, the 2009 Maryland Nanobiotechnology Research and Industry Competition Grants program jointly administered between DBED and TEDCO provided the first-ever statewide nanobiotechnology research grants and the first-in-the-nation funding program dedicated solely to nanobiotechnology. That competitive, peer-reviewed grant program drew significant interest from both companies and research institutions; over 100 applications were received and awards were made to four companies, a research foundation, and JHU (one with a Maryland company and the other with UMBC), UMB, and UMCP, and several in collaboration with Maryland-based federal laboratories.

The Coordinating Emerging Nanobiotechnology Research (CENTR) in Maryland Program was enacted in 2008 to enable TEDCO to provide capital and operating grants for nanobiotechnology projects at higher education institutions and companies. Despite its statutory authorization, the CENTR program has yet to ever receive any funding.

CENTR funding can be used to leverage federal funding for the establishment or construction of research centers in the State, provide pilot funding for faculty at institutions of higher education in the State to develop initial research data for the development of larger grant funding proposals, and assist with the transfer of nanobiotechnology research into commercial

applications. The grants are eligible to support graduate level or post-doctorate level collaborations with private sector entities on nanobiotechnology projects, collaborative grants to support research teams from institutions of higher education working with private sector entities on collaborative research projects, and prototype matching grants to enable institutions of higher education and companies to demonstrate whether a prototype is functional and able to be manufactured and demonstrates the cost effectiveness of nanotechnology-related applications.

Sixteen of the State's two dozen nanobiotechnology companies have successfully competed for research funding from the National Institutes of Health, much of the funding came through the federal Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) awards. The Oregon Nanoscience and Microtechnologies Institute (ONAMI) concluded that SBIR and STTR, while vitally important to small companies, do not enable them to navigate the "valley of death" between research findings and finance-ready companies, because these researcher peer-reviewed awards "do not mimic business investment processes, in particular the importance of identifying large, profitable markets and recruiting management teams capable of leading growth companies." *(Rung 2010)*

The ONAMI Commercialization Gap Fund makes "proof of concept" grants to research institutions[26] take research results to the next level, for example a more product-like prototype and/or demonstration of cost-effective fabrication methods. Proposals must include collaboration with an already-formed for-profit company that has already licensed or optioned the technology, or in some cases, Oregon companies utilizing ONAMI's user facilities to develop their own intellectual property. In the second element, ONAMI's commercialization program, follow-on funding activities with other public and private funding sources are pursued.

The ONAMI Commercialization Gap Fund is professionally run and advised by a Commercialization Advisory Council consisting of three large and three early stage VC firms, two corporate investment arms, (five of them from outside Oregon) and a representative of a DOE national laboratory in a neighbor state. ONAMI's board includes senior executives from Hewlett Packard, FEI, Pixelworks, OVP Venture Partners, and Battelle.

The Maryland Industrial Partnerships Program (MIPS) supports R&D collaborations between companies and University System o f Maryland institutions. Several Maryland nanobiotechnology companies have won MIPS awards. Maryland Technology Development Corporation's (TEDCO) University Technology Development Fund (UTDF) provides resources to Maryland universities to support pre-commercial research on university intellectual property to increase the likelihood of commercializing that intellectual property.

MIPS helps universities to license early stage technologies more effectively and serves as a source of technology development projects for Maryland companies that are eligible for additional TEDCO and other State financing programs. As the applications of nanobiotechnology for improving stem cell therapies mature, the Maryland Stem Cell Research Fund may be usefully deployed to support R&D in this realm.

[26] Principal Investigators, i.e. leaders of research projects.

TEDCO's Maryland Technology Transfer and Commercialization Fund (MTTCF**)** provides funding for Maryland companies that would like to develop technology-based products and/or services in collaboration with the Universities and/or federal laboratories in Maryland or are located in an incubator. MTTCF includes funding from the Johnson & Johnson Corporate Office of Science and Technology that can be used for projects of interest to J&J, which is one of the leaders in nanomedicine development.

The Maryland Department of Business and Economic Development has been able to help fund university discovery infrastructure as well as provide early stage and growth capital for innovating entrepreneurs through its Maryland Venture Fund programs. Most of the nanobiotechnology companies in the State are not yet mature enough to successfully compete for these funds.

The Maryland Biotechnology Center also offers potentially $200,000 awards to companies for translational research and commercialization projects. Since its opening a year ago, the Maryland Biotechnology Center has received about 100 applications for and awarded over $3 million in grants to more than 10 companies. Companies engaged in nanobiotechnology applications are eligible to apply for these competitive awards.

Maryland's Biotechnology Investment Incentive Tax Credit, the State's tax credit for investors in biotechnology companies has proven immensely helpful to young companies. Six of the State's nanobiotechnology companies reside in Baltimore City, Frederick County, or Montgomery County incubators, where they receive intensive commercialization help; two of the companies are incubator graduates located in Maryland.

Nanofabrication equipment to assist companies to manufacture on the nanoscale is an important need for local companies to succeed. One Maryland company was able to use the GMP (meets FDA's standards for good manufacturing practice) manufacturing scale-up facilities at the Center for Advanced Research in Biotechnology (CARB), a collaboration of University of Maryland Biotechnology Institute (UMBI) and NIST. In the wake of the dissolution of UMBI, however, this facility has been closed and leaves this and other companies searching for suitable alternative resources for nanofab collaboration.

PUBLIC UNDERSTANDING AND ACCEPTANCE OF NANOBIOTECHNOLOGY

Public understanding of nanotechnology will be critical to scientific, medical, and engineering advances in the field and to commercialization of their findings. The federal government, most notably the National Science Foundation, has developed useful tools but their widespread use will be dependent on State's and other advocates' actions.

NSF has provided a five-year $20 million grant to the Nanoscale Informal Science Education (NISE) Network,[27] which brings researchers and informal science educators together to inform the public about nanoscience and technology. Its Web site, nisenet.org, allows access to a vast collection of educational resources, including study materials, academic approaches, collections of graphics, a newsletter, and links to other institutions working in the field. The NISE Network works to create new methods and approaches to communicate the work of nanoscale scientists and engineers, inform the public about the advances in the scientific research, and capture the imagination of youth who may choose careers in nanoscale science and engineering.

The Maryland Science Center is a member of the NISE Network and participated in the nationwide annual public awareness event, Nano Days 2009, as did the University of Maryland College Park Materials Research Science and Engineering Center (MRSEC).

A Northeastern University professor who has tracked studies of public perceptions of nanotechnology concludes that the public does not understand the technical and scientific aspects of nanotechnology, but it largely does understand that it is likely to undergird the next revolution in technology and industry and will have a large social impact. He doubts, however, whether the public understands well enough yet to debate the important economic, social, ethical, and environmental issues that will need to be addressed. He emphasizes the importance of the connections people have with private organizations such as citizen groups, environmental organizations and foundations that are educating themselves about nanotechnology, for it is to these organizations that people will turn for advice. *(Zenka 2006)*

In a mid-decade article in *Issues in Science and Technology*, authors John Balbus, Richard Denison and Laren Florini wrote: "…nanotechnology development and commercialization are still at an early stage, so it is not too late to begin managing this process wisely. Nanotechnology offers an important opportunity to apply the lessons from prior mistakes by identifying risks up front, taking the necessary steps to address them, and meaningfully engaging stakeholders to help shape this technology's trajectory. There is an opportunity to get nanotechnology right the first time." *(Balbus 2005)*

[27] The NISE Network consists of the Museum of Science, Boston, the Exploratorium in San Francisco, the Science Museum of Minnesota and a growing group of partners and advisors.

THE IMPACT OF THE REGULATORY PROCESS ON COMMERCIALIZING NANOBIOTECHNOLOGY

Regulation of nanomaterials poses another dilemma for government at both the federal and State levels. The Food and Drug Administration, the Environmental Protection Agency, and the National Institute of Occupational Safety and Health (HHS) are addressing these challenges.

As pointed out in a "policy primer" on nanotechnology issued by the Congressional Research Service earlier in 2010, the issues are not solely the direct consequences for health, safety, and the environment, but also the effect that uncertainty about regulation may have on investor decisions by researchers, companies, and external financiers. Much of the concern has been focused on the early intentionally engineered and produced nanoparticles such as carbon nanotubes and other fullerenes[28] which have been the subject of conflicting studies.

More fundamentally daunting for regulators, nanoscale particles may have both beneficial and dangerous effects, such as the ability to cross the blood-brain barrier to deliver life-saving drugs or, if unintentionally released, harm people or animals. The FDA has not established benchmarks for nanomedicines, guidance on manufacturing benchmarks, or consensus on formulations for optimal biodistribution.

The Maryland Department of the Environment monitors air, water, hazardous materials, and waste disposal, all of which may be affected by nanoparticles, and has responsibility for enforcing State and federal regulations. Similarly, the Maryland Department of Labor, Licensing and Regulation's Division of Industry, specifically Maryland Occupational Safety and Health (MOSH), regulates workplace safety. Under an agreement with the Federal Occupational Safety and Health Administration (OSHA), MOSH promotes occupational safety and health in workplaces across Maryland. In addition to adopting many of the federal standards for General Industry, Construction, and Agriculture, MOSH has supplemented the OSHA standards with several requirements unique to Maryland.

[28] Molecules formed entirely of carbon atoms in various shapes.

TASK FORCE RECOMMENDATIONS TO SUPPORT NANOBIOTECHNOLOGY IN MARYLAND

Perhaps the State's most important role is leadership, evidenced in the articulation of nanobiotechnology goals, development of opportunistic strategies to attain them, marshalling of resources inside and outside State government, and measuring results. Towards that goal, the following recommendations were developed.

These recommendations were developed with the input of the Task Force meetings and are consistent with the BioMaryland 2020 ten-year strategic plan, created by the Maryland Life Sciences Advisory Board (LSAB). These nanobiotechnology recommendations reiterate many of the thrusts of the BioMaryland 2020 recommendations. The recommendations support nanobiotechnology research and commercialization, education and workforce, and responsible advocacy and promotion.

The Maryland Life Sciences Advisory Board, a permanent commission created by law and charged to oversee the implementation of the BioMaryland 2020 strategic plan, intends to carry forward the Task Force recommendations through its Emerging Technologies Working Group. The LSAB Emerging Technologies Working Group is chaired by Dr. Stephen Desiderio, who serves on both the Task Force as well as the LSAB representative.

A. DEVELOP SPECIFIC NANOBIOTECHNOLOGY STRATEGIES FOR MARYLAND LEADERSHIP.

1. **Inventory Maryland's resources, analyze the State's competitive position, and identify gaps** in the areas of discovery, commercialization supports, and talent.

2. **Enhance the potential for collaboration** among Maryland research institutions and companies and with external partners that can jointly seek external funding for nanobiotechnology initiatives.

3. **Articulate Maryland's nanobiotechnology goals** based on economic analysis of the industry trends based on the State's strengths and potential.

4. **Develop nanobiotechnology strategies** for achieving goals in research and commercialization that knit together core components in academia, companies, government, and investors, including an integrated plan for engaging and educating the public about the technology, its promise, and steps needed to assure its safe development.

B. TARGET MARYLAND'S ASSETS TO ENHANCE NANOBIOTECHNOLOGY COLLABORATION.

1. **Support research in this emerging growth area,** particularly investments that leverage funding from other sources. Where appropriate, support research collaborations with young and established companies in Maryland and globally.

2. **Intensify R&D collaboration with nearby federal laboratories** through cooperative research and development agreements (CRADA), informal collaborations, guest researcher arrangements, material transfer agreements, supporting strategic faculty hires, encouraging clinical research partnerships, and encouraging industry outreach.

3. **Develop substantial, highly targeted resources to support large scale nanobio-enabled projects and programs**, e.g. personalized medicine, by leveraging strategic State investments in partnership with major federal, philanthropic, and corporate funding.

4. **Support the development and continuous upgrading of nanobiotechnology research infrastructure** at Maryland colleges and universities and community colleges through federal/State agreements for shared use of specialized research facilities and equipment and strategic State capital investments that leverage federal funding whenever possible.

5. **Provide funding for the Coordinating Emerging Nanobiotechnology Research (CENTR) in Maryland Program** to foster research partnerships among federal institutions, private sector entities, and institutions of higher education, including pilot funding for faculty to develop research data to be used in larger grant funding proposals and research infrastructure, as well as human capital development in nanobiotechnology research.

6. **Support Maryland nanobiotechnology companies' pursuit of external research funding** from the federal government and other sources.

C. SUPPORT THE COMMERCIALIZATION OF NANOBIOTECHNOLOGY RESEARCH IN MARYLAND.

1. **Support pre-commercialization translational reduction of research to practice** by providing funding and spaces where talented faculty, students, and post-docs can perform the proof-of-principle demonstration or prototype device demonstration that is necessary to seek funding to start a company. A possible model could be the Georgia Research Alliance Venture Lab.

2. **Increase the availability of product development capital for promising nanobiotechnology** companies, particularly those entering clinical studies, by increasing appropriations to the Maryland Venture Fund and TEDCO's Maryland Technology Transfer and Commercialization Fund (MTTCF), and explore other commercialization support programs. A possible model could be the Oregon Nanoscience and Microtechnologies Institute's ONAMI Commercialization Gap Fund.

3. **Capitalize on Maryland's unique array of federal commercialization assets** including the NCI/FDA/NIST National Nanotechnology Characterization Laboratory and the Center for Nanoscale Science and Technology at NIST for nanofabrication. Refer companies that use the Maryland Biotechnology Center and TEDCO to these federal resources.

4. **Support nanobiotechnology commercialization planning and execution by the most promising Maryland companies** through intensive mentoring and tiered funding, with strong capabilities for assisting companies with intellectual property issues. A possible model could be the Texas Emerging Technology Fund.

5. **Support broad funding instruments for innovative technologies, including the proposed InvestMaryland initiative**, which would be able to seed nanobiotechnology companies with its focused early stage funding for qualified Maryland companies.

6. **Explore State funding for high potential SBIR/STTR nanobiotechnology and other emerging technology winners** judged by the Maryland Venture Fund to have feasible commercialization plans and the capacity to implement them. Consider bridge funding between Phase I and Phase II awards, and strong links to commercialization resources for those nanobiotechnology companies completing Phase II projects.

7. **Strengthen technology transfer at research universities and the ability to launch nanobiotechnology ventures based on university and federal laboratory research** by supporting TEDCO's technology transfer and proof-of-concept funding; allowing for the Maryland Industrial Partnerships (MIPS) program to expand; increasing funding for scientifically and commercially skilled technology transfer personnel, patent expenses; and conducting a comprehensive review of internal and extramural policies and procedures that affect university/private sector collaboration.

8. **Expand the availability of GMP facilities** for Maryland nanobiotechnology companies to use in order to scale-up or to manufacture nano-enabled products.

9. **Enhance incentives to private investors that invest in nanobiotechnology companies** by supporting the Maryland Biotechnology Investment Incentive Tax Credit.

10. **Expand the availability of investments from State pension funds** by specifying nanobiotechnology as an eligible field that has applicability to all currently named industry segments -- biotechnology, information technology, green technology, and medical device technologies.

D. ADVANCE MARYLAND NANOBIOTECHNOLOGY TALENT AND WORKFORCE DEVELOPMENT.

1. **Provide and leverage external funding for top level and young faculty recruitment.** The University of Maryland has demonstrated past success by prioritizing faculty recruitment. The ability to attract and train the best and the brightest allows for institutionalized success. A possible model could be the Georgia Research Alliance.

2. **Support undergraduate and graduation education** that prepares students for meaningful contributions in nanobiotechnology and its interdisciplinary realms, building on pilots and models being developed at Maryland higher education institutions and elsewhere.

3. **Establish a Maryland Bioscience Talent Bridge program** to provide fellowships to enable bioscience companies to employ postdoctoral students and recent Ph.D's, to help students to gain initial industry experience in nanobiotechnology.

4. **Take an active part in the National Nanotechnology Infrastructure Network (NNIN)**, which aims to expose young people to advanced and exciting research in nanotechnology and motivate them to educate themselves for careers in the sciences or engineering; train teachers and guidance counselors about the disciplines of experimental sciences; create and distribute educational materials for children, college students, technical professionals, teachers, and the general population; and focus these efforts on population segments having disproportionately low educational attainment and employment experience in science.
5. **Implement the Governor's Workforce Investment Board's Maryland Bioscience recommendations** for addressing the ability of industry (and research institutions) to attract, recruit, train, and/or retain a highly skilled nanobiotechnology workforce; support collaborative efforts by industry and State government to attract, recruit, and retain nanobiotechnology talent; and work cooperatively to align employers' knowledge and rapidly changing skill needs with the content and delivery of the education system**.**

6. **Establish a bioscience skills alliance – with a strong subset of nanobiotechnology employers – and a skill development fund** to support curriculum development, teacher professional development, and postsecondary instructional equipment needs for institutions with a strong track record of training and placing graduates.

E. PROMOTE NANOBIOTECHNOLOGY RESPONSIBLY TO ACHIEVE PUBLIC ACCEPTANCE.

1. **Maximize the value of the proximity of nearby federal regulatory agencies to make Maryland a national and international exemplar of responsible and economically productive development and deployment of nanobiotechnology** by engaging federal and State policymakers and regulators, researchers, and industry in regular dialogue about ways to ensure the safe development of nano-enabled products throughout their life cycle, from research through deployment in humans and ultimate disposal.

2. **Follow and seek to influence the ongoing discussions by the NSET Nanotechnology Environmental and Health Implications Working Group**, the International Risk Governance Council, and EPA's voluntary measures.

3. **Examine and discuss with State regulators the existing policies or recommendations from industry associations and other States regarding sustainable nanotechnology**, including the NanoBusiness Alliance's Position Statement on Nanomaterials Product Sustainability[29] and Massachusetts' Nanotechnology-Considerations for Safe Development.[30]

4. **Prepare for the mass application of nanobiotechnology,** even while we have only the earliest notions of all the possible ways in which it will be deployed, establishing a clear regulatory framework and understanding of ethical and societal implications for a technology which has and will progress from relatively simple passive nanostructures to molecular nanosystems in two decades.

[29] www.vincentcaprio.org/nanobuiness-alliance-issues-statement -on-sustainable-development-of-nanotechnology.
[30] www.mass.gov/Eoeea/docs/eea/ota/tech_reports/ota_nanotech_guidance.pdf

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APPENDIX A

Maryland Task Force to Study Nanobiotechnology Roster and Contact Information

The Honorable Jennie Forehand (Co-Chair)
Maryland State Senator
Task Force Senate Chair
223 James Senate Office Building
Annapolis, Maryland 21401
(301) 858-3134
jennie.forehand@senate.state.md.us

The Honorable Susan Lee (Co-Chair)
Maryland House of Delegates
Task Force House Chair
221 Lowe House Office Bldg
Annapolis, MD 21401
(301) 858-3019
susan.lee@house.state.md.us

Dr. Judith Britz
Executive Director
Maryland Biotechnology Center
401 East Pratt Street, 7th Floor
Baltimore, MD 21202
(410) 767-0505
jbritz@choosemaryland.org

Dr. Esther Chang
President, American Society for Nanomedicine
Professor of Oncology and Otolaryngology
Lombardi Comprehensive Cancer Center
Georgetown University Medical Center
E420A Research Building
3800 Reservoir Road
Washington, D.C. 20057
(202) 687-8418
change@georgetown.edu

Dr. Stephen Desiderio
Director, ICE Immunobiology Program
Johns Hopkins University School of Medicine
733 N. Broadway, 619 BRB
Baltimore, MD 21205
(410) 955-4735
sdesider@jhmi.edu

Dr. Nariman Farvardin
Provost and Acting President
University of Maryland College Park
1119 Main Administration Building
University of Maryland
College Park, MD 20742
(301) 405-1603
farvardin@umd.edu

Dr. Patrick Lu
CEO, President and Founder
Sirnaomics, Inc.
401 Professional Drive, Suite 130
Gaithersburg, MD 20879
(301) 740-1370
patricklu@sirnaomics.com

Ms. Lisbeth Pettengill
Vice President
Greater Baltimore Committee
111 S. Calvert Street
Baltimore, MD 21075
(410) 727-2820
lisbethp@gbc.org

Mr. Robert Rosenbaum
President and Executive Director
Mr. John Wasilisin
Executive Vice President
Maryland Technology Development Corporation (TEDCO)
5565 Sterrett Place, Suite 214
Columbia MD 21044
(410) 740-9442
rrosenbaum@marylandtedco.org
jwasilisin@marylandtedco.org

Dr. Peter Searson
Director, Institute for Nanobiotechnology
Johns Hopkins University
102 Maryland Hall
3400 N. Charles Street
Baltimore, MD 21218
(410) 516-8774
searson@jhu.edu

Dr. Peter Swaan
Director, Center for Nanomedicine and Cellular Delivery
University of Maryland School of Pharmacy
Health Sciences Facility II, Room 621
20 North Pine Street
Baltimore, MD 21201
(410) 706-0103
pswaan@rx.umaryland.edu

Dr. Lawrence Tamarkin
CEO and Founder
CytImmune Sciences, Inc.
9640 Medical Center Drive
Rockville, MD 20850
(301) 825-3041
ltamarkin@cytimmune.com

Ms. Renée Winsky
Chief Executive Officer
Tech Council of Maryland
9713 Key West Avenue, Suite 100
Rockville, MD 20850
(240) 243-4026
rwinsky@techcoucilmd.com

Task Force Contributors:

Ms. R. Alta Charo, Esquire
Senior Advisor
FDA Office of the Commissioner
Bldg. WO-32, Room 4228
10903 New Hampshire Avenue
Silver Spring, MD 20993
(301) 796-5257
robinalta.chara@fda.hhs.gov

Dr. Dietrich Ruehlmann
Director Business Development
Izon Science
4841 International Blvd., Suite 105
Frederick, MD 21703
(240) 643-9252
dietrich@izon.com

Dr.Nakissa Sadrieh
Associate Director for Research Policy and Implementation
Center for Drug Evaluation and Research
Food and Drug Administration
FDA/CDER/OPS
Building 51, Room 4172
10903 New Hampshire Avenue
Silver Spring, MD 20993-0002
(301) 796-1598
nakissa.sadrieh@fda.hhs.gov

Dr. Sally Tinkle
Deputy Director
National Nanotechnology Coordination Office
4201 Wilson Blvd., Stafford II Rm 405,
Arlington, VA 22230
(703) 292-8626
stinkle@nnco.nano.gov

Dr. Michael Weinrich
Director, National Center for Medical Rehabilitation Research
National Institutes of Health
6100 Executive Boulevard
Room 2A03, MSC 7510
Bethesda, MD 20892
(301) 402-4201
weinrichm@mail.nih.gov

Dr. Lloyd J. Whitman
Deputy Director
Center for Nanoscale Science and Technology
National Institute of Standards and Technology
100 Bureau Drive, MS 6200
Gaithersburg, MD 20899
(301) 975-8002
lloyd.whitman@nist.gov

Dr. Martin Woodle
CEO and Co-Founder
Aparna Biosciences Corp.
12111 Parklawn Drive, Suite 123
Rockville, MD 20852
(301) 770-2101
mwoodle@aparnabio.com

Task Force Staff:

Dr. Linda D. Saffer
Program Manager, University Programs
Maryland Technology Development Corporation (TEDCO)
5565 Sterrett Place, Suite 214
Columbia MD 21044
(410) 740-9442
lsaffer@marylandtedco.org

Benjamin H. Wu
Senior Technology Policy Advisor
Maryland Department of Business and Development (DBED)
Maryland Biotechnology Center
9700 Great Seneca Highway
Rockville, MD 20850
(301) 762-9214
benwu@choosemaryland.org

APPENDIX B

Maryland Task Force to Study Nanobiotechnology Member Biographies

The Honorable Jennie Forehand, Maryland State Senator (Co-Chair)

Senator Jennie Forehand is a fourth term member of the Maryland State Senate representing Garrett Park, Gaithersburg, and Rockville, an area that is home to many new and growing biotechnology companies.

Senator Forehand has been a community representative on the NIH Bio-Safety Committee for over 15 years. As former chair of the Task Force on *Genetic Technologies and Public Policy* of the National Conference of State Legislatures, she has participated in genetic technology, ethics, and policy study groups of the American Bar Association, Georgetown University Law Center, and the HHS Office of Maternal & Child Health.

In 2006, she was the Senate sponsor of the *Biotechnology Investment Incentive Act,* legislation creating tax credits to bring venture capital to Maryland start-up biotech firms. She also sponsored the Senate bill creating property tax credits for publicly sponsored business incubators to foster new company growth. She is also an ardent supporter of the Universities at Shady Grove in Rockville.

Among her awards, Senator Forehand has received the *Biotechnology Leadership Award* from the University of Maryland Biotechnology Institute, and the *Director's Award for Leadership* from the NIH Biosafety Committee. She was has also been named to THE DAILY RECORD's *Maryland Top 100 Women Circle of Excellence.* Senator Forehand is a graduate of the University of North Carolina at Chapel Hill.

The Honorable Susan C. Lee, Maryland Delegate

Delegate Susan C. Lee was elected to the House of Delegates of the Maryland General Assembly in 2002. She is the House Chairman of the Nanobiotechnology Task Force, Deputy Majority Whip; House Judiciary Committee Member; Juvenile Law Subcommittee Chair; Montgomery County House Delegation Vice Chair; Identity Theft Task Force House Chair; Women Legislators of Maryland President-Elect, Member of BioScience Caucus and Green Caucus. Lee is also a civil rights and intellectual property attorney.

During the 2010 legislative session, she authored and passed legislation to form the Maryland General Assembly's Nanobiotechnology Task Force to develop a strategic road map for creating jobs and lifesaving medical innovations, generating revenues, and making Maryland the leader in this field. Lee has been a strong advocate for and has helped pass legislation to advance bioscience, high tech, and green technologies in Maryland.

Delegate Lee represents District 16 which includes most of Bethesda, Friendship Heights, Glen Echo, Cabin John and parts of Rockville, Chevy Chase, and Potomac.

Dr. Judith A. Britz, Executive Director, Maryland Biotechnology Center

Dr. Judy Britz, the Executive Director of the Maryland Biotechnology Center, has more than 25 years of experience in the *in vitro* diagnostics industry. She is a serial entrepreneur who has been the President and CEO of Cylex Inc. and the General Manager of Sienna Biotech, Inc., both Maryland-based companies. Dr. Britz previously held positions in business development and research and development at Becton Dickinson and Johnson and Johnson's Ortho Diagnostic Division. As a research scientist at Electro-Nucleonics Inc., she was responsible for developing one of the first licensed blood screening tests for HIV.

Dr. Britz' academic career includes a PhD from Stanford University in Immunology and Medical Microbiology. She completed postdoctoral fellowships at Yale University and Johns Hopkins in cellular immunology. She has served on the scientific advisory boards of two startup pharma companies. As an active participant in the technology community, she has held several Board and advisory positions in organizations throughout Maryland.

Dr. Esther Chang, President of the American Society for Nanomedicine

Dr. Esther Chang is the President of the American Society for Nanomedicine and a Professor of Oncology and Otolaryngology at the Lombardi Comprehensive Cancer Center of Georgetown University Medical Center. As a pioneer and one of the leading scientists in the field of nanomedicine, she has been recognized by *Science News Magazine* for her work as being one of the most promising in this field.

Dr. Chang has not only produced over 130 publications, but has also served on the advisory boards of the National Cancer Institute, NASA, U.S. Military Cancer Institute, and the U.S. Department of Energy.

Last year, Dr. Chang organized at the Bolger Center in Potomac, Maryland, the American Society for Nanomedicine's Annual Conference, which drew several hundred top scientists from around the country and world. As President, she has led and propelled the Society forward as one of the most respected organizations in this field.

Dr. Stephen Desiderio, Johns Hopkins University School of Medicine

Dr. Desiderio is the Director of the Institute for Basic Biomedical Sciences at Johns Hopkins University. He is also an appointed member of Governor Martin O'Malley's Life Science Advisory Board where he holds the title of Chair of the Working Group on Academic Institutions and Translational Research. As a member of the LSAB, Dr. Desiderio played a key role in crafting the BioMaryland 2020 strategic plan.

Dr. Desiderio received his B.A. degree in biology and in Russian from Haverford College and his M.D. degree and Ph.D. degree in biochemistry and cellular and molecular biology from the Johns Hopkins University School of Medicine. After a postdoctoral fellowship at the Massachusetts Institute of Technology with David Baltimore, he returned to Johns Hopkins.

Nariman Farvardin, Provost, University of Maryland College Park

Nariman Farvardin became Senior Vice President for Academic Affairs and Provost at the University of Maryland, College Park in July 2007. He is also Professor of Electrical and Computer Engineering. Prior to his appointment as Provost, Dr. Farvardin was the Dean of the A. James Clark School of Engineering (2000-2007) and Chair of the Department of Electrical and Computer Engineering (1994-2000).

As Provost, he has spearheaded the development of the University's ambitious strategic plan, *Transforming Maryland: Higher Expectations*, and is leading the implementation of the plan within the Division of Academic Affairs.

During his seven-year tenure as Dean, Dr. Farvardin promoted the development of innovative educational programs, especially at the undergraduate level; supported the development of major research programs; developed new initiatives to improve student and faculty diversity; and enhanced the School's partnerships with industry.

Farvardin received his B.S., M.S., and Ph.D. degrees in Electrical Engineering from Rensselaer Polytechnic Institute in 1979, 1980, and 1983 respectively.

Dr. Patrick L. Lu, CEO & Founder Sirnaomics

Dr. Patrick L. Lu is CEO, President and Founder of Sirnaomics, Inc., a biopharmaceutical company headquartered in Gaithersburg, Maryland which has focused on Nanoparticle-Enhanced RNAi technology for drug discovery and targeted therapeutics. He has 25 years of biomedical research and development experience, including 18 years in the biopharmaceutical industry specializing in nanoparticle-enhanced nucleic acid therapeutics.

Dr. Lu is a member of the American Society for Nanomedicine and has served on the Editorial Board of the *Nanotechnology, Science and Applications*.

Lisbeth Pettengill, Vice President, Greater Baltimore Committee

Lisbeth Pettengill is the Vice President of the Greater Baltimore Committee, a regional membership organization of more than 500 businesses, non-profit organizations, and educational and civic institutions. The GBC works toward improving the business climate of the Baltimore area.

Prior to her position with the GBC, Ms. Pettengill served as Director of Development Communications for the University of Maryland, College Park. Previous positions include Associate Vice Chancellor of Public Affairs for North Carolina State University; Director of Public and Federal Affairs for Johns Hopkins Bloomberg School of Public Health; Director of Communications for the United States Senate and Communications Director for the United States House of Representatives.

Ms. Pettengill received her B.A. at Bryn Mawr College; Boston University and her M.A. at the University of Rhode Island.

Dr. Peter Searson, Johns Hopkins University Institute for Nanobiotechnology

Dr. Peter Searson is the Director of the Johns Hopkins Institute for Nanobiotechnology as well as Professor of Materials Science and Engineering at Johns Hopkins University. A noted scholar in nanoscience, biophysics and bioengineering, Dr. Searson led the successful launch of the Institute for Nanobiotechnology in 2006.

Prior to his position at Johns Hopkins University, Dr. Searson was a Research Associate at MIT from 1986 – 1990. Dr. Searson received his BSc and PhD at the University of Manchester, England. His organizational affiliations include the American Physical Society, the American Association for the Advancement of Science and the Electrochemical Society.

Dr. Peter Swaan, University of Maryland School of Medicine

Dr. Peter Swaan is Professor of Pharmaceutical Sciences and Director of the Center for Nanomedicine and Cellular Delivery at the University of Maryland in Baltimore, MD. He has a worked with federally funded biomedical and nanomedicine research.

Dr. Swaan received his Ph.D. in Biopharmaceutical Sciences from Utrecht University in The Netherlands in 1993. He was a postdoctoral fellow at the University of California, San Francisco until he accepted a faculty position at the Ohio State University in 1996.

Dr. Swaan received the AAPS New Investigator Award in Pharmaceutics and Pharmaceutical Technology in 2000. He is a member of the editorial board for The AAPS Journal, the Journal of Pharmaceutical Sciences and serves as Editor-in-Chief for Pharmaceutical Research. He has published over 90 original research articles focusing on all aspects of transport proteins in drug targeting and delivery, pharmacokinetics and pharmacodynamics.

Dr. Lawrence Tamarkin, CEO & Founder, CytImmune

Dr. Lawrence Tamarkin, who is the CEO and Founder of CytImmune Services, Inc., is one of the pioneer and leading scientists, experts, and entrepreneurs in Nanobiotechnology in the country. Since 1988, he has led CytImmune from a diagnostic to a therapeutics focused company and is the co-inventor of its core colloidal gold-based nanomedicine platform technology, which is covered in 35 allowed and 46 pending U.S. and international patents.

Dr. Tamarkin's professional experience also includes his distinguished service at the National Institutes of Health and the University of Maryland. His outstanding public and private sector professional credentials combined with his adept knowledge and understanding of the myriad of issues and challenges faced by companies in transferring research to product will enable him to contribute enormously to the important mission and work of the task force.

Robert Rosenbaum, President and Executive Director, TEDCO

Mr. Rosenbaum is an strategy, finance and operations executive with a 30 year history of building and managing high performance teams and organizations, both entrepreneurial and corporate. As the recently named President and Executive Director, he is responsible for the strategic and operational leadership to ensure TEDCO's position as a national leader in technology transfer from academic and federal research labs, as a seed and early-stage investor and as a provider of entrepreneurial business assistance. Additionally, he is charged with leading TEDCO's efforts to expand its corporate partnerships, strengthen its ties with later-stage investors and to position it to make follow-on investments in its portfolio companies.

Prior to coming to TEDCO, Mr. Rosenbaum joined Nobska Group, a strategy consulting firm, in 2003 as a Partner and was a founder and Managing Director of the General Partner of Nobska Ventures, an early stage venture capital fund focused on technology and medical devices. He earned a Bachelor's Degree in Mechanical Engineering from the Georgia Institute of Technology and his MBA from Columbia University.

Renee Winsky, CEO, Tech Council of Maryland

Renée Winsky is the chief executive officer of the Tech Council of Maryland. She is responsible for charting the tactical course of action given the strategic input from the constituent boards, and leading the activities of the TCM staff to achieve those strategic objectives. She is also responsible for the financial management of the council and each of its constituent organizations.

Prior to joining TCM as CEO in September 2009, Ms. Winsky served as president and executive director of the Maryland Technology Development Corporation (TEDCO), a public instrumentality established by the Maryland General Assembly to promote economic development through the development, transfer and commercialization of technology. Ms. Winsky was responsible for all operational, staff, technical, financial and program functions of the corporation.

Ms. Winsky previously held positions at the Information Technology Association of America, the National League of Cities and its affiliate, and the National Association of Telecommunications Officers and Advisors. She has also worked with the Maryland Municipal League and the City of Greenbelt, Maryland and has served on the City of Bowie Ethics Commission and on the Technology Council of the American Society of Association Executives.

Ms. Winsky is a graduate of the University of Maryland and a graduate of the Leadership Maryland Class of 2005.

Maryland Task Force to Study Nanobiotechnology Additional Contributor Biographies

R. Alta Charo, Esq., Senior Advisor, Office of the Commissioner, U.S. Food and Drug Administration

Alta Charo works for the FDA's Office of Policy as a senior advisor on a range of issues raised by emerging technologies, such as genetics, biotechnology, nanotechnology, and synthetic biology. Ms. Charo was a member of the NIH Human Embryo Research Panel and President Clinton's National Bioethics Advisory Commission. Since 1989, she has been a professor of law and bioethics at the law and medical schools of the University of Wisconsin–Madison. She also serves on the faculty of the UW Masters in Biotechnology Studies program and lectures in the MPH program of the Dept. of Population Health Sciences.

Ms. Charo (B.A. biology, Harvard 1979; J.D. Columbia, 1982) is an elected member (2004) of the World Technology Network and (2005) the Wisconsin Academy of Sciences, Arts and Letters. In 2006, she was elected to membership in the National Academies' Institute of Medicine. Professor Charo is the author of nearly 100 articles, book chapters and government reports on law and policy related to environmental protection, reproductive health, new reproductive technologies, medical genetics, stem cell research, science funding, and research ethics.

Dr. Dietrich Ruehlmann, Director, Business Development North America, Izon Science

Dietrich joined Izon Science in July 2010, leading the North American operations from the regional office in Maryland. He has substantial experience in the design and commercialization of laboratory instrumentation through successive positions at the global health technology firms Amersham Biosciences (now part of GE Healthcare) and Becton Dickinson. Prior to joining Izon Science, Dietrich was the Senior Business Development Manager for Biotechnology and Medical Devices, with responsibility for both North and South America, for New Zealand Trade and Enterprise.

Dietrich received his scientific education in Germany and in the UK finishing with a Wellcome Trust Prize PhD in cardiovascular physiology from King's College London. He also has an executive MBA from University of Maryland. His work in environmental pollutants and their effects on the cardiovascular system generated numerous linked research studies in the field and opened a new chapter in the study of non-genomic steroid actions.

Dr. Nakissa Sadrieh, Associate Director of Research, Policy & Implementation, U.S. Food and Drug Administration

Dr. Sadrieh obtained her doctorate in Toxicology in 1993 from Rutgers University in New Jersey. Following a postdoctoral fellowship in the Laboratory of Chemical Carcinogenesis at the National Cancer Institute, Dr. Sadrieh joined the Food and Drug Administration in 1996 as a pharmacology and toxicology reviewer. In 1998, Dr. Sadrieh became the supervisory pharmacologist in the Division of Medical Imaging and Radiopharmaceutical Drug Products, Center for Drug Evaluation and Research (CDER). Dr. Sadrieh has been directly involved in the review and approval of many drug products and subsequently she has expertise in the preclinical studies needed to support the safety of new drug applications.

In 2002, Dr. Sadrieh joined CDER's Office of Pharmaceutical Science, as the Associate Director for Research Policy and Implementation. Dr. Sadrieh's work currently focuses on scientific research that will directly impact regulatory decisions. As a scientific advisor to the Office of Pharmaceutical Science, Dr. Sadrieh is also directly involved in assessing the impact of new technologies on drug development. Nanotechnology, having been identified as an opportunity under the FDA's Critical Path Initiative, is one area which is expected to impact regulatory submissions in the future. As such, Dr. Sadrieh is the chair of the CDER Nanotechnology Working Group, as well as the CDER representative on several other nanotechnology interest groups within the Agency and the National Institutes of Health.

Dr. Sally Tinkle, Deputy Director, National Nanotechnology Coordination Office

Sally Tinkle acts as the Deputy Director of the National Nanotechnology Coordination Office (NNCO) and Coordinator for Environment, Health and Safety. Before her appointment to the NNCO, Dr. Sally Tinkle served as the Senior Science Advisor in the Office of the Director, National Institute of Environmental Health Sciences (NIEHS), National Institutes of Health (NIH). Her nanotechnology experience includes development of the NIEHS nanotoxicology extramural research portfolio and the NIEHS NanoHealth and Safety Enterprise, a framework for public-private partnerships. She has been an active member of the trans-NIH Nanotechnology Task Force and is senior author of the health implications of engineered nanomaterials section of the NIH Nanotechnology Report to the Director.

Dr. Tinkle received her PhD from the Department of Physiology at the University of Colorado School Of Medicine in and was a postdoctoral fellow at the National Jewish Center for Immunology and Respiratory Medicine, Department of Occupational and Environmental Health Science. Prior to joining NIH, she was the leader of a pulmonary and dermal toxicology laboratory at the National Institute of Occupational Safety and Health.

Dr. Michael Weinrich, Director of the National Center for Medical Rehabilitation Research (NCMRR) in the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) at NIH

Michael Weinrich, M.D., assumed the Directorship of the NCMRR in February 2000. He received his undergraduate and medical degrees from Harvard University and was trained in neurology at the University of Chicago, and in neurophysiology at the NIH. Dr. Weinrich has served on the faculties of Stanford University and the University of Maryland. Prior to joining the NCMRR, Dr. Weinrich was professor of neurology at the University of Maryland and medical director for rehabilitation in the University of Maryland Medical System. From 1998 to 1999, he served on the staff of Maryland Congressman Benjamin Cardin as a health policy fellow. His research has focused on applications of computer technology to problems in rehabilitation, and on health policy for vulnerable populations.

Dr. Lloyd Whitman, Deputy Director, Center for Nanoscale Science and Technology, National Institute of Science and Technology

Lloyd Whitman joined the Center for Nanoscale Science and Technology as the Deputy Director in April 2008. He received a B.S. in Physics from Brown University (with honors, magna cum laude), and M.S. and Ph.D. degrees in Physics from Cornell University. After an NRC Postdoctoral Research Fellowship at NIST, he joined the research staff at the Naval Research Laboratory (NRL). At NRL, Lloyd was most recently the Head of the Surface Nanoscience and Sensor Technology Section, a multidisciplinary research group working at the nexus of nanoscience, biotechnology, and microsystems. He led a diverse portfolio of research studying semiconductor, organic, and biomolecular nanostructures, their use in novel functional surfaces, and their integration into advanced sensor systems for national security applications. In addition to leading research at NRL, Lloyd served as a Science Advisor to the Special Assistant to the Secretary of Defense for Chemical and Biological Defense and Chemical Demilitarization Programs. In this capacity, he represented the Department of Defense on the National Science and Technology Council, Committee on Technology Subcommittee on Nanoscale Science, Engineering and Technology. Lloyd has over 140 publications and patent applications in the areas of nanoscience and sensor technology, and numerous media citations and awards, including the Navy Meritorious Civilian Service Award.

Dr. Martin Woodle, Chief Executive and Science Officer, Co-founder, ApernaBio

Dr. Woodle has over 20 years of experience in drug delivery and therapeutic drug development, including leading the research department at Liposome Technology, Inc. (marketed by J&J) that developed PEGylated Stealth® liposomes for Doxil®, marketed by J&J, leading toxicology and formulation development at Genta that supported initiation of Genasense clinical development, and leading the Synthetic Gene Vector department within Novartis he spun off to form Intradigm Corp., which developed the first nanoparticle siRNA formulation showing preclinical efficacy.

APPENDIX C

Task Force Meeting Minutes, September 29, 2010

Meeting Date: Wednesday, September 29, 2010

Time: 10:30 a.m. to 2:30 p.m.

Location: Maryland Biotechnology Center
The Shady Grove Innovation Center
9700 Great Seneca Highway
Rockville, Maryland 20850

Task Force Members in Attendance:
Susan Lee (Co-Chair), Jennie Forehand (Co-Chair), Judy Britz, Esther Chang, Stephen Desiderio, Nariman Farvardin, Peter Searson, Peter Swaan, Larry Tamarkin, John Wasilisin, Renee Winsky

Absent Task Force Members:
Patrick Lu, Lisbeth Pettengill

Task Force Board Staff: Linda Saffer, Ben Wu
Consultant: Marsha Schachtel, Johns Hopkins Institute for Policy Studies

Co-Chair's Opening Remarks

- The inaugural meeting of the Maryland Task Force on Nanobiotechnology was called to order by the Co-Chairs with a quorum present. Delegate Lee and Senator Forehand welcomed the members of the Task Force. The Task Force was created by legislation sponsored by Delegate Lee and will report its findings and recommendations to the Governor by January 1, 2011.
- In order to meet this ambitious goal of submitting a report to the Governor by the end of the year, the Co-Chairs laid out their expectation that the Task Force will formally meet twice before commencing with the writing of the report. This first meeting would allow for an inventory of assets and resources within the State that support nanobiotechnology. The second meeting would provide an opportunity for an assessment of relevant activities taking place in federal facilities located in Maryland to support and leverage their national nanobiotechnology research and development.

Review of H.B. 795: Legislation Creating the Task Force on Nanobiotechnology

- The Maryland General Assembly enacted Delegate Lee's bill, House Bill 795, in this year's legislative session. Delegate Lee reviewed the legislative history and the statutory requirements for the legislation.
- The Task Force shall make recommendations on ***the benefits of nanobiotechnology***, with attention to: job creation; development of lifesaving treatments, reductions in health care costs; development of state-of-the-art electronics, medical equipment, chemical processes, and other commercial products; generation of revenue for the State; and improvements to the quality of life for the State's citizens. The Task Force shall make recommendations on ***the State's role in supporting Maryland's leadership in nanobiotechnology***, with

attention to: promoting public-private partnerships; assisting companies in technology transfer, including from research to commercial product; promoting research; protecting intellectual property; offering appropriate financial incentives, including tax credits; and capturing and leveraging federal funds for both public and private ventures.

Maryland Biotechnology Center Resources and the Life Sciences Advisory Board's BioMaryland 2020 Strategic Plan

- Judy Britz, the Executive Director of the Maryland Biotechnology Center, provided an overview of nanobiotechnology to the Task Force and discussed programs of the Maryland Biotechnology Center that could support research and commercialization. Dr. Britz noted that nanobiotechnology was a component of the BioMaryland 2020 Strategic Plan, a comprehensive 10-year plan to maintain Maryland's competitive position in biotechnology that was created by the Life Sciences Advisory Board. Additionally, the Life Sciences Advisory Board has established an Emerging Technologies Working Group that will include a review of nanobiotechnology. The Working Group is chaired by Steve Desiderio, a Task Force member.

- ***RECOMMENDATION:***
  - Potential issues for the Task Force to consider regarding Nanobiotechnology include:
    - Nanobiotechnology Manufacturing since it differs from conventional manufacturing, and
    - The Safety Issues of Nanostructures such as toxicity, inhalation of particles, dermatological exposure, and environmental transport and ecological impact

TEDCO Resources and Statutory Authority: General Assembly enactment of the "Coordinating Emerging Nanobiotechnology Research (CENTR) in Maryland" legislation

- John Wasilisin, Acting President of the Maryland Technology Development Corporation (TEDCO), noted that in the 2008 Maryland General Assembly, the Coordinating Emerging Nanobiotechnology Research (CENTR) in Maryland legislation was enacted into law. The CENTR law established a program to be administered by TEDCO to provide grants for nanobiotechnology research projects. The program has never been funded. TEDCO will once again seek to request CENTR funding in the upcoming Fiscal Year 2012 budget cycle.

- ***RECOMMENDATION:***
  - Since statutory approval for a Maryland nanobiotechnology research program already exists within TEDCO, the CENTR program should be funded.

The 2009 Maryland Nanobiotechnology Research and Industry Competition Grants Program

- Ben Wu and Linda Saffer spoke of the 2009 Maryland Nanobiotechnology Research and Industry Competition Grants Program that provided the first-ever Statewide nanobiotechnology research grants. The competitive grants were jointly administered by the Department of Business and Economic Development (DBED) and TEDCO with DBED providing the $3 million in funding.
- 13 industry-leading research projects from the public and private sector received a one-time award for operating and capital funding. A total of $3 million was available in the competition for research projects, up to $250,000 per grant. 103 applications were received in response to the competition's solicitation with 43 finalists subject to technical reviews of their research proposals. The 13 selected grant recipients were all Maryland-sited and include institutes of higher education, public and private; nonprofit organizations; and for-profit entities, including small businesses.

- ***RECOMMENDATION:***
    - Based on the 2009 nanobiotechnology grants competition, the only competitive grants experience in Maryland thus far, there appears to be strong interest in grant programs within academia and industry to support nanobio research and development.

Technology Council of Maryland (TCM)/MdBio Resources for the Nanobiotechnology Industry

- Renee Winsky, CEO of the Technology Council of Maryland discussed TCM/MdBio resources to support nanobiotechnology. TCM is the largest technology trade group serving the advanced technology and biotechnology communities of Maryland. TCM has over 450 member companies and represent over 250,000 total member contacts.

- ***RECOMMENDATION:***
    - With its broad base of members and its mission of supporting Maryland technology, TCM/MdBio can be helpful in outreach to the community as the Task Force considers priority areas regarding venture capital for nanobio start-ups, workforce and training, and supporting STEM education, among other issue areas.

State Support (DBED) of Nanobiotechnology Programs for University System of Maryland Research, Faculty, and Facilities

- Nariman Farvardin, Provost and Acting President of the University of Maryland at College Park, provided an overview of the nanobiotechnology research and development programs within the University System of Maryland. Provost Farvardin detailed the State support that began in 2004 for the university's major effort to build strength in nanoscience, nanotechnology, and bioengineering.
- DBED provided significant assistance to build the laboratory infrastructure for nano-fabrication and nano-characterization ($3.6 million) and to strengthen research support in nano-biotechnology ($6.2 million in 2007, 2008 and 2009) within the USM. As a result, 22 new faculty members were hired within USM institutions. Of the $6.2 million, $3.6 million were used toward the start-up packages of 22 new faculty in nano-biotechnology, $2.0 million were used to provide seed funding toward 13 cutting-edge nano-biotechnology research projects, and $0.6 million were used to provide infrastructure support for the Fischell Department of Bioengineering and the Maryland NanoCenter. This investment generated 182 proposals with a value of $119 million. To date, 44 proposals have been awarded with a total value of $48 million, with 37 proposals pending with a value of $21 million.

- ***RECOMMENDATION:***
    - The University System of Maryland has been able to leverage State support for nanobiotechnology programs to position Maryland as a nanobio leader and has demonstrated great success. This success merits further support.

Nanobiotechnology Research at University of Maryland, Baltimore

- Peter Swaan, the Director of the Center for Nanomedicine and Cellular Delivery and Professor of Pharmaceutical Sciences at the University of Maryland, Baltimore, discussed the application of nanotechnology in the health sciences. Dr. Swaan discussed the Center for Cancer Nanotechnology Excellence at UMB and some of its core projects, such as Silicon Nanotubes for Image-guided targeted drug delivery, Targeted Delivery using Surfactant Nanovesicles, Multiphoton Imaging of Functionalized Gold Nanorods, Delivery of Magnetic Particles, and Gold nanoparticle delivery & angiogenesis inhibitors.

- ***RECOMMENDATION:***
  - Maryland can exploit its current strengths of: Materials Science, Fabrication Facilities, Characterization, GMP (Good Manufacturing Practice), Pharmacokinetic Analysis, Clinical trials experience with nanoconstructs, and Education.
  - For nanobiotechnology success, good clinical trials need good manufacturing.
  - The Future Needs are: Local Nanobiotechnology GMP facilities, Venture Capital for start-up and spin-offs, and Integrated Educational Resources to supply Maryland industry with a skilled workforce.

The Institute for Nanobiotechnology (INBT) at Johns Hopkins University

- Peter Searson, the Director of the Institute for Nanobiotechnology, pointed out that nanobiotechnology can transform healthcare and medicine. It is a multidisciplinary field that needs collaboration between researchers in physical sciences, engineering, biological sciences, and medicine. The market sectors with a stake in Nanobiotechnology include pharmaceuticals, medical devices, medical instrumentation, materials suppliers, chemical products, sensors, homeland security, and microelectronics.
- The INBT was launched in May 2006. More than 200 affiliated faculty from 22 departments in medical, public health, engineering, among others participate. INBT also coordinates groundbreaking research in nanobiotechnology at Hopkins. There are major federally funded centers with innovative new training programs at the interface of engineering and medicine, as well as a corporate partnership program. The INBT annual symposium in 2010 focused on: *Environmental & Health Impacts of Engineered Nanoparticles.*

- ***RECOMMENDATION:***
  - The Hopkins INBT offers to Maryland: New science, New technologies, Talented Expertise: scientists/engineers who can bridge the gap between the physical sciences/engineering and the biological sciences/medicine, and Translation (from the bench to the bedside).

Nanobiotechnology Research at the Johns Hopkins University School of Medicine

- Steve Desiderio, the Director of the Institute for Basic Biomedical Sciences (IBBS) and the Director of the Immunobiology Unit, Institute for Cell Engineering at the Johns Hopkins University School of Medicine, offered a molecular biologist's perspective of nanobiotechnology. The IBBS has nine departments in: Biological Chemistry; Biophysics; Biomedical Engineering; Cell Biology; Molecular Biology; Genetics, Molecular and Comparative Pathobiology; Neuroscience; Pharmacology; and Physiology.

- ***RECOMMENDATION:***
    - Some of the nanobiotechnology strengths at Hopkins include: Basic Research, Diagnostics, Therapeutics, and Environmental Science. These are potential areas for Maryland to focus on to gain a national niche.

Nanobiotechnology and the American Society for Nanomedicine

- Esther Chang is the President of the American Society for Nanomedicine (ASNM) and a Professor of Oncology and Otolaryngology at the Lombardi Comprehensive Cancer Center of the Georgetown University Medical Center. Last year, Dr. Chang organized the ASNM annual conference in Maryland which drew several hundred top scientists from around the country and the world. This year, the ASNM 2nd annual conference will be held on October 14-16 in Potomac, Maryland. ASNM has worked closely with the HIV/AIDS Research Program at the National Institute of Allergy and Infectious Diseases (NIAID) to create a conference with a special focus on exploring the use of nanotechnology to address HIV/AIDS-specific research challenges and clinical applications. Dr. Chang also spoke about The Impact of Nanomedicine on Cancer Therapy and Diagnosis.

- ***RECOMMENDATION:***
    - The American Society for Nanomedicine can work closely with the Task Force to implement recommendations and to promote Maryland as a national center for Nanobiotechnology.

An Industry Perspective on Nanobiotechnology Commercialization

- Larry Tamarkin, CEO and Founder of CytImmune Sciences, Inc., spoke as an industry representative and a recipient of a 2009 Maryland Nanobiotechnology Research and Industry Competition Grant. CytImmune is a clinical stage nanomedicine company with a core focus on tumor-targeted therapies, and has used colloidal gold-based nanomedicine platform technology as a diagnostic and a therapeutics company.
- The promise of cancer nanomedicines is: Deliver potent anti-cancer agents directly to the site of disease; Reduced or no toxicity; Improved efficacy; Treat cancer as a chronic medical disease; Dose intravenously prior to surgery; Limited biodistribution due to leaky tumor blood vessels; Reduce tumor burden by tumor-targeted nanomedicines; Reduce or eliminate sophisticated surgical procedures; Improve patient outcomes; Treat periodically to destroy nascent tumor neovasculature; and to Suppress metastatic disease.

- ***RECOMMENDATION:***
    - In order to meet the promise of cancer nanomedicines, the following challenges must be overcome: Use nanotechnology to deliver potent, but toxic drugs that are not approved by the Food and Drug Administration (not a re-formulation technology); FDA has not established benchmarks for nanomedicines: No guidance on manufacturing benchmarks and analytics, No established consensus on formulations for optimal biodistribution (e.g., immune avoidance), No parameters leads to uncertainty causing potential investors to be skeptical about FDA approval of any nanotechnology-based medicines; and the Benefits Vs. Risks: public perception unclear; not understood that nanomedicines will change the way we treat cancer.

Next Steps

- The second meeting of the Task Force is scheduled for Wednesday, November 10, 2010 in Baltimore.

APPENDIX D

Task Force Meeting Minutes, November 10, 2010

Meeting Date: Wednesday, November 10, 2010

Time: 10:30 a.m. to 2:30 p.m.

Location: Maryland Biotechnology Center
The World Trade Center
410 E. Pratt Street
Baltimore, Maryland 21202

Task Force Members in Attendance:
Susan Lee (Co-Chair), Judy Britz, Patrick Lu, Stephen Desiderio, Lisbeth Pettengill, Peter Searson, Peter Swaan, Larry Tamarkin, Rob Rosenbaum/John Wasilisin, Renee Winsky

Absent Task Force Members:
Jennie Forehand (Co-Chair), Esther Chang, Nariman Farvardin

Federal and Industry Participants:
Alta Charo (FDA), Dietrich Ruehlmann (Izon Science), Nakissa Sadrieh (FDA), Sally Tinkle (NNCO), Michael Weinrich (NIH), Lloyd Whitman (NIST), Martin Woodle (Aparna Biosciences)

Task Force Board Staff: Linda Saffer, Ben Wu
Consultant: Marsha Schachtel, Johns Hopkins Institute for Policy Studies

AGENDA

Co-Chair's Opening Remarks

- The second meeting of the Maryland Task Force on Nanobiotechnology was called to order by Delegate Lee with a quorum present. Delegate Lee expressed Senator Forehand's regrets on her absence. The Co-Chair noted that this will be the last formal Task Force meeting before beginning the process for developing findings and recommendations.

- Delegate Lee summarized the inaugural September 29, 2010 Task Force meeting that provided an inventory of assets and resources within the State that support nanobiotechnology. Delegate Lee asked for a motion to approve the September meeting minutes. Hearing no objection, the minutes were approved.

- The Co-Chair noted that this second Task Force meeting would provide an opportunity for an assessment of relevant activities taking place in federal facilities located in Maryland to support and leverage nanobiotechnology research and development.

Greater Baltimore Committee (GBC) Resources for the Nanobiotechnology Industry

- Ms. Liz Pettengill, Vice President of the Greater Baltimore Committee, discussed GBC resources and past activities to support life sciences and nanobiotechnology. As a business organization with 550 of the State's top companies, GBC has formed a Bioscience Committee to address and overcome barriers to company formation.

- ***RECOMMENDATION:***
  - With its broad base of members, GBC can be helpful in outreach to the community as the Task Force considers priority areas such as access to capital, workforce formation, and expediting tech transfer, among other issue areas.

The National Nanotechnology Initiative: Federal nanotechnology R&D activities and outreach from the National Nanotechnology Coordination Office

- Dr. Sally Tinkle, the Deputy Director of the National Nanotechnology Coordination Office, gave an overview of the National Nanotechnology Initiative (NNI) via conference call. The NNI is a collaborative, multi-agency program among 25 federal agencies to ensure U.S. leadership in nanotechnology for the national economic benefit, national security, and improved quality of life. The 25 federal agencies in the NNI include FDA, NIH, NIST, PTO, DOE, DOT, DHS, EPA, and USDA among others.

- There has been a cumulative NNI investment of nearly $14 billion with over 4500 research projects in all 50 States. Funding includes programs to establish networks for developing public awareness and education, as well as activities such as workshops on cross-cutting areas of nanotechnology applications. Additionally, there has been over $390 million in nanotechnology-related Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) funding between 2004 and 2008.

- The NNI has developed a Strategic Plan to inform and influence the federal budget and planning process with four goals. The first goal is to advance a world-class nanotechnology research and development program. The second goal is to foster the transfer of new technologies into products for commercial and public benefit. The third goal is to develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology. The fourth goal is to support responsible development of nanotechnology.

- The NNI serves as a central point of communication and coordination on national nanotechnology efforts but is neither a funding agency with a separate budget line nor a program with authority to direct agency research and investment.

- The NNI has State, local, and regional initiatives. These initiatives include workshops to exchange information and stimulate collaboration, mechanisms to better link with the NNI, identification of common goals and objectives, and efforts to enhance the effectiveness of the initiatives through collaboration, information exchange, and resource sharing. The 2009 State, Local, and Regional Workshop focused on collaboration building, partnership models, workforce education and development, research and development infrastructure, economic development and commercialization, and resource exchanges.

- ***RECOMMENDATION:***
- The National Nanotechnology Initiative (NNI) has identified opportunities for NNI to collaborate with State partners.
    - These potential NNI opportunities include: joint industry-university alliances to co-engineer fundamental research results with specific goals; a clearinghouse that identifies laboratory capabilities, provides contracts, and defines how one obtains access to these resources; and a national nanomaterials database for researchers and companies that are planning the use of the materials in their processes and products.
    - Additionally, there are potential collaborative models for State research and commercialization to support the national mission that include incubator models, government-university-industry partnership models, and State government investment models.

NIH activities and coordination in support of the National Nanotechnology Initiative

- Dr. Michael Weinrich, Director of the National Center for Medical Rehabilitation Research, has been a leader in the National Institute of Health (NIH) contribution to the NNI and its coordination of NIH's 27 institutes and centers. NIH invests in the promise of nanotechnology for biomedicine and healthcare through detection of disease before the health has deteriorated (i.e., sensors and imaging), tissue engineering to repair or replace worn or damaged body parts (i.e., controlling interactions of synthetic and inorganic materials with the body), and delivery of therapeutics (i.e., particle size and targeting of materials).

- NIH support for nanoscience and nanotechnology research is led by a Trans-NIH NANO Task Force with representation from all the institutes and centers. NIH also supports investigator-initiated nanobiotechnology grants, as well as Institute nanosci/tech programs at NHLBI, NCI, NIEHS, among other institutes.

- NIH supports a Bioengineering Nanotechnology Initiative through SBIR/STTR funding. A team approach to nanotechnology research is encouraged for small businesses with explicit plans for commercialization.

- ***RECOMMENDATION:***
- The National Institutes of Health (NIH) has several avenues for nanobiotechnology collaboration.
    - Potential collaboration can be found directly through the 27 NIH institutes and centers.
    - NIH supports investigator-initiated anobiotechnology grants.
    - Funding can also be found in a NIH Bioengineering Nanotechnology Initiative funded through SBIR/STTR.

FDA activities and coordination in support of the National Nanotechnology Initiative

- Ms. Alta Charo, Senior Advisor to the Commissioner of the Food and Drug Administration (FDA), spoke about the FDA approaches to nanotechnology regulation. Nanotechnology is special because it is a rapidly developing science with a broad range of properties and applications. FDA has a responsibility to the public and industry to deliver regulations with clear expectations, a transparent process, inclusive of stakeholder input, and a pragmatic and adaptable approach.

- FDA has multi-level agency coordination including a Nanotechnology Task Force, a Nanotechnology Regulatory Science Plan which has been presented to the FDA Science Board, and nanotechnology intramural research programs.

- Dr. Nakissa Sadrieh of the FDA's Center for Drug Evaluation and Research (CDER) gave a perspective on the FDA Nanotechnology Task Force and the CDER's nanobio engagement. The most important FDA considerations for regulating nanomaterial-containing drugs include product quality assessment (i.e., characterization, quality control, and manufacturing) and product safety assessment (i.e., biodistribution, clearance, metabolism, and toxicology).

- ***RECOMMENDATION:***
  - At this time, FDA's CDER believes the existing regulatory framework has been adequate and has worked well in the approval of therapeutic nanoparticles currently on the market.
    - CDER believes the existing framework will also accommodate the types of nanoparticle therapeutics under development.
  - Other FDA Centers are also working on guidance documents that address nano-related issues.
  - FDA is completing and analyzing a database to evaluate policies regarding nanomaterials, for example in drugs.
    - There may be opportunities to help inform and contribute in FDA's on-going development of guidance documents and database information to assist in FDA's evaluations.

NIST activities and coordination in support of the National Nanotechnology Initiative

- Dr. Lloyd Whitman, Deputy Director of the Center for Nanoscale Science and Technology (CNST) at the National Institute of Standards and Technology (NIST), provided information about NIST and CNST. NIST is the nation's oldest federal laboratory and has an express mission of working with industry. NIST regularly holds workshops to identify industry needs and has held several nanotechnology workshops. NIST's nanotechnology strategy is to assist in the standards setting and calibrations on the nanoscale, form public-private partnerships, and support nanotechnology through research and construction grants.

- The CNST is a multidisciplinary user facility, including a shared resource for nanofabrication. The CNST programs include characterization and metrology, energy, photonics and plasmonics, materials and chemistry, environmental health and safety, electronics, and magnetics, among others. The CNST was established in 2007 to develop nanoscale measurement and fabrication methods. The CNST is accessible to all, including industry.

- ***RECOMMENDATION:***
  - The National Institute of Standards and Technology (NIST) has a Center for Nanoscale Science and Technology (CNST) that operates as a national, shared resource with world-class nanoscale fabrication and measurement capabilities.
    - The CNST is a shared-use operation based on cost-reimbursement. There is no entry fee to use the CNST and charges are based on operating costs.
    - Researchers can apply for NIST to share a portion of the operating costs to further reduce costs. CNST will also train scientists in nanotool use.
  - There are other ways to engage with NIST on nanobiotechnology. These possibilities include international collaborations, guest researcher arrangements, cooperative research and development agreements (CRADA's), and summer undergraduate research fellowships (SURF), among others.

An Industry Perspective on Nanobiotechnology Commercialization and Collaboration: The Sirnaomics, AparnaBio, and Izon Stories

- Dr. Patrick Lu, President and CEO of Sirnaomics, presented the potential applications his company is developing in nanoparticle-enhanced multi-targeted sIRNA therapeutics.

- Dr. Martin Woodle, Co-Founder and CEO of Aparna Biosciences, presented on the work of his company in developing the next "antibody" through tissue targeted RNAi nanoparticles. Aparna has collaborated with Sirnaomics in the past with the sharing of research and resources.

- Dr. Dietrich Ruehlmann, Director of Business Development of Izon Science USA, presented on his company's device for a portable and field depoyable nanoparticle analysis system. He also discussed the company's plan to create a particle characterization lab in Frederick. Izon is an example of an international company (New Zealand-based) looking to Maryland to create a nanobiotechnology presence.

- ***RECOMMENDATION:***
    - There is a community foundation for successful nanobio collaboration in Maryland. The regional federal laboratories can offer a multitude of support through expertise, resources, and funding. The State through its academic institutions and its programs can provide laboratory and financial support. The industry community can also find collaboration opportunities with like-minded partners that can leverage each of their strengths and provide cost-savings and research development through shared facilities and activities.

Next Steps

- A draft document will be circulated to the Task Force in December.
- The final report will be submitted to the Governor by January 1, 2011.

APPENDIX E

Examples of Nanobiotechnology Companies in Maryland

COMPANY	COUNTY	INCUBATOR?
Advanced Biomimetic Sensors	Montgomery	Y
Aeras Global	Montgomery	
Affinigen	Frederick	Y
Allegiance NanoSolutions	Baltimore City	Y
Aparna	Montgomery	Y
Applied Sensor Research & Development Corp.	Anne Arundel	Y
AriaVax	Montgomery	
Avanti NanoSciences	Baltimore County	
BioActive Surgical	Howard	
BioAssay Works	Frederick	
BriJen Biotech	Baltimore City	
Champions Biotechnology	Baltimore City	
Chikujee Therapeutics	Montgomery	
Columbia Biosciences	Howard	
Creatv Microtech	Montgomery	
CytImmune Sciences	Montgomery	Y*
General Research Laboratory	Montgomery	
Intelligent Substrates	Baltimore City	
Izon Science	Frederick	
NanoRods	Montgomery	Y
Noxilizer	Baltimore County	
Rexahn Pharmaceuticals	Montgomery	Y
SAIC-Frederick	Frederick	
Sirnaomics	Montgomery	
Valens Therapeutics	Baltimore County	

**incubator graduate*

SOURCE: Maryland Biotechnology Center, December 2010

APPENDIX F

Task Force Recommendations to Support Nanobiotechnology in Maryland

Perhaps the State's most important role is leadership, evidenced in the articulation of nanobiotechnology goals, development of opportunistic strategies to attain them, marshalling of resources inside and outside State government, and measuring results. Towards that goal, the following recommendations were developed.

These recommendations were developed with the input of the Task Force meetings and are consistent with the BioMaryland 2020 ten-year strategic plan, created by the Maryland Life Sciences Advisory Board (LSAB). These nanobiotechnology recommendations reiterate many of the thrusts of the BioMaryland 2020 recommendations. The recommendations support nanobiotechnology research and commercialization, education and workforce, and responsible advocacy and promotion.

The Maryland Life Sciences Advisory Board, a permanent commission created by law and charged to oversee the implementation of the BioMaryland 2020 strategic plan, intends to carry forward the Task Force recommendations through its Emerging Technologies Working Group. The LSAB Emerging Technologies Working Group is chaired by Dr. Stephen Desiderio, who serves on both the Task Force as well as the LSAB representative.

A. DEVELOP SPECIFIC NANOBIOTECHNOLOGY STRATEGIES FOR MARYLAND LEADERSHIP.

1. **Inventory Maryland's resources, analyze the State's competitive position, and identify gaps** in the areas of discovery, commercialization supports, and talent.

2. **Enhance the potential for collaboration** among Maryland research institutions and companies and with external partners that can jointly seek external funding for nanobiotechnology initiatives.

3. **Articulate Maryland's nanobiotechnology goals** based on economic analysis of the industry trends based on the State's strengths and potential.

4. **Develop nanobiotechnology strategies** for achieving goals in research and commercialization that knit together core components in academia, companies, government, and investors, including an integrated plan for engaging and educating the public about the technology, its promise, and steps needed to assure its safe development.

B. TARGET MARYLAND'S ASSETS TO ENHANCE NANOBIOTECHNOLOGY COLLABORATION.

1. **Support research in this emerging growth area,** particularly investments that leverage funding from other sources. Where appropriate, support research collaborations with young and established companies in Maryland and globally.

2. **Intensify R&D collaboration with nearby federal laboratories** through cooperative research and development agreements (CRADA), informal collaborations, guest researcher arrangements, material transfer agreements, supporting strategic faculty hires, encouraging clinical research partnerships, and encouraging industry outreach.

3. **Develop substantial, highly targeted resources to support large scale nanobio-enabled projects and programs**, e.g. personalized medicine, by leveraging strategic State investments in partnership with major federal, philanthropic, and corporate funding.

4. **Support the development and continuous upgrading of nanobiotechnology research infrastructure** at Maryland colleges and universities and community colleges through federal/State agreements for shared use of specialized research facilities and equipment and strategic State capital investments that leverage federal funding whenever possible.

5. **Provide funding for the Coordinating Emerging Nanobiotechnology Research (CENTR) in Maryland Program** to foster research partnerships among federal institutions, private sector entities, and institutions of higher education, including pilot funding for faculty to develop research data to be used in larger grant funding proposals and research infrastructure, as well as human capital development in nanobiotechnology research.

6. **Support Maryland nanobiotechnology companies' pursuit of external research funding** from the federal government and other sources.

C. SUPPORT THE COMMERCIALIZATION OF NANOBIOTECHNOLOGY RESEARCH IN MARYLAND.

1. **Support pre-commercialization translational reduction of research to practice** by providing funding and spaces where talented faculty, students, and post-docs can perform the proof-of-principle demonstration or prototype device demonstration that is necessary to seek funding to start a company. A possible model could be the Georgia Research Alliance Venture Lab.

2. **Increase the availability of product development capital for promising nanobiotechnology** companies, particularly those entering clinical studies, by increasing appropriations to the Maryland Venture Fund and TEDCO's **Maryland Technology Transfer and Commercialization Fund (MTTCF), and explore other commercialization support programs. A possible model could be the** Oregon Nanoscience and Microtechnologies Institute's ONAMI Commercialization Gap Fund.

3. **Capitalize on Maryland's unique array of federal commercialization assets** including the NCI/FDA/NIST National Nanotechnology Characterization Laboratory and the Center for Nanoscale Science and Technology at NIST for nanofabrication. Refer companies that use the Maryland Biotechnology Center and TEDCO to these federal resources.

4. **Support nanobiotechnology commercialization planning and execution by the most promising Maryland companies** through intensive mentoring and tiered funding, with strong capabilities for assisting companies with intellectual property issues. A possible model could be the Texas Emerging Technology Fund.

5. **Support broad funding instruments for innovative technologies, including the proposed InvestMaryland initiative**, which would be able to seed nanobiotechnology companies with its focused early stage funding for qualified Maryland companies.

6. **Explore State funding for high potential SBIR/STTR nanobiotechnology and other emerging technology winners** judged by the Maryland Venture Fund to have feasible commercialization plans and the capacity to implement them. Consider bridge funding between Phase I and Phase II awards, and strong links to commercialization resources for those nanobiotechnology companies completing Phase II projects.

7. **Strengthen technology transfer at research universities and the ability to launch nanobiotechnology ventures based on university and federal laboratory research** by supporting TEDCO's technology transfer and proof-of-concept funding; allowing for the Maryland Industrial Partnerships (MIPS) program to expand; increasing funding for scientifically and commercially skilled technology transfer personnel, patent expenses; and conducting a comprehensive review of internal and extramural policies and procedures that affect university/private sector collaboration.

8. **Expand the availability of GMP facilities** for Maryland nanobiotechnology companies to use in order to scale-up or to manufacture nano-enabled products.

9. **Enhance incentives to private investors that invest in nanobiotechnology companies** by supporting the Maryland Biotechnology Investment Incentive Tax Credit.

10. **Expand the availability of investments from State pension funds** by specifying nanobiotechnology as an eligible field that has applicability to all currently named industry segments -- biotechnology, information technology, green technology, and medical device technologies.

D. ADVANCE MARYLAND NANOBIOTECHNOLOGY TALENT AND WORKFORCE DEVELOPMENT.

1. **Provide and leverage external funding for top level and young faculty recruitment.** The University of Maryland has demonstrated past success by prioritizing faculty recruitment. The ability to attract and train the best and the brightest allows for institutionalized success. A possible model could be the Georgia Research Alliance.

2. **Support undergraduate and graduation education** that prepares students for meaningful contributions in nanobiotechnology and its interdisciplinary realms, building on pilots and models being developed at Maryland higher education institutions and elsewhere.

3. **Establish a Maryland Bioscience Talent Bridge program** to provide fellowships to enable bioscience companies to employ postdoctoral students and recent Ph.D's, to help students to gain initial industry experience in nanobiotechnology.

4. **Take an active part in the National Nanotechnology Infrastructure Network (NNIN)**, which aims to expose young people to advanced and exciting research in nanotechnology and motivate them to educate themselves for careers in the sciences or engineering; train teachers and guidance counselors about the disciplines of experimental sciences; create and distribute educational materials for children, college students, technical professionals, teachers, and the general population; and focus these efforts on population segments having disproportionately low educational attainment and employment experience in science.
5. **Implement the Governor's Workforce Investment Board's Maryland Bioscience recommendations** for addressing the ability of industry (and research institutions) to attract, recruit, train, and/or retain a highly skilled nanobiotechnology workforce; support collaborative efforts by industry and State government to attract, recruit, and retain nanobiotechnology talent; and work cooperatively to align employers' knowledge and rapidly changing skill needs with the content and delivery of the education system**.**

6. **Establish a bioscience skills alliance – with a strong subset of nanobiotechnology employers – and a skill development fund** to support curriculum development, teacher professional development, and postsecondary instructional equipment needs for institutions with a strong track record of training and placing graduates.

E. PROMOTE NANOBIOTECHNOLOGY RESPONSIBLY TO ACHIEVE PUBLIC ACCEPTANCE.

1. **Maximize the value of the proximity of nearby federal regulatory agencies to make Maryland a national and international exemplar of responsible and economically productive development and deployment of nanobiotechnology** by engaging federal and State policymakers and regulators, researchers, and industry in regular dialogue about ways to ensure the safe development of nano-enabled products throughout their life cycle, from research through deployment in humans and ultimate disposal.

2. **Follow and seek to influence the ongoing discussions by the NSET Nanotechnology Environmental and Health Implications Working Group**, the International Risk Governance Council, and EPA's voluntary measures.

3. **Examine and discuss with State regulators the existing policies or recommendations from industry associations and other States regarding sustainable nanotechnology**, including the NanoBusiness Alliance's Position Statement on Nanomaterials Product Sustainability[31] and Massachusetts' Nanotechnology-Considerations for Safe Development.[32]

4. **Prepare for the mass application of nanobiotechnology,** even while we have only the earliest notions of all the possible ways in which it will be deployed, establishing a clear regulatory framework and understanding of ethical and societal implications for a technology which has and will progress from relatively simple passive nanostructures to molecular nanosystems in two decades.

[31] www.vincentcaprio.org/nanobuiness-alliance-issues-statement -on-sustainable-development-of-nanotechnology.
[32] www.mass.gov/Eoeea/docs/eea/ota/tech_reports/ota_nanotech_guidance.pdf