Nanotechnology in Virginia

Presented

December 12, 2006

to

The Virginia Joint Commission on Technology and Science

prepared by

The 2006 JCOTS Nanotechnology
Research & Development and Manufacturing Advisory Committees

Executive Summary

> ***Nanotechnology is here now.***
>
> In 2005: **$30 billion** manufactured goods incorporated nanotechnology.
> By 2014: **$2.6 trillion** in global manufactured good will incorporate nanotechnology.
> -LuxResearch 2006
> *http://www.luxresearchinc.com/press/RELEASE_TNR4.pdf
>
> In Virginia, approximately **$1billion** manufactured goods will incorporate nanotechnology in 2006.
> -Industry sources

Nanotechnology is the enabling force behind the evolving economical and technological revolution which will impact nearly every aspect of our lives. In fact, the revolution has already begun. In 2005, ***thirty billion dollars**** worth of manufactured goods incorporated nanotechnology. Nano-enabled commercial products such as magnetic storage devices have entered the mainstream. The true benefits of nanotechnology, however, are yet to be realized in an enormous range of applications, including advanced electronics, healthcare, energy, homeland security and defense. All of these are important economic sectors for Virginia. To help realize this potential, ***$9.6 billion**** was invested in 2005 worldwide by corporations, governments, and venture capitalists on nanotechnology research and development. Companies- from the developers and manufacturers of nanomaterials to the defense contractors who will eventually integrate the technology- are ***doing business in Virginia***. These organizations are supported by strong research programs at the Commonwealth's academic institutions and federal laboratories.

Nanotechnology embraces the understanding, design and manipulation of matter at dimensions of less than a billionth of a meter, (approximately 1/100,000th the thickness of a typical sheet of paper). The impact of understanding and control of matter at the atomic and molecular level will be pervasive. Nanotechnology will not only enable our computers to become smaller and faster, but will impact the way we diagnose and treat disease, provide cleaner and more efficient energy, produce stronger and lighter materials for everything from golf clubs to airplanes, and enable smart clothing not just stain resistant, but with sensors to keep us comfortable and safe, and will even impact the food we eat.

Nanotechnology in Virginia

Nanotechnology is a part of today's industry in Virginia. Nanomaterials are being commercially produced for application in sectors such as microelectronics, life sciences, energy, and defense. Virginia firms active in nanotechnology range from the equipment manufacturers that enable fabrication or imaging at the nanoscale, to those that make the enabling nanomaterials, and to companies that are or will become the integrators and end users of nanotechnology. At academic institutions and federal laboratories across the Commonwealth, nanotechnology is an area of significant strength and the research infrastructure and educational programs can be leveraged to support existing industry and spawn or attract new companies. Virginia's fundamental research expertise, including broad areas such as self assembly and nanocharacterization, can provide the foundation for future technological breakthroughs.

> **Sample of Virginia Companies Engaged in Nanotechnology**
>
> 4Wave, Inc (Sterling)
> Abtech Scientific, Inc. (Richmond)
> BAE Systems (Manassas)
> CPFilms, Inc (Martinsville)
> Lockheed Martin Corporation (Manassas)
> Luna Innovations, Inc. (Blacksburg, Charlottesville, Danville, Hampton, McLean, Roanoke)
> Materials Modification, Inc. (McLean)
> Micron Technology, Inc. (Manassas)
> NanoChemonics, Inc. (Pulaski)
> NanoMatrix, Inc. (Richmond)
> NanoSonic, Inc. (Blacksburg)
> NanoTITAN (Potomac Falls)
> NBE (Blacksburg)
> Northrop Grumman Newport News (Newport News)
> Phillip Morris USA (Richmond)
> Qimonda (Richmond)
> Science Applications International Corporation, SAIC (McLean)
> Virginia Beach Sensors (Virginia Beach)
> Vistec Semiconductor Systems (Chantilly)

This is particularly true in four areas, **Microelectronics**, **Life Sciences**, **Defense,** and **Energy**. ***Microelectronic devices*** are now the leading manufactured export of the Commonwealth. In 2005 the value of memory devices exported ($645.6M) by Micron Technology and Qimonda surpassed tobacco products ($439.5M). Nanotechnology is already impacting microelectronics and will continue to become more significant as electronics become increasingly faster and smaller. It is imperative that we sustain and enable increased capacity of this industry.

Nanotechnology promises to revolutionize ***healthcare and medicine***, from early diagnosis and treatment options for diseases such as cancer, to wound care and tissue regeneration. Virginia industry is working with our hospitals and medical schools to accelerate advances in areas such as magnetic resonance imaging with carbonaceous nanomaterials and artificial vessels made from nanofiberous materials.

In ***Defense and Homeland Security***, nanotechnology promises the development of many revolutionary technologies, including ultra-hard and corrosion resistant coatings for air, sea and land vehicles; self-repairing materials for space; ultra-quiet and light propulsion systems; and ultra-sensitive pathogen detection, among a myriad of possibilities.

Energy is one of the most significant challenges of our generation. Nanotechnology will be key to development of alternative energy sources such as biorenewables, photovoltaics (solar cells), and fuel cells. Nanoscale catalysts will be critical in the development of biodiesels as well as for improved combustion kinetics to facilitate clean coal technologies. More broadly, nanoscale understanding and control of chemical reactions will enable much more efficient chemical processing and manufacturing, and much great control over waste products with concomitant benefits to the environment.

Table of Contents

Introduction

> ***Nanotechnology is here now.***
>
> In 2005: **$30 billion** manufactured goods incorporated nanotechnology.
> By 2014: **$2.6 trillion** in global manufactured good will incorporate nanotechnology.
> -LuxResearch 2006
> *http://www.luxresearchinc.com/press/RELEASE_TNR4.pdf
>
> In Virginia, approximately **$1billion** manufactured goods will incorporate nanotechnology in 2006.
> -Industry sources

Nanotechnology is the enabling force behind the evolving economical and technological industrial which will impact nearly every aspect of our lives. In fact, the revolution has already begun. In 2005, ***thirty billion dollars**** worth of manufactured goods incorporated nanotechnology. Commercial products are in the market and have entered the mainstream. The true potential of nanotechnology, however, has yet to be realized in advanced electronics, healthcare, energy, homeland security and defense. All of these are important economic sectors for Virginia. To help realize this potential, ***$9.6 billion**** was invested worldwide in 2005 by corporations, governments, and venture capitalists on nanotechnology research and development. Companies from the developers and manufacturers of nanomaterials to the defense contractors who will eventually integrate the technology are ***doing business in Virginia***. These organizations are supported by strong research programs at the Commonwealth's academic institutions and federal laboratories.

Nanotechnology is the understanding, design and manipulation of matter at dimensions of less than a billionth of a meter, (approximately 1/100,000th the thickness of a typical sheet of paper). The impact of understanding and control of matter at the atomic and molecular level will be pervasive. Nanotechnology will not only enable our computers to become smaller and faster, but will impact the way we diagnose and treat disease, provide cleaner and more efficient energy, provide stronger and lighter materials for everything from golf clubs to airplanes, enable smart clothing with sensors to keep us comfortable and safe, and it will even impact the food we eat.

What is so special about the nanoscale?
The properties of materials depend on the way they are arranged at the nanoscale. For example, graphite and diamond are two materials with the same chemical composition, they are pure carbon, but the atoms are arranged differently. Because of the arrangement of the carbon atoms, graphite is slippery and black, diamond is hard and transparent. Even a material in the same structure can have different and unique optical, electrical, or physical properties at the nanoscale enabling exciting new innovations. For example, we are familiar with silver in its bulk form used for jewelry, flatware, and dishes; however, at the nanoscale, silver has antimicrobial properties which is of use in wound dressings to prevent infection.

The development of the instrumentation to image and manipulate materials at this level has enabled the discovery of previously unknown materials. For example, other forms of carbon based nanomaterials include carbon nanotubes, fullerenes (or buckeyballs), and carbon sheets. These materials have amazing properties. Carbon nanotubes, for example, are light but 100 times stronger than steel, conduct heat better than diamond and, depending on the type of tube, can conduct electricity better than copper or can be semiconducting and have interesting optical properties as well. Due to the geometry of the tubes, they can be used as probes or to extract or deliver very small quantities of materials to individual biological cells.


C_{60}

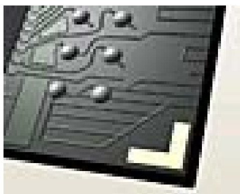
> "It's (nanotechnology) going to impact virtually every one of our business areas and products."
> -Sharon Smith, Director of Technology, Lockheed Martin Corporation.
> (Orlando Sentinel, Sept. 11, 2006)

Virginia has significant strength in the area of carbonaceous nanomaterials, as discussed throughout the following sections, from fundamental research to production and development of commercial products that exploit the unique properties of these materials. For example, ***CPFilms*** (Martinsville) uses nanotubes in their optical coatings, ***BAE Systems*** (Manassas) is looking at carbon nanotube electronics, and ***Luna nanoWorks*** (Danville) is producing carbonaceous nanomaterials for medical and other applications.

Nanotechnology in Virginia

Nanotechnology is a part of today's industry in Virginia. Nanomaterials are being commercially produced for application in sectors such as life sciences, microelectronics, energy, and defense. Virginia firms active in nanotechnology range from the equipment manufacturers that enable fabrication or imaging at the nanoscale [***4Wave, Inc.*** (Sterling), ***Vistec Semiconductor Systems*** (Chantilly)], to those that make the nanomaterials [***Luna nanoWorks*** (Danville), ***NanoChemonics*** (Pulaski) ***Materials Modification, Inc***. (McLean), ***NanoMatrix, Inc.*** (Richmond), and ***NBE*** (Blacksburg)], and to companies that are or will become the integrators and end users of nanotechnology, (see inserts).

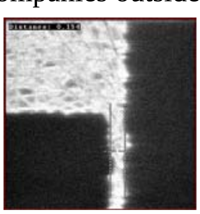
Microelectronics



DRAM Component
Micron Technology

Microelectronic devices are now the leading manufactured export of the Commonwealth. In 2005 the value of memory devices exported ($645.6M) by Micron Technology and Qimonda surpassed tobacco products ($439.5M). It is understood that this is the first time in the 400 year history of Virginia that a technology product has surpassed agricultural exports. Nanotechnology is already impacting microelectronics and will continue to become more significant as electronics become faster and smaller. The microelectronics industry drives the application of nanotechnology in high volume production through the use of materials and structures that approach atomic dimensions to create new electronic device properties. Virginia companies engaged in nanotechnology include ***Micron Technology*** (Manassas), ***Qimonda*** (Richmond), ***BAE Systems*** (Manassas), and ***NBE*** (Blacksburg). For example, in the last two fiscal years, Micron Technologies and Qimonda have expanded their Virginia chip fabrication facilities and ***invested over $2.3 billion*** to ramp-up production in their Manassas and Richmond facilities, respectively. This has increased their combined workforce by nearly ***1200 new high-tech jobs***, and they've hired from our academic institutions including Virginia Tech, University of Virginia, Old Dominion, Virginia Commonwealth, George Mason, and Northern Virginia Community College. The impact of this investment goes beyond the individual hires and impacts the economy of the surrounding area and the Commonwealth. (See Micron's Multiplying effect in Manassas, Washington Post 9/25/06 http://www.washingtonpost.com/wp-dyn/content/article/2006/09/24/AR2006092400791_pf.html)

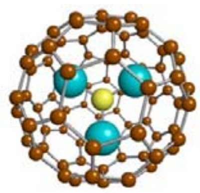
Important research programs at our universities are advancing future generations of nanoelectronics, (see research section below). Cutting edge research in collaboration with industry will help Virginia maintain and build this economic sector. Furthermore, active research programs are building relationships with companies outside of Virginia, including IBM, Intel, Honeywell, Freescale, Seagate, Rockwell, and Hewlett Packard, in areas such as spintronics, quantum dot electronics, and molecular electronics. Virginia also has active programs in carbon nanotube-based electronics. This is an area of particular interest to Virginia businesses, for example, in July of 2004, ***BAE Systems*** (Manassas) announced a joint effort with Nantero, Inc. to investigate the potential development of carbon nanotube-based devices for aerospace and advanced defense systems (http://www.nanotechwire.com/news.asp?nid=955). Furthermore, there are other efforts focused on the production, properties, and use of carbonaceous nanomaterials, at academic institutions across the Commonwealth, at industries such as ***Luna nanoWorks***, and at federal laboratories such as***Jefferson Laboratory*** and ***NASA Langley Research Center***.



Patterned carbon nanotubes
BAE Systems and Nanotero

Life Sciences

Nanotechnology will have a profound impact on how we ***prevent, detect and treat disease***. Nanoscale materials will allow evaluation and treatment ***at the cellular level***. It will be possible, for example, for nanoparticles to be treated to target cancerous cells and be sent directly to the tumor leaving healthy cells undamaged, or magnetic nanomaterials with therapeutics to be directed to a point of eye injury to promote retinal repair. Advanced imaging will allow detection of disease at a much earlier stage and lab-on-a-chip technologies will enable rapid and low cost diagnosis in a physician's office or in the field. Virginia has unique strengths in nanomedicine. Originally developed at Virginia Tech, Luna Innovations has exclusive rights to a new composition of matter called TRIMETASPHERE™ carbon nanomaterials - a fullerene sphere enclosing three metal atoms in a nitride molecule. The entrapped metals provide unique physical, chemical, thermal, magnetic, biological, optical and electronic properties that differentiate them from other carbon nanomaterials. ***Luna's nanoWorks*** Division is working with imaging experts to develop enhanced Magnetic Resonance Imaging (MRI) contrast agents (***a $ billion/year industry***) to reduce toxicity while increasing sensitivity for diagnostic imaging to detect disease earlier.



Luna's proprietary TRIMETASPHERE™ carbon nanomaterials

Another Virginia strength is the engineering of nanoscale fibrous biopolymers for cell and tissue scaffolds and controlled drug delivery platforms. ***NanoMatrix*** (Richmond) is using an electrospinning technology for the preparation of artificial blood vessels, skin and tissue scaffolds that may be used in wound healing, surgical applications, and in battlefield tourniquets. Supporting research efforts are underway at VCU and UVa.

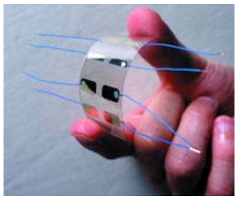
Nanotechnology enables the opportunity to probe sub-cellular biochemical activity. The development of detection systems, specifically, nanobiosensors and nanobioprobes, that are capable of penetration and location at specific sites within single living cells is made possible through nano-biotechnology. Single walled carbon nanotubes, chemically modified and selectively coupled to biological indicator molecules, enable the development of such sensors that could be used as alternatives to whole animal chemical toxicity assessments and as biological warfare agent detection and monitoring systems. Carbon nanotube research is strong across Virginia with efforts in academia, at ***Jefferson Laboratory***, ***NASA Langley Research Center***, and commercial production at ***Luna nanoWorks***. Nanoscale materials also play a critical role in lab-on-a-chip applications [***Abtech Scientific, Inc***. (Richmond)] for the separation and identification of biomarkers. With technology developed at UVa in collaboration with VCU and JMU, a diagnosis that would typically take a laboratory with three technicians and substantial equipment a week, can be made in just thirty minutes with a lab-on-a chip.

Sample of Virginia Companies Engaged in Nanotechnology

4Wave, Inc (Sterling)
Abtech Scientific, Inc. (Richmond)
BAE Systems (Manassas)
CPFilms, Inc (Martinsville)
Lockheed Martin Corporation (Manassas)
Luna Innovations, Inc. (Blacksburg, Charlottesville, Danville, Hampton, McLean, Roanoke)
Materials Modification, Inc. (McLean)
Micron Technology, Inc. (Manassas)
NanoChemonics, Inc. (Pulaski)
NanoMatrix, Inc. (Richmond)
NanoSonic, Inc. (Blacksburg)
NanoTITAN (Potomac Falls)
NBE (Blacksburg)
Northrop Grumman Newport News (Newport News)
Phillip Morris USA (Richmond)
Qimonda (Richmond)
Science Applications International Corporation, SAIC (McLean)
Virginia Beach Sensors (Virginia Beach)
Vistec Semiconductor Systems (Chantilly)

Energy

Energy is one of the most significant challenges of our generation. Improvements in the efficient use of fossil fuels, collection of combustion by-products, development of alternative energy sources, and conservation efforts will need to be pursued in concert to meet all of our future energy demands. Nanotechnology will be key to development of alternative energy sources such as biorenewables, photovoltaics (solar cells), fuel cells, and wind power. Much of this work, however, remains in the research stage. Nanoscale catalysts will be critical in the development of biodiesels as well as for improved combustion kinetics to facilitate clean coal technologies [***NanoChemonics (Pulaski***)]. Many approaches and materials are being investigated for photovoltaics, such as improving traditional silicon based systems with surface modifications and amorphous silicon. Lighter, cheaper, and flexible organic based photovoltaic systems are of interest and may eventually be incorporated in windows, paint on buildings, etc. These systems have the potential for a tremendous impact on local energy production and will affect the way new buildings are designed. Organic materials such as self assembled monolayers, organic systems involving fullerenes, carbon nanotubes, titanium oxide nanoparticles and silicon/germanium quantum dots are under investigation at many of the Commonwealth's universities and at ***Luna nanoWorks.*** The Surface Meteorology and Solar Energy Project, an applied science program at ***NASA Langley Research Center***, provides satellite derived solar and meteorological data which will help show regional viability of solar power and will complement the research efforts at the universities.



Organic photovoltaics, Heflin, VT

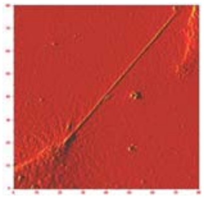
Fuel cells may have a tremendous impact on reducing the country's dependency on foreign oil, and several research programs are focusing on their development, as discussed in the research section below

Homeland Security and Defense

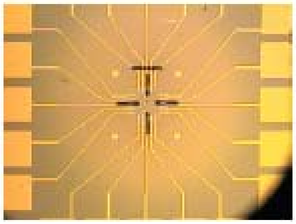
Nanotechnology is already seeing significant application in the defense sector. For the soldier or first responder, nanosensors will warn of possible dangers, and use of nanomaterials will provide improved filtering of nuclear, biological, and chemical toxins in gas masks as well as lightweight protective clothing. Fuel cell and photovoltaic technologies will enable light, portable power supplies. Nanotechnology is also playing a role in all forms of vehicles, from enhanced armor, stronger, lighter materials for ships and aircraft, and in coatings for corrosion control and stealth. [***NanoSonic*** (Blacksburg), ***Luna Innovations***, (Blacksburg, Charlottesville, Danville, Hampton, McLean), ***Northrop Grumman Newport News*** (Newport News), ***Lockheed Martin, Inc*** (Manassas) ***NanoChemonics*** (Pulaski)]. Advanced electronics for military applications will involve nanotechnology, in areas such as spintronics, molecular electronics, quantum dot electronics, and nanotube electronics and will impact the microelectronics industry (see above) as well as those integrating the technology into advanced systems. [***Lockheed Martin, Inc*** (Manassas), Science Applications International Corporation, SAIC (McLean), ***Northrop Grumman Newport News*** (Newport News), ***BAE Systems*** (Manassas)].

Research

Developing the understanding of and controlling the unique properties of materials at the nanolevel is the role of the nanotechnology researchers and scientists at our institutions and laboratories. Virginia's academic institutions have been nationally recognized for their nanotechnology research and are host to hundreds of faculty members actively engaged in nanotechnology research and development that support each of the above, and other, industry sectors. A few brief highlights of ongoing research are presented below. For example, Virginia researchers are using nanotechnology to treat brain tumors and are investigating nanoporous coatings on surgical instruments to enable drug delivery or to prevent infection.



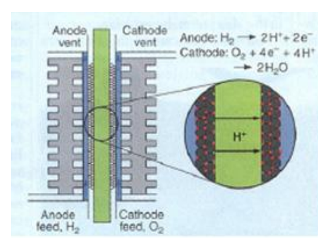
AFM image of brain cancer cells. G. Gilles, UVa, VCU



The Center for Nanoscopic Materials Design, UVa

The advancement of the microelectronics industry requires continual research on new materials, processes, characterization techniques and devices. This research contains two major thrusts; 1) those directed towards extending the current state of the art in silicon based technology and 2) those directed at novel technologies that will transform the industry. Research efforts are underway in both of these key areas. Research and development efforts aimed at extending current silicon-based technology are directed towards allowing producers to continue to utilize their huge capital investments in the technology for several more generations of products. This research includes extending lithographic techniques to define ever shrinking device ground rules, developing new and exotic dielectrics and conductors that allow extensions of existing electronic structures, and creating novel techniques for control, measurement, analysis and production that allow improved efficiencies. Of the current electronic architectures under development, the leading candidates are: ***spintronic devices***, based upon manipulation of electron spins rather than charges; ***molecular electronics***, using the non-linear electronic properties of individual molecules as active or passive device elements; ***quantum dot (QD)electronics***, using the storage and motion of individual electronic charges, in concepts such as single electron transistors and quantum cellular automata (QCA); and ***nanotube based devices (carbon and inorganic)*** and the related field in semiconductor nanowire devices. These potential solutions are dependant upon fundamental advances in material and quantum science joined with the rapid ability to bring new systems using these advances into practice. Research programs in each of these areas are moving forward in Virginia as well as joint programs with and directly funded by industry. For example, a spintronics project involves Freescale Semiconductor, a Motorola spinoff, which began commercial shipments of Magnetic Random Access Memory (MRAM) based on spin principles in July of this year. Other industry partners include Intel, IBM, Hewlett-Packard, Seagate, and Honeywell. The use of epitaxial semiconductor quantum dots to store, manipulate and transfer charge down to the single electron level has been recognized for well over a decade. Virginia has a nationally leading program in this field in spatial control of quantum dot assembly using focused ion beam (FIB) templating techniques. IBM and FEI are industrial partners in this research. Pulsed laser deposition is being used to grow quantum dots and near infrared QD detectors have been fabricated and tested in collaboration with NASA Langley Research Center.

As mentioned above, researchers are focusing on the application of nanotechnology to alternative energy in the areas of solar cells, biofuels, and fuel cells. Solid oxide fuel cells (SOFC) may see more rapid and broader implementation as research and development enables them to use a range of combustible fuels such as gasoline, diesel, or biofuel. SOFC's are ideal for applications such as home use and distributed power production. A number of efforts are active across the Commonwealth to investigate the materials and catalysts required to optimize their operation, as well as in modeling and experimental measurement of reaction rate kinetics for candidate materials. Another strong topic area is materials development for proton exchange membranes (PEMs) for use in hydrogen or methanol-based fuel cells. Before the '***hydrogen economy***' is possible, significant technical challenges need to be addressed. Beyond the issues of materials, catalysts, and reaction kinetics common in fuel cells as mentioned above, methods for clean production and safe distribution and storage of hydrogen must be established. Current research includes technology for hydrogen storage in nanostructured materials to achieve potentially large gravimetric and volumetric storage capacity suitable for commercial applications. The Virginia Coastal Energy Research Consortium is investigating the potential to develop offshore renewables that currently focuses on the development of wind energy. Nanotechnology will play a role in the turbine applications for coatings to prevent corrosion and reduce drag.



McGrath, VT

Education and Workforce Development

Currently, there are many nanotechnology education initiatives underway and outreach programs for K-12 students. Danville Community College is working with Luna nanoWorks to develop a technician training program focusing on the needs of nanomaterials manufacturing. J.Sargent Reynolds Community College and Northern Virginia Community College are working with Qimonda and Micron Technology for manufacturing technician training. Several universities have NSF Research Experiences for Teachers (RET) and Research Experiences for Undergraduate (REU) programs. These are often tied to research centers or large research programs that give teachers or undergraduate students an opportunity to conduct research in the laboratories during the summer. The undergraduate programs have been quite successful, drawing students from across the country to our research institutions. In the RET programs, however, it is often quite difficult to find enough teachers interested in participating to fill the available slots. Perhaps a mechanism such as professional education credits would encourage teachers to participate.

At the undergraduate level, there are several courses being offered that focus on nanotechnology. Several universities have received Nanotechnology Undergraduate Education awards from NSF, including JMU, VT, and UVa. These programs enable the development of classes and/or laboratories that focus on nanotechnology. The program at James Madison University has integrated nanotechnology throughout the chemistry curriculum. A unique aspect of their program is the use pre-service science teachers (upper level teaching students) as laboratory assistants in the nanotechnology laboratory classes to give them exposure to nanotechnology as well as experience running a lab. The organization and operation of a chemistry laboratory is often a difficult skill for new teachers to obtain and master. This program not only impacts the chemistry students at JMU, but middle and high school students who are subsequently taught by the trained teachers.

Graduate level nanotechnology courses are being offered as part of the science and engineering curriculum at our institutions. A Certificate Program for working professionals is offered by George Mason University. The recent National Science Foundation Partnership for Innovation ($600,000) grant awarded to George Mason University, the College of William & Mary, Old Dominion University, the University of Virginia, Virginia Commonwealth University and Virginia Tech will help lay the foundation for shared graduate level nanoelectronics courses through the Commonwealth Graduate Engineering Program, CGEP. CGEP also received some funding from the Commonwealth of Virginia this year in support of this program to deliver shared nanotechnology courses for its member institutions and industry. Expanding this program to a full asynchronous capability would benefit working professionals.

Advancing Nanotechnology in Virginia

The 2006 JCOTS Nanotechnology Advisory Committees worked together to define a vision for the Commonwealth:

Vision Statement: ***"Position Virginia at the forefront of nanotechnology from research to manufacturing for economic growth and creation of high technology jobs."***

Over the past several months, representatives from industry, academia, and government have met to discuss issues significant to the advancement of nanotechnology in Virginia. These committees divided into the following focus groups; education, research, business development, manufacturing, and finance. The critical issues identified are discussed briefly below. The focus group reports and recommendations can be found on the JCOTS website.

Education and Workforce Development

To prepare the necessary workforce, education needs to be addressed at all levels. Strong science and math skills need to be taught in grades K-12 across the commonwealth, and teachers need to be given the opportunity to learn about emerging technologies like nanotechnology. Community colleges will be critical, not just for training technicians, but for educating students working toward transfer to four year or advanced degrees. The Commonwealth's colleges and universities will need to continue to expand their nanotechnology offerings in related science and engineering disciplines for degree, minor, and certificate programs.

Innovations are the driving force behind our economy and in order to drive future innovations the United States needs around 100,000 new engineers each year but only produces around 57,000 and imports the remainder. Are these figures sustainable? No, for two reasons; (1) since 9/11 we have tightened our visa process, and, even more worrisome, (2) we are no longer the only location of choice for bright young minds. We are in severe competition with Asian countries such as India and China.

We must maintain and enhance the number of domestically produced engineers each year in order to maintain our position of prominence in technological innovation and thus our robust economy. This means we must implement strong measures to interest students from elementary level through high school in science and engineering and bolster the output of our nation's schools of engineering. The Committee recognizes that devoted science teachers are crucial to the Commonwealth's goal of producing motivated science students; a devoted science teacher can create many motivated science students in one year, and a generation of students over a career. Therefore, it is important not only to provide the training and skills to keep our teachers aware of technological advances, but to recognize outstanding science teachers in the Commonwealth.

The development of asynchronous undergraduate engineering degree programs to support nanotechnology and electrical engineering is required to support the increasing need of working professionals in Virginia's nanotechnology, microelectronics, energy, and automotive industries who want to pursue Bachelors degrees while working shift schedules or are located remotely from educational providers. These programs require a significant commitment of resources but would support continued professional development needs across the Commonwealth.

We must direct our collective energy to seeing and seizing upon the latest areas of innovation that will help us maintain our position of international leadership. The area of nanotechnology is such an area.

Research and Development

Excellent research programs and facilities have been established, but with so much of the promise of nanotechnology yet to be realized, it is critical to maintain and strengthen the research infrastructure in Virginia. With a strong research infrastructure, Virginia will be the state known for nanotechnology discovery and innovation. Supporting collaborative research programs will enable the leveraging of existing resources and allow our institutions to compete successfully for large center-level federal funding. Federal research centers not only bring prestige and significant funding, but will also bring private matching funds and other collaborative research with industry.

In addition to the nanotechnology research programs with direct technological implications described above, research laboratories in Virginia have leading programs in broad areas of fundamental research that are foundational to future broad areas of nanotechnology. Investment in these areas will build the intellectual capital and infrastructure necessary for Virginia to emerge as one of the handful of leaders in nanotechnology – both in scientific and engineering advances, and in the creation of new technologies and industries – in the coming decades. Three broad areas of strength and importance are: i) Nanoscale control of the natural forces of self assembly. Self assembly, whereby short range natural forces govern the assembly of stable and often very complex structures at the nanoscale level, is one of the paramount tools of nanotechnology. At the very length scales which represent the limit of nano-manufacturing methods such as lithography, nature can take over. Although the concept of self assembly is pervasive throughout nanoscience, and its importance is universally recognized, there is really is no substantial scientific framework – or even language – to describe this phenomenon. We have multiple programs in the field of self-assembly institutions across the Commonwealth, and believe we have the opportunity to build the internationally defining program in this area. ii) Discovery and creation of new nanomaterials. The discovery of new materials and phenomena at the nanoscale have driven entire fields of sciences and revolutionized many industries. At the international level, the discovery of carbon nanotubes and fullerenes have spawned whole new scientific and technological "industries". At the Virginia level, leading examples include the discovery of the class of trinitrile endohedral fullerenes, and the discovery of a new class of Al-based amorphous metallic alloys. New materials always have been, and will continue to be, a key driver in the emergence of new technologies and industries. We believe that fostering the environment for future major discoveries in Virginia will be a major plank of our future competitiveness. iii) The nano toolset. Instruments for atomic scale fabrication and measurement are the indispensable tools of nanotechnology. Ever since Galileo first turned his telescope to the heavens, new methods for imaging and measurement have revolutionized our understanding of the universe. This is as true of the atomic-scale world as it is of the astronomical. We should take full advantage of this opportunity by assembling the people, instruments and culture for excellence in nanoscale instrumentation. On one hand, this will mean establishing a state-wide "Virginia Nanotechnology Users Network", see below, where a co-operative network of state-of-the-art instruments is established across the Commonwealth. On the other hand, it will mean encouraging innovation in the science of measurement, to enable entirely new imaging and fabrication techniques. Realization of these goals would give us an extraordinary research and development edge.

Nanotechnology research and development requires state-of-the-art synthesis and fabrication equipment and characterization facilities. Some of these individual instruments can cost several million dollars to purchase, which can be difficult or prohibitive for a single institution to buy and maintain. Although some general purpose instruments are needed at every institution, it is unnecessary and unreasonable to duplicate some of the high-end items of equipment critical to this research.

Over the past 5 years, a solution to this issue has frequently been proposed: a "virtual center" was proposed as VMEC was being founded; more recently, a users network was suggested by a working group commissioned by VRTAC to develop a white paper for nanomanufacturing in 2003. In May 2006, the same concept was presented to VRTAC outlining the need to establish a cooperative network of state-of-the-art characterization and fabrication facilities at academic institutions across the Commonwealth. The key elements required to form this network are the identification of existing instruments to be included, development of policies to enable access, a one time purchase of a few critical instruments currently unavailable in the Commonwealth, a mechanism for future annual purchases and upgrades and sustained support for the operating scientists that are necessary to maximize the potential of this equipment. There exists a strong foundation, however, and many facilities with excellent capabilities are present. Virginia Commonwealth University, the University of Virginia, and Virginia Tech have cleanroom facilities which encompass micro and nanoelectronics research and are equipped with state-of-the-art semiconductor deposition, fabrication, and testing equipment. Relevant facilities and equipment (with cleanrooms in some cases) also exist at James Madison, William and Mary, Old Dominion, Norfolk State, the Applied Research Center (ARC) located next to Jefferson Laboratory, George Mason, NASA Langley and across the Commonwealth.

Business Development and Finance

Virginia has a solid entry into the nanoelectronics business arena with the major investments that companies such as Micron Technology, BAE Systems, and Qimonda have made in their corporate facilities in Virginia. The other nanotechnology markets are emerging with small businesses taking the lead, and much of the risks in developing products. Virginia must work with existing corporations to ensure that continued investments are made so Virginia stays a leader in the nanoelectronics industry. Furthermore, Virginia should establish a support network to target the establishment and initial expansion stages of the nanotechnology startups. The network should develop core expertise to assist in the growth of nanotechnology startup businesses to build a national reputation as a leader in nanotechnology. This can be accomplished by nurturing nanotechnology companies that complement existing regional areas of technical expertise as well as provide opportunities to support the transfer of new technologies into the marketplace to develop additional nano-related businesses.

As we move forward, it may be useful to consider the application of innovation based models for economic development. In essence, the core of the new innovation-based economic growth models is about building an "innovation ecology" – that is, taking a holistic view to developing economic resources and capabilities, since any sector that is a "weak-link" will result in a significant disadvantage in competitiveness in today's globalizing economy. The policy tools for developing such an ecosystem are, *inter alia*, public-private partnerships, social and business networking activities, educational and outreach activities, and leveraging of funding and financing from a variety of sources. The technological tools for developing an ecosystem are primarily from information technology, including web, wireless, and visualization tools and new learning and virtual meeting applications. Also, new models for financing and IP transition could be creating distinct advantages for those companies and regions which can develop them.

Small businesses and start-ups need easy access to a variety of resources including financial assistance, business consulting including mentoring on business management, finance and human resource issues, workforce, and marketing as well as capital equipment and space. Private and federal funding must be attracted to help collaborative industry/academic research programs and support business development.

Manufacturing

Many of the companies discussed above are currently manufacturing products, which incorporate nanotechnology in Virginia. Manufacturing remains a major component of Virginia's economy with over 295,000 people working in this sector in 2005. While this represents Virginia's third largest sector, its future health is fragile. Between 2000 and 2005, the sector lost 66,000 jobs, which constitutes nearly one-fifth of all manufacturing jobs in Virginia.

The future of manufacturing in Virginia lies with the rapid adoption of modern technological and process improvements. High tech manufacturing processes drive productivity. Between 1995 and 2005, U.S. manufacturing output per person increased more than 50 percent due to improvements in productivity gained from automation and other process developments.

High tech manufacturing requires two key ingredients: namely, automation and a skilled workforce.

The ability for a Virginia manufacturer to compete globally is directly tied to adopting the most advanced manufacturing processes. This requires substantial capital resources to automate processes and constantly modernize tools to ensure that the most advanced - and productive – processes are in place to compete in a global market. State level policies are required to encourage the spending of capital to modernize facilities. An example of a tax policy that is a disincentive to modernize and automate manufacturing facilities is the machinery and tools tax. This tax is applied to all tangible property "used directly" in manufacturing. A recent study by the General Assembly, SJR 361, found manufacturers have a higher effective tax rate than agriculture, retail, professional services, or information sectors.

Virginia's tax structure should encourage a healthy environment for manufacturing to remain in Virginia and generate high quality, high wage and high tech manufacturing jobs.

Summary

Nanotechnology is already having a significant impact on Virginia's economy, with an expected ***$1 billion of manufactured goods incorporating nanotechnology in 2006***. Commercial activities are supported by strong research, education, and workforce development programs across the Commonwealth. In order for Virginia to reap the benefits of this revolution, we must invest in our nanotechnology future, by developing policies to encourage business development and private investments, by supporting the research to enable future innovations, by providing resources for education and training programs to ensure a qualified workforce, and by continuing to look for opportunities to work together and leverage our significant strengths.

2006 JCOTS Nanotechnology Advisory Committee Members
(Research & Development and Manufacturing)
Delegate Purkey, Delegate Plum, and Delegate Cosgrove

Citizen Members
John Curtin, Capitol Patent & Trademark Law Firm
Henry Daley, Venable LLP
Steve Danziger, BAE Systems
Lisa E. Friedersdorf, University of Virginia
Charles B. Gause, Luna Innovations, Inc.
Charles A. Gleason, Jr., Liberty Ventures Intl., LLC
Fred T. Grasso, Kenyon & Kenyon LLP
Richard V. Gregory, Old Dominion University
Tim Hopkins, NanoChemonics Corp.
Michael A. Huff, MEMS and Nanotechnology Exchange
Robert Hull, University of Virginia
James Kadtke, Accelerating Innovation Foundation
Terrence C. Leslie, Micron Technology, Inc.
J. Glynn Loope, NanoChemonics Corp.
Dennis Manos, College of William and Mary
R.J. Mattauch, Virginia Commonwealth University
Duncan McIver, Technology Commercialization Center
Kathleen Meehan, Virginia Tech
Thomas E. Myers, Sirius Consulting, Inc.
Jeffrey Nelson, Nixon & Vanderhye, P.C.
John B. Noftsinger, Jr., James Madison University
Usha Varshney, National Science Foundation