A **Roadmap** for **Nanotechnology** in **North Carolina's 21st Century Economy**

Findings and Strategic Imperatives of the Governor's Task Force on Nanotechnology and North Carolina's Economy

April 2006

NC BOARD OF SCIENCE & TECHNOLOGY
A Division of the North Carolina Department of Commerce

Contents

STATE OF NORTH CAROLINA

NORTH CAROLINA BOARD OF SCIENCE AND TECHNOLOGY

April 2006

To the Citizens of North Carolina:

Science and technology are now the primary driving forces of change and growth around the world. Advances in fields such as medicine, electronics, computers, materials, and chemicals are changing the way we work, the way we play, the way we communicate, and the way we produce. These changes are "shrinking" the world, both figuratively and literally.

In a figurative sense, the world is shrinking because we can now interact and compete with others individually—but on a global scale. Thanks to computers, cell phones, video conferencing, and the Internet, we now can do business instantaneously with billions of people across the world. As a result, economic activity is becoming increasingly knowledge-based, job placements are shifting from low- to high-skilled workers, and productivity and employment growth depend on favorable conditions for economy-wide diffusion of new and innovative products and processes.

In a literal sense, the world is shrinking because we now have the ability to measure, see, predict, and make things on the scale of atoms and molecules. As this report illustrates, innovations in materials technologies and processes now enable us to create with manmade tools what only nature has been able to in the past. These innovations—these nanotechnologies—will affect almost every aspect of our lives and will revolutionize both the products we make as well as the processes we use to make them.

For all of its novelty, nanotechnology has roots in our past. The glazes found in ancient pottery and in pottery produced in North Carolina for centuries exploit for visual effect the nanoscale properties of the materials of which they are made. What is new about nanotechnology, though, is the extent to which it now permits us to control, harness, and reap the benefits of processes working and materials manufactured at the atomic scale. The economic impact on North Carolina of these innovations will be broad—affecting both our traditional industries, like textiles, as well as our emerging ones, like biotechnology.

The increasing pace of technological innovation that now supports the growth of our economy and undergirds our productivity growth demands that science and technology policy be made an integral part of our state's economic development agenda. Over the coming decades, North Carolina can create more new, high-wage jobs for its citizens from the effective use of science and technology-based economic development policy than from any other source.

To make this happen, we must continue to be proactive and innovative in embracing science and technology as the engine of our future economic success. This report provides a roadmap for how we can do this by enhancing North Carolina's competitiveness and prosperity in our growing—yet shrinking—world.

Margaret B. Dardess

Margaret B. Dardess, Ph.D., J.D.
Chair, NC Board of Science and Technology
Associate Provost for Strategic Partnerships,
University of North Carolina at Chapel Hill

Robert K. McMahan, Ph.D.
State Advisor for Science and Technology
Executive Director, NC Board of Science and Technology

301 North Wilmington Street • 1326 Mail Service Center
Raleigh, North Carolina 27699-1326
http://www.ncscienceandtechnology.com
919.715.0035 □ FAX 919.733.8356

Executive Summary

Nanotechnology: The Next Industrial Revolution

North Carolina, the nation, and the world are in the middle of a 21st century industrial revolution. Unlike the first industrial revolution, which occurred in the early part of the 20th century and was brawn-driven, this second industrial revolution is brain-driven. Innovations in science and technology are giving us unparalleled ability to determine the types of products we produce and the way we produce them.

This revolution is occurring, however, at the smallest scales imaginable and at the level at which nature designs: molecules and atoms. Operating at scales 1/100,000 the size of a human hair, *nanotechnology* is creating a wealth of new materials and manufacturing possibilities, which in turn will profoundly impact our economy, our environment, and our society. The degree to which we prosper as a result of these impacts will depend in large part on how quickly and effectively we respond to the challenges they present.

North Carolina is Poised for Success

North Carolina ranks among leading states in the quality of its nanotechnology research base. Reflecting this, nanotechnology startup companies are forming and growing across the state, and North Carolina is well positioned in industry sectors predicted to benefit greatly from nanotechnology, like biotechnology and information technology. North Carolina should include nanotechnology as a core component of its technology-based economic development strategy.

Creating a Roadmap for Success

In the spring of 2005, the State Advisor for Science and Technology, the Department of Commerce, and the North Carolina Board of Science and Technology formed the *Governor's Task Force on Nanotechnology and North Carolina's Economy*. Composed of twenty-eight members and broadly representing business, academia, and the public sector from across the state, the Task Force's charge was to:

> **Develop a roadmap for an aggressive and coordinated initiative to advance successful nanotechnology-based economic development and high-wage employment across North Carolina.**

Two approaches underlie that roadmap:

1. **Strengthen North Carolina's core economic development approach to advancing technology-based economic development**

2. **Strengthen the building blocks within that core approach that focus specifically on nanotechnology**

The Roadmap

This roadmap is a call to action for North Carolina's political and policy leaders, industry, research institutions, educators, and the public to:

- Increase our ability to innovate;
- Increase the levels of collaboration between our companies and R&D centers;
- Develop a well-educated and trained workforce;
- Provide a supportive public and political policy environment; and,
- Diversify our technology cluster portfolio to include nanotechnology.

Findings: A Framework for Action

Improving and Developing North Carolina's:

TECHNOLOGY Economy

1. Establish a "Technology and the Economy" information agenda and strategy for North Carolina that builds upon the relationships between nanotechnology, biotechnology, information technology and other emerging fields.
2. Strengthen the Science and Technology Division of the Department of Commerce to provide leadership, direction, coordination, and assistance to the state's science and technology-based economic development efforts.
3. Strengthen alignment of the committee and staff structure of the General Assembly with the needs of the 21st century economy.
4. More closely align university R&D with the needs of industry.
5. Align university strengths with the needs of regional economic clusters and develop strategies to address those needs.
6. Enhance the technology modernization of existing industry and increase the amount of industry R&D performed in North Carolina.
7. Establish a North Carolina Technology Investment Fund.
8. Aggressively encourage early-stage risk capital formation.
9. Explicitly link the state's incubator efforts with other technology development and deployment organizations.
10. Better align technology transfer offices in higher education institutions to emphasize company and job creation over license revenue.
11. Enhance the quality of K–12 science, technology, engineering and math (STEM) education across the state, to include better coordination of K–12 STEM initiatives with public postsecondary institutions.
12. Develop an explicit North Carolina technology workforce agenda and strategy to include enhancing existing workforce technology-oriented training structures and fast-tracking the development of critically needed pools of technology-trained workers.

NANOTECHNOLOGY Economy

1. Establish a North Carolina Nanotechnology Alliance.
2. Through the development of multiple centers of nanotechnology excellence at North Carolina's universities, develop a diverse critical mass of nanotechnology research, development, education, and outreach expertise in the state.
3. Establish a not-for-profit nanotechnology "Imagineering" group staffed to identify emerging nanotechnology opportunities and execution agents.
4. Create an information clearinghouse about nanotechnology in North Carolina.
5. Convene an annual North Carolina Symposium on Nanotechnology.
6. Ensure that nanotechnology is explicitly considered in education and workforce development activities.
7. Strengthen teacher knowledge of advances in nanoscale science.
8. Integrate information about nanotechnology into the North Carolina Biomanufacturing and Pharmaceutical Training Consortium.
9. Explicitly integrate the environmental, ethical, health, legal, safety, and other societal implications of nanotechnology.
10. Emphasize education of policy makers, the public, the business community, and the scientific community on issues related to nanotechnology.

Nanotechnology: The New Industrial Revolution

At the smallest scales imaginable, a quiet transformation of our economy is underway. Emerging innovations in materials technologies and processes are enabling scientists to build new and improved structures atom-by-atom and molecule-by-molecule, harnessing previously inaccessible properties of matter. These innovations, collectively known as *nanotechnology*, are the building blocks of an industrial revolution that will fundamentally change and drive the manufacturing and technology economy of the 21st century.

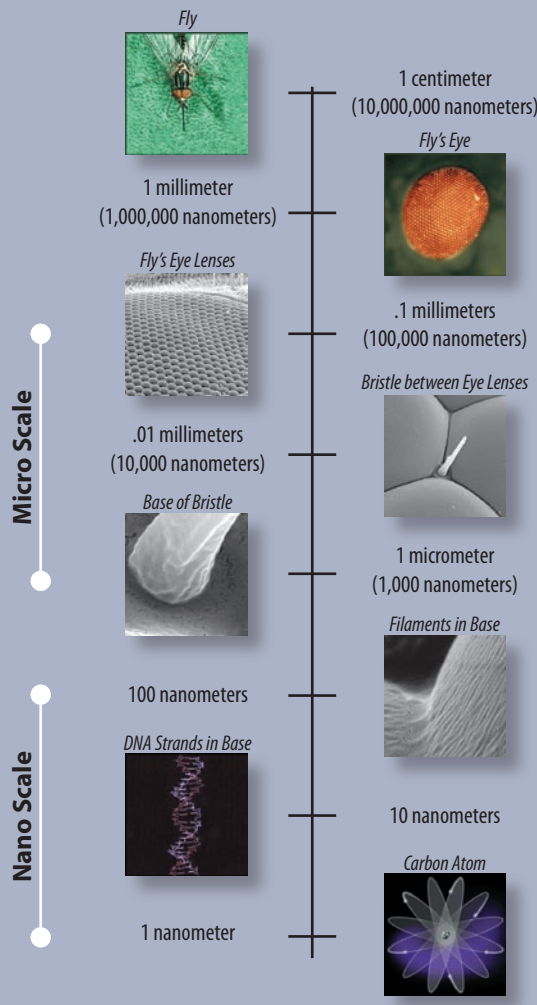
Nanotechnology will have a significant impact on virtually every commercial sector. Unlike a standalone industry, however, nanotechnology is an enabling technology. It will drive the creation of entirely new industries. But equally as important, it will be critical to making a wide variety of existing industries better and more competitive in our rapidly globalizing world.

Companies in the life science, energy, automotive, textile, agriculture, and information technology sectors are already using nanotechnology to enhance their existing products—as well as to create entirely new ones. Nanotechnology is already a part of everyday products such as sunscreens, golf clubs, clothing, and cell phones. Within the next decade, it will be commonplace in drug therapies, water filters, fuel cells, power lines, computers, and a wide range of other applications.

The impacts of nanotechnology on the global economy will be profound and widespread. States that concentrate on developing nanotechnology in the context of a broad technology-based economic agenda will be well positioned to compete in the global economy. Those that do not will fall behind.

Nanotechnology in Perspective

Nanotechnology refers to research and technology development on the scale of approximately 1-100 nanometers. This is the smallest scale at which we can meaningfully study and manipulate matter. One nanometer is the size of a group of atoms, as shown at the bottom of the spectrum below.



Source: Powers of Ten, CERN.

Nanotechnology Defined

"Nano" means *one-billionth*. Thus nanotechnology draws its name from the scale at which the technology operates—at nanometers, or 1/1,000,000,000 (one one-billionth) of a meter. This almost inconceivably small dimension is 100,000 times thinner than a strand of human hair. Individual atoms, the fundamental building blocks of all matter, are of this size. For example, the DNA molecule, the blueprint of life and the basis of the genome, is a twisted double-strand of molecules approximately two nanometers (2nm) across.

"As you go about making America competitive in the future, nanotechnology is the future."

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Phillip J. Bond, Under-Secretary of Commerce for Technology, United States Department of Commerce, **November 2003.**

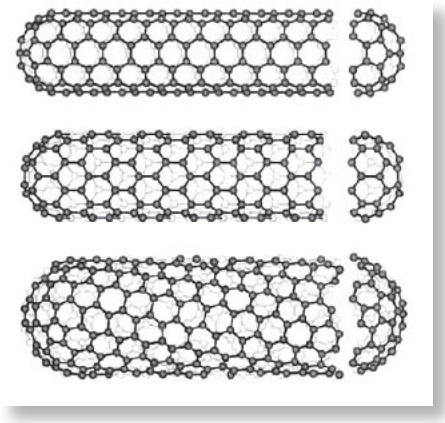
Using nanotechnology, researchers and manufacturers can fabricate materials literally molecule-by-molecule. They can "custom-design" ultra-precise new material structures, devices, and systems with unique and often remarkable properties—such as materials with vastly increased strength or the ability to change shape on demand.[1]

Nanotechnology is a basic research and development technology, a materials science, and an advanced manufacturing discipline. Amazingly, virtually all of science and engineering—in fields ranging from biology and chemistry to physics and mechanics—have independently converged to work at the nanoscale. Together, they are giving us unprecedented understanding and control of elemental phenomena such as intracellular processes, chemical reactions, and quantum mechanics—the fundamental building blocks of all physical structures.

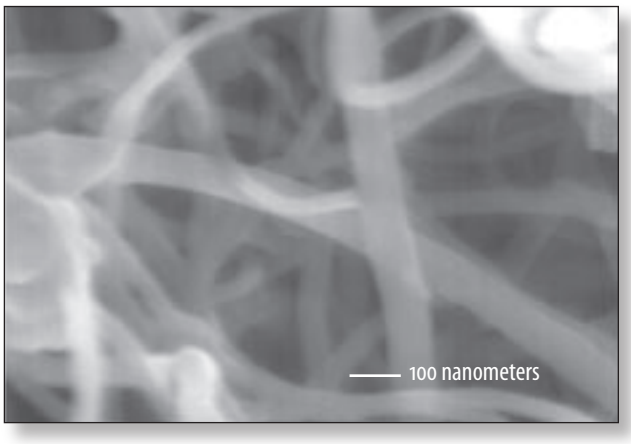
Nanotechnology will become a standard, integral, and seamless part of manufacturing and research processes around the world, much like microtechnology is today. As consumers continue to demand and expect products that are faster, less expensive, more powerful, more efficient, smarter, and better for the environment, exploiting the power of nanotechnology will become imperative across the entire product lifecycle of globally competitive companies.

The ability to build with atomic precision has already led to the development of materials with new and improved magnetic, tensile, thermal, and electrical properties. One such material is the carbon nanotube—carbon atoms assembled into a tube-like structure that is 60 times more rigid than high-grade steel, six times lighter than steel, 10 times stiffer than conventional graphite, and 50,000 times thinner than a human hair. Carbon nanotubes can transmit electricity without resistance, making them a likely ingredient in the next generation of electronics—nanoelectronics—that will dramatically increase the power and shrink the size of computers and other electronic devices.

A number of startup companies—including several in North Carolina—have already formed to produce commercial nanotubes or nanotube-based products. Other companies using nanotechnology in innovative ways are just around the corner.



Computer-generated schematic of three types of carbon nanotubes. The diameter of the nanotube in the center of the picture equals approximately 2 nanometers. Illustration courtesy R. Smalley Group, Rice University.



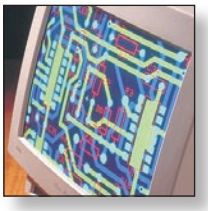
Bundle of multi-wall nanotubes via scanning electron microscopy. The bar at the bottom of the picture represents 100 nanometers. Image courtesy Russell E. Gorga, North Carolina State University.

[1] National Nanotechnology Initiative.

New Jobs, New Companies, and the Nanotechnology Economy

Clusters critical to North Carolina's economy will benefit greatly from developments in nanotechnology. Consider the following nanotechnology applications already in use or under development:[2]

Textiles: Using nanotechnology, companies are producing fabrics that have permanent stain-repellant properties and that retain their original look and feel. "Smart" fabrics are being developed that can monitor vital signs and even change their physical properties according to surrounding conditions.

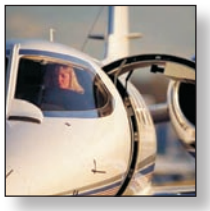


Electronics: The latest display technology—based upon Organic Light Emitting Diodes (OLEDs)—for laptop computers, cell phones, digital cameras, and other uses are made of nanostructured polymer films. OLED screens have brighter images, are lighter weight, consume less power, and have wider viewing angles than traditional displays.

Medicine: Using nanotechnology, researchers are developing advanced drug delivery systems, including implantable devices that automatically administer drugs and sense drug levels. Also under development are medical diagnostic tools, such as cancer tagging mechanisms and labs-on-a-chip that provide real-time diagnostics.

Environment: Because of their small size, filters made of nanoparticles have excellent properties for liquid filtration. Several products, using materials porous on the nanoscale, are now available for large-scale water purification that can take out the tiniest bacteria, particulates and viruses from water systems.

Energy: The oil industry relies on nanoscale catalysts for refining petroleum, while the automobile industry is saving large sums of money by using nanosized platinum particles in its catalytic converters. Greater reactivity of these nanosized agents dramatically reduces the quantity of catalytic materials necessary to produce desired results. Nanostructured photovoltaics are being used to create vastly cheaper and more efficient solar cells.



Machinery: Nanoparticles have been used to create wear-resistant coatings for use on U.S. Navy ships. The Department of Defense estimates that use of the coatings will result in a $20 million reduction in maintenance costs over 10 years. The coatings will lead to commercial applications that can extend the lifetime of moving parts in everything from personal cars to heavy industrial machinery.

[2] National Nanotechnology Initiative; NanoBusiness Alliance.

The Global Race for Nanotechnology Leadership:

North Carolina Can Compete

Researchers have been working at the nanoscale for over 40 years. Spending on research and development (R&D) and commercial activity in nanotechnology has increased dramatically only recently, however, as the promise of these technologies has become clear and achievable. Worldwide investment in nanotechnology is now measured in billions of dollars, and the global race is now in high gear.

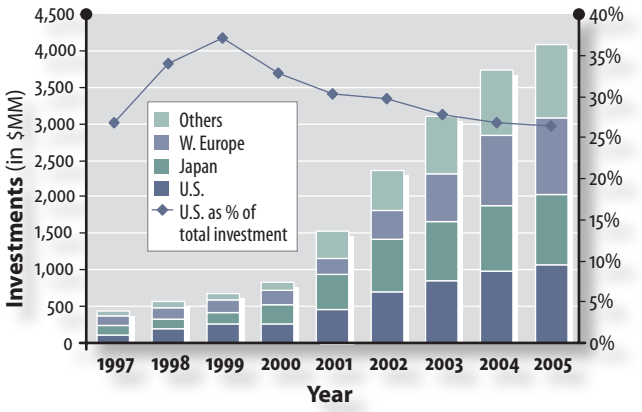
Worldwide

Since 1997, worldwide government funding for nanotechnology research and development (R&D) has increased more than five-fold, exceeding $4 billion in 2004. In that same year, total spending on nanotechnology R&D by governments, companies, and venture capitalists worldwide was more than $8.6 billion. Today, virtually every country that provides significant support for R&D in the sciences has developed a nanotechnology strategy. Asian countries, including Japan, China, and South Korea, as well as several European countries, have made international nanotechnology leadership a *strategic national priority*.

Another measure of the growth of nanotechnology—and one that illustrates its rising commercial potential—is the number of nanotechnology patents issued. Between 1997 and 2003, the total number of patents worldwide increased more than three-fold, exceeding more than 1,500 patents in 2003. Over the same period, patents issued in the U.S. accounted for over 60 percent the worldwide total; they were also the most highly referenced, pointing to strong U.S. leadership on the commercialization front.[3] Overall and in order, the U.S., Japan, Germany, Canada, and France issued the highest number of nanotechnology-related patents in 2003.

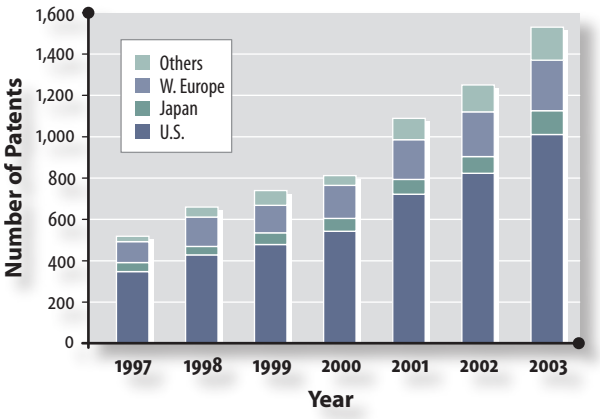
More than 1,500 nanotechnology companies are now active worldwide, including approximately 1,100 in the United States. About 20,000 people are now directly working with nanotechnologies daily, and in the next 10-15 years, estimates are that nanotechnology will open a $1 trillion market and grow the global workforce by at least 2 million people.[4]

Government Nanotechnology R&D Investments, 1997-2004



Source: M. Roco, National Science Foundation.

Number of Nanotechnology-Related Patents, 1997-2003



Source: Huang, Chen, Chen, and Roco 2004.

[3] Huang, Chen, Chen, and Roco 2004. Search of patent title, abstract, and claims.

[4] Lux Research; President's Council of Advisors on Science and Technology.

"The 21st Century Nanotechnology Research and Development Act makes nanotechnology the highest priority funded science and technology effort since the space race."

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F. Mark Modzelewski, Executive Director NanoBusiness Alliance, December 2003.

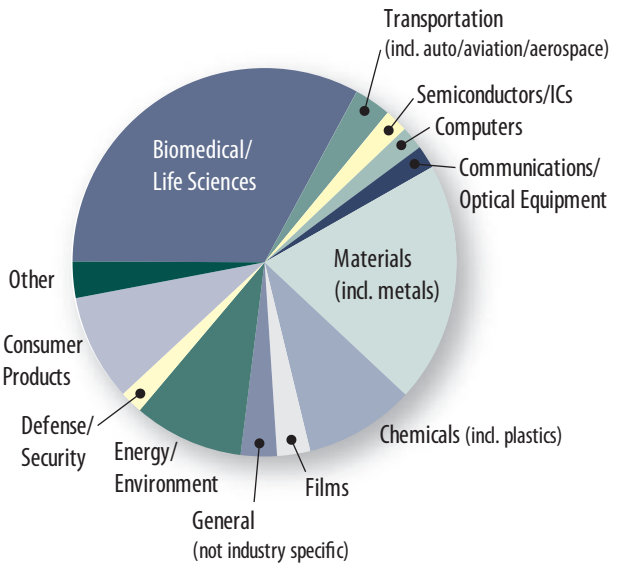
United States

In December 2003, President George Bush signed into law the **21st Century Nanotechnology Research and Development Act**, which authorized $3.7 billion in federal nanotech-related R&D spending over four years, starting in FY 2005. Receiving broad bipartisan support in the House and Senate, the Act puts into law the programs and activities supported by the National Nanotechnology Initiative (NNI), one of the President's highest multi-agency R&D priorities.

U.S. federal investment in nanotechnology R&D has increased from $116 million in fiscal year 1997 to $982 million in fiscal year 2005, a seven-fold increase. Private industry invests at least as much as the government, and nearly every Fortune 500 company involved in manufacturing has an active nanotechnology initiative.

The States themselves are also active. At least twenty states and regions have organized nanotechnology initiatives.

Target Industries for Companies Involved in R&D, Manufacture, Sale, and Use of Nanotechnology in 2004 (Total Number of Companies = 599)



Source: EmTech Research, 2005.

Widespread commercial adoption of nanotechnology is growing rapidly. Early commercial applications of nanotechnology have focused on improving existing products in the cosmetic, coating, sensor, and display markets.

Examples of near-, mid- and long-term areas in which nanotechnology is expected to have a high commercial impact include:[5]

Near-term (1-5 years)

- Improved chemical and biological sensors
- Point-of-care medical diagnostic devices
- Long-lasting rechargeable batteries

Mid-term (5-10 years)

- New targeted drug therapies
- Enhanced medical imaging
- High-efficiency, cost-effective solar cells

Long-term (20+ years)

- New molecular electronics
- New all-optical information processing
- New neural prosthetics for numerous medical conditions

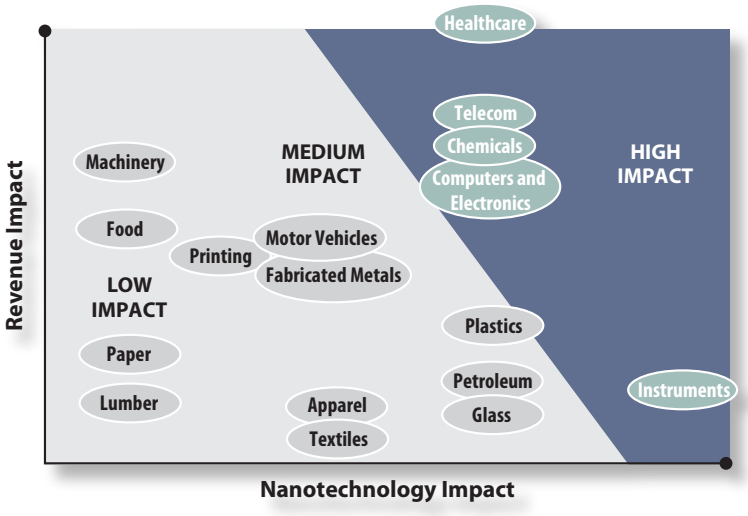
North Carolina

Building upon a long tradition of research excellence in science and technology, North Carolina currently ranks among the country's leading performers in the quality and breadth of its nanotechnology R&D base. While the level of commercial activity across the state in nanotechnology is currently modest, nanotechnology-based startups are forming and growing, and the state shows strength in sectors predicted to benefit greatly from nanotechnology. This is a situation similar in many ways to that which existed in the state at the time of the creation of the North Carolina Biotechnology Center.

In fact, North Carolina has created a tremendous economic engine in biotechnology because it recognized the power of coordinated public and private economic-development action around an emerging technology sector. As such, North Carolina has benefited significantly from its early and sustained investments in biotechnology, and it can reap similar benefits from developing the emerging nanotechnology economy across the state. As important, however, is a second imperative: strategic investments in nanotechnology are required to

[5] National Nanotechnology Advisory Panel.

Nanotechnology's Probable Business Impact in 2007



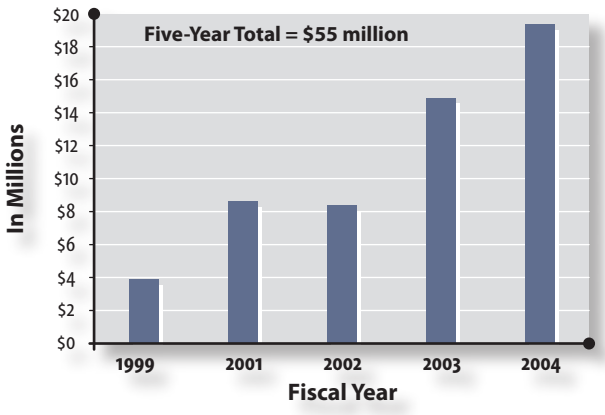
Source: Rohit et al. 2003.

preserve our competitive advantage in our core clusters like biotechnology, because much of the forthcoming innovation in biotechnology will occur at the nanoscale, as information technologies, biotechnology, and materials technologies converge. North Carolina can compete and lead in all of these areas if it invests wisely and strategically, as it has in fields such as biotechnology.

Innovation Capacity

The best way to assess the innovation capacity—the ability to generate new ideas, new technologies, and product innovations—of a state is to measure the amount of funding devoted to R&D (both inside the universities as well as in the commercial sector) across the state.

Nanotechnology Sponsored Program Awards to North Carolina Universities



Sources: University of North Carolina System (all 16 institutions), Duke University, and Wake Forest University.

In 2003, North Carolina ranked 8th in the nation in R&D funding from the National Nanotechnology Initiative. Between 2001 and 2003, organizations within the state received 85 nanoscale science R&D awards from the federal government, placing the state in the top 10 in national rankings.[6] Furthermore, between 1991 and 1999, the Research Triangle placed in the top ten on national assessments of regions with respect to publication rates in nanotechnology-related fields.[7]

Within the state, public and private universities received the largest share of federal nanotechnology-related program funding over this period.[8] Between 1999 and 2004, nanotechnology-related sponsored program awards to North Carolina universities increased five-fold.[9] At least nine universities across the state received funding awards from more than 10 federal agencies and nearly 40 private companies and foundations.[10]

"In past years North Carolina showed it had the right stuff . . . it appears to be building all the critical pieces—its universities, businesses, private funding—simultaneously for a slow but steady rise."

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Small Times Media, March 2005.

Examples of nanotechnology-related R&D programs—spanning disciplines such as Physics, Engineering, Medicine, Chemistry and Education—at North Carolina universities include:

- **Multifunctional Materials, Structures, and Sensors for Defense and Homeland Security**
- **Investigating Viruses with Touch: Nanotechnology and Science Inquiry**
- **Nanotechnology for Cardiovascular Systems**
- **Nanosecond Pulsed Laser for Human Surgery**

[6] Roco 2004, 2003.
[7] Zucker and Darby 2005.
[8] University activities supported by external funding.
[9] Conservative estimate; does not include private universities other than Duke and Wake Forest, and includes only those sponsored programs having "nano" in their title or abstract.
[10] The nine universities are Duke, ECU, NC A&T, NCCU, NCSU, UNCC, UNC-CH, UNCW, and Wake Forest.

- **Water Soluble Gold Nanoparticles: Toward a New Type of Chemical Sensor**

North Carolina universities are also home to over 27 organized R&D centers and institutes focusing on nanotechnology. These units, established only after a collection of faculty have secured long-term funding commitments from external agencies, have a strong positive economic development impact on the state by providing job opportunities, supplying technical assistance and training, fostering community development, and enhancing the transfer of new technologies to businesses.

University R&D activities are producing new knowledge and products that will help build North Carolina's 21st century economy, enhance the quality of life, protect the environment, and promote national security, both at home and abroad. The key to realizing those rewards, however, lies in the ability of North Carolina businesses to utilize the basic nanotechnology research that is largely resident in the universities.

Commercial Opportunities

Consistent with national and international trends, levels of nanotechnology-related commercial activity in

"State and local governments can play a crucial role in helping to promote commercialization of federally funded nanotechnology research."

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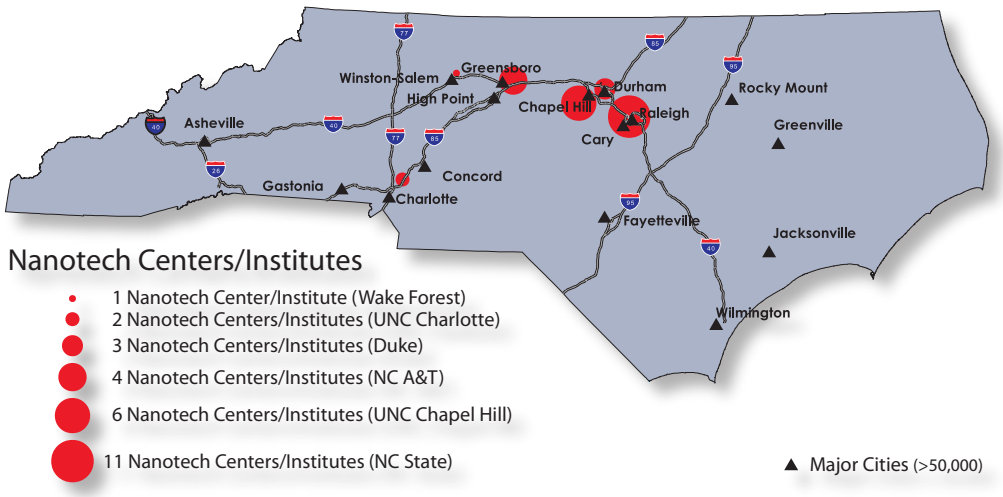
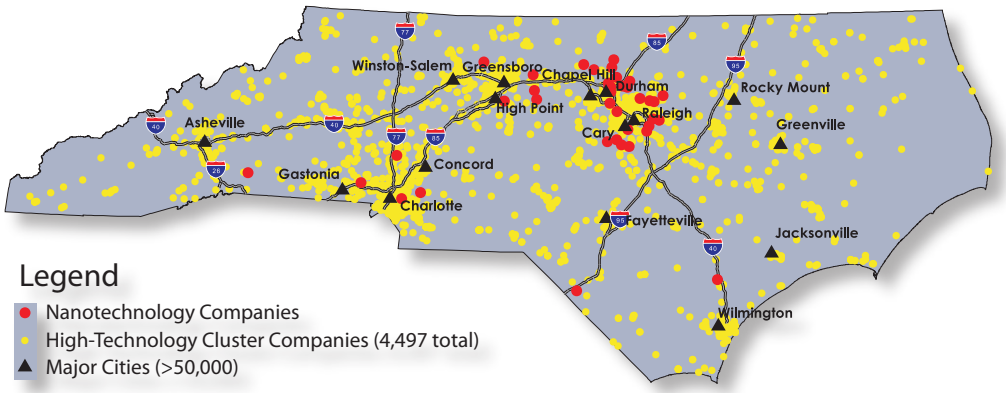
The National Nanotechnology Initiative at Five Years, March 2005.

University Centers/Institutes Focusing on Nanotechnology



Nanotechnology Companies and High-Technology Companies[11]



[11] Locations of nanotechnology companies and university centers/institutes were identified and verified by staff of the North Carolina Board of Science and Technology. Locations of high-technology companies were identified by searching Harris InfoSource for all companies that are classified into one or more of the core U.S. Technology Clusters in North Carolina. Maps courtesy of the Division of Policy, Research, and Strategic Planning, North Carolina Department of Commerce.

Core U.S. Technology Clusters in North Carolina[12]

Cluster	Jobs (2002)	Average Wages (2002)	Real Wage Growth (1989-2002)
Information Technology/Instruments	84,113	$ 71,639	59.7%
Communication Services and Software	69,768	$ 61,917	54.5%
Chemicals/Plastics	48,789	$ 45,038	12.8%
Motor Vehicle Manufacturing	37,078	$ 44,661	28.6%
Pharmaceuticals and Medical Technologies	36,120	$ 59,387	54.4%
Industrial Machinery	16,210	$ 48,870	20.6%
Aerospace	4,146	$ 50,091	31.2%
Total/Weighted Average	**296,224**	**$58,549**	

North Carolina are growing rapidly. The state has at least 40 companies actively working with nanotechnology; these companies range from small, relatively new start-ups using nanotechnology as a core part of their manufacturing processes, to large, well-established firms that use nanotechnology in their existing operations. Most of these companies are located in central regions of the state near universities with active nanotechnology research programs; however, this cluster pattern will diffuse across the state as nanotechnology becomes a common and essential component of industry.

Initially, certain high-technology companies and clusters will benefit most from developments in nanotechnology. Several of these specific clusters have developed in North Carolina, and they include more than 4,400 companies employing nearly 300,000 workers at an average salary of nearly $60,000.[12]

Competition around the commercial adoption of nanotechnology will continue to increase domestically and internationally. At this time, North Carolina's position as a research leader in nanotechnology is being aggressively challenged by other states (e.g., Washington, California, Virginia, Georgia, New Mexico, and others) and nations.

This competition will have economic impacts on our state. Nanotechnology will be a critical feature of industries that North Carolina's Department of Commerce has targeted to grow in coming years,[13] including:

- Advanced Manufacturing
- Advanced Materials (including chemicals, plastics and nanotechnology)
- Biotechnology and Pharmacology
- Computing, Software, and the Internet
- Design and Arts
- Logistics and Distribution

To successfully target and grow these clusters, the state and its regions will need to incorporate nanotechnology into their economic development strategies explicitly. This will require that they focus on increasing the ability to innovate; increasing the levels of collaboration between companies and R&D centers; developing a well-educated and trained workforce; providing a supportive public and political policy environment statewide; and, diversifying technology cluster portfolios by explicitly including nanotechnology.

"Economic development groups need to examine their region's micro and nanotechnology activity closely because states taking an early lead will reap the economic rewards over the next five to 10 years. Because micro and nanotechnology are platforms that are utilized in almost all industries, states can capitalize on the sectors they have already worked hard to build."

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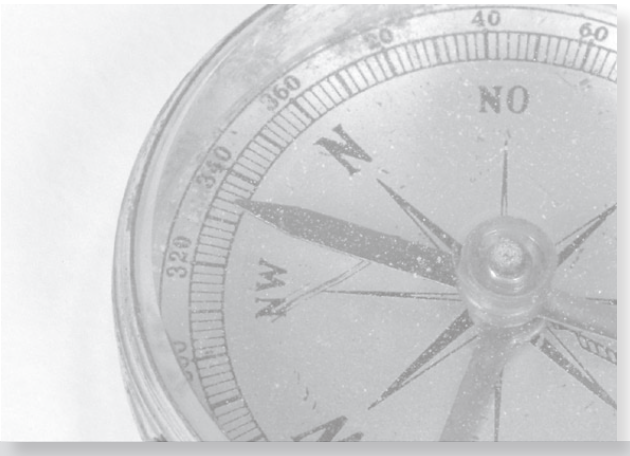
Patti Glaza,
Chief Executive Officer,
Small Times Media,
March 2005

[12] NC Employment Security Commission; US Bureau of Labor Statistics.

[13] Papas Consulting Group.



The Global Race for Nanotechnology Leadership:

North Carolina Can Rise to the Challenge

North Carolina's future economic success will depend on how well we respond to the challenges of an evolving technology economy, and one that increasingly works at the nanoscale. In response to the challenges and opportunities presented by nanotechnology, the Department of Commerce, the State Science and Technology Advisor, and the North Carolina Board of Science and Technology formed the **Governor's Task Force on Nanotechnology and North Carolina's Economy** in the spring of 2005.

Composed of 28 members from key sectors across the state, the Task Force's charge was to:

- ***Develop a roadmap for an aggressive and coordinated initiative to advance successful nanotechnology-based economic development and high-wage employment across North Carolina.***

The Task Force responded with an outline for a two-pronged approach to developing the nanotechnology economy in North Carolina by focusing on:

1. **Strengthening North Carolina's core economic development approach to advancing technology-based economic development, and**

2. **Strengthening the building blocks within that core approach that focus specifically on nanotechnology,**

with the goal of outlining a process to create the widest variety of positive outcomes—**better-educated workers, more jobs, higher wage levels, more competitive businesses, and higher standards of living.**

This agenda is nothing short of building a roadmap for a critical transformation in our economy, the success of which will depends heavily on having the appropriate conditions in place—funding, facilities, equipment, personnel, policies, cultures, and goals—at each link in the economic chain. Public understanding and public leadership must also play key roles in this effort.

Public sector institutions have the ability to articulate a pubic agenda and then act as a catalyst. Government's role as a convenor of different interests helps to build bridges across disciplines and between upstream and downstream activities.

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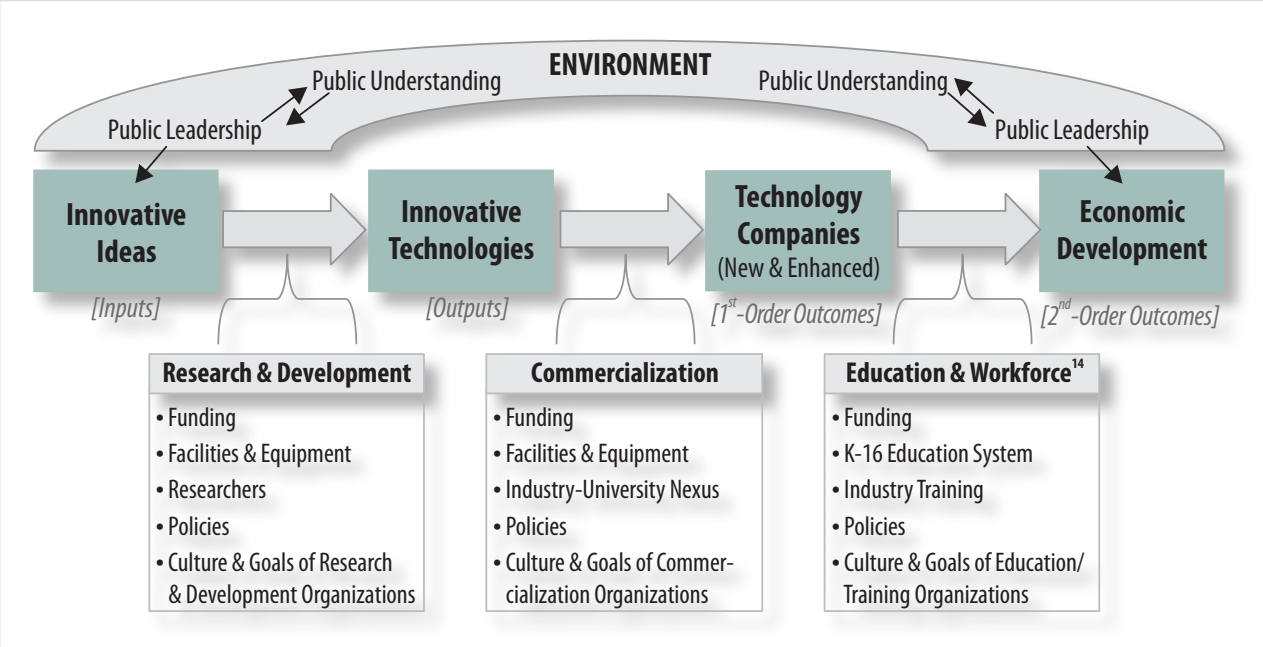
New Foundations for Growth: The U.S. Innovation System Today and Tomorrow, RAND Corporation, January 2002

To facilitate its efforts, the Nanotechnology Task Force formed three working groups:

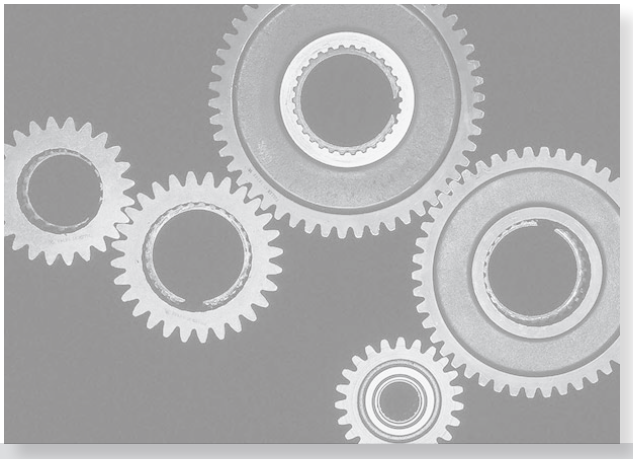
- Research and Development
- Commercialization
- Education and Workforce Development

Drawing upon a variety of statistical indicators, policy reports, surveys of nanotechnology companies, and best practices in other states, each working group conducted detailed "state of the State" assessments of North Carolina's technology economy, which yielded findings and strategic imperatives for future action. These are outlined on the following pages, and are organized according to the technology-based economic development flowchart shown on the next page. Together, they provide a roadmap for strengthening the technology-based economy and nanotechnology in North Carolina.

Technology-Based Economic Development Approach



[14] Education and Workforce are key conditions at all stages of the approach. However, for the purposes of this model, their most critical role is in fostering economic development by providing an educated workforce for technology companies.



IMPERATIVES:

Enhancing North Carolina's Technology Economy

Recognizing that competitive states do not stand still, **the Task Force deems the 12 actions below imperative for mobilizing and equipping North Carolina to grow and develop its statewide technology economy**.

These actions are intended to serve as a substantive "front-burner" framework for critical evaluation and future development by policymakers, state agencies, and organizations. In combination, they serve to engage as many individuals and organizations as possible around the goal of further strengthening North Carolina's core approach to advancing its economy through the use of technology-based economic development.

1. **Establish a "Technology and the Economy" information agenda and strategy for North Carolina that builds upon the relationships between nanotechnology, biotechnology, information technology and other emerging fields.** State government must develop an agenda and strategy for appropriate programs targeted at educating the public and policy leaders on the nature and importance of technology-based economies, emphasizing best practices and key elements that produce the widest prosperity and economic benefit.

2. **Strengthen the Science and Technology Division of the Department of Commerce to provide leadership, direction, coordination, and assistance to the state's science and technology-based economic development efforts.** The Division's responsibilities, directed by the Science Advisor, should include, but not be limited to, programs and advocacy for:

    - Updating and extending statewide strategies to make the best use of our technological resources and help maintain a healthy industrial base in North Carolina;
    - Increasing external R&D funding to North Carolina's colleges, community colleges, universities, and industry;
    - Enhancing the effectiveness of R&D programs and accelerating the transfer of technology;
    - Supporting North Carolina's industrial base through a responsive and effective technology development and deployment system;
    - Increasing the rate of investment in innovative technology and industrial modernization;
    - Increasing the science and technology awareness and literacy of North Carolina citizens and policy makers;
    - Evaluating technology-based economic performance in the state and its regions to provide policymakers with improved information.

3. **Strengthen alignment of the committee and staff structure of the General Assembly with the needs of the 21st century economy.** The General Assembly should establish one or more standing committees explicitly designed to consider issues related to science, technology, technology-based economic development, and the knowledge economy. In recent years, many state legislatures have established committees focusing on the challenges posed by rapid economic change. For example, the California State Legislature created the

Joint Committee to Prepare California for the 21st Century, and Indiana's House of Representatives recently created a *Committee on Technology Research and Development*, and its Senate created a *Committee on Economic Development and Technology*. These committees are organized to focus legislative attention on the development of a robust statewide technology economy.

4. **More closely align university R&D with the needs of industry.** Policy makers and university administrators must provide competitive faculty salaries and graduate student stipends, invest in state-of-the art R&D facilities and equipment, increase opportunities and incentives for faculty collaboration with other organizations, and review and revise promotion and tenure guidelines to reflect and incorporate the increasing importance of collaboration, business development, entrepreneurship, and scholarly community assistance.

5. **Align university strengths with the needs of regional economic clusters and develop strategies to address those needs**. Universities and regional economic development organizations should complete regional resource analyses across the state to understand regional strengths and opportunities and align university expertise with the needs of regional economic development clusters.

6. **Enhance the technology modernization of existing industry and increase the amount of industry R&D performed in North Carolina.** To improve and modernize the competitive position of the state's industry, policy makers should consider and propose additional tax and incentive policies for R&D and modernization, expand the level of assistance available to small and medium firms, form regional alliances among industry, educational institutions, and government (see imperative 4 above), and insure greater predictability and certainty in the state regulatory environment.

7. **Establish a North Carolina Technology Investment Fund.** A fund should be established to serve as a flexible source of matching funds to attract new federal R&D centers to the state, leverage private funds, and help communities link industry needs with higher education centers and other service providers through business networks and other services. The fund would also be used to provide funding for state agencies and organizations to meet new needs of industry and to establish education and research consortia with industry clusters throughout the state.

8. **Aggressively encourage early-stage risk capital formation.** State policy makers and financial institutions must increase and enhance the institutional and informal mechanisms and networks that direct existing capital assets to innovative technologies and entrepreneurial activities. Examples include tax incentives, expanded angel networks, investment pools, and state and private seed capital funds. In addition, a review of the state's securities laws must be undertaken to ensure they are not restricting the ability to raise capital in-state.

9. **Explicitly link the state's incubator efforts with other technology development and deployment organizations.** The private sector and universities must be encouraged to increase business plan and marketing assistance available to entrepreneurs. The state's business incubators must be linked with the managerial and technological resources the state is supporting through other organizations such as the Small Business and Technology Development Center and the Manufacturing Extension Program.

10. **Better align technology transfer offices in higher education institutions to emphasize company and job creation over licensing.**

11. **Enhance the quality of K–12 science, technology, engineering and math (STEM) education across the state, to include better coordination of K–12 STEM initiatives with public postsecondary institutions.**

12. **Develop an explicit North Carolina technology workforce agenda and strategy to include enhancing existing workforce technology-oriented training structures and fast-tracking the development of critically needed pools of technology-trained workers.** North Carolina's companies and educators must develop an agenda and strategy to provide the state's citizens with the skill and knowledge needed to succeed in the 21st century economy.

STATE OF THE STATE:

North Carolina's Nanotechnology Economy

All disruptive technologies evolve in a lifecycle, characterized first by a phase of early adoption, then by phases of growth and maturation, and then ending with a phase of decline and replacement. Different types of public policy support are appropriate at each phase. Nanotechnology is currently in an early adoption phase, as reflected in the current state of R&D, commercial activity, education and workforce development, and public understanding and leadership related to it.

"Too much of North Carolina's stellar research languishes in the labs, but that could change."

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Annual State-by-State Ranking of Small Tech
Small Times Media,
April 2004

Research and Development

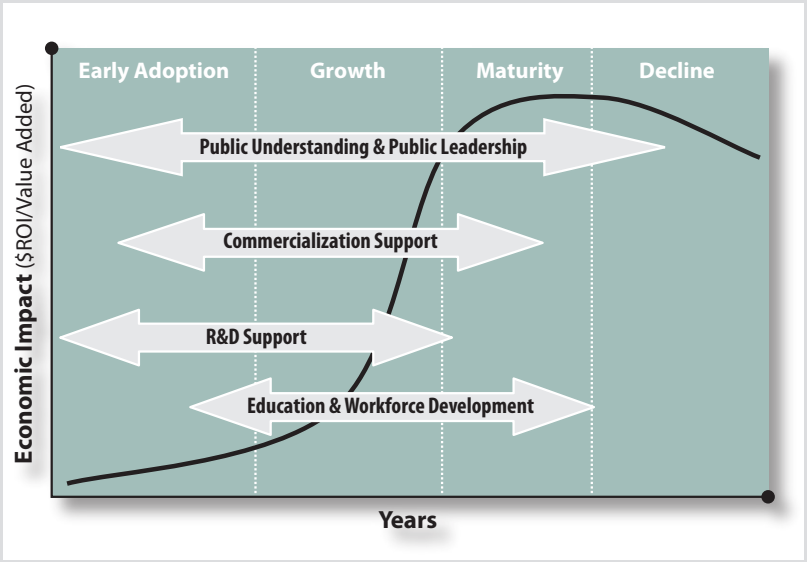
In North Carolina, basic research is the dominant form of nanotechnology-related activity. North Carolina currently ranks in the top 10 nationally in levels of nanotechnology research funding received. Consistent with broader national patterns, the vast majority of this research is conducted in the state's universities, which are the largest repositories of the facilities, equipment, and personnel needed to support it. However, businesses in biotechnology, information technology, and micro-electronics, among others, are beginning to build significant nanotechnology-related R&D programs external to and often in collaboration with the universities.

The dominance of universities in R&D will lessen as the application of nanotechnology becomes more ubiquitous and industries incorporate nanotechnologies into their products and processes. However, universities will continue to house the largest research programs in this area for the immediate future. Most of these efforts will track federal funding and will therefore be focused on basic research rather than commercial application of the technology. North Carolina companies using nanotechnology have expressed a desire to work more closely with universities that have nanotechnology-related facilities and equipment and faculty conducting research related to nanotechnology.

Commercialization

Innovative nanotechnology applications are just beginning to emerge as—and in—commercial products, and North Carolina has a considerable capability to create nanotechnology innovations ready for commercialization. Realizing the commercial promise of nanotechnology will be particularly challenging, however, because the technology is inherently interdisciplinary and complex and the equipment needed to develop nanotechnology applications is often very expensive. Linking nanotechnology capabilities to nanotechnology opportunities requires a wide

Technology Lifecycle



"The widespread application of nanotechnology in coming decades means that the United States will need trained workers in many fields, including future researchers in every technical discipline, skilled technicians or jobs in various industries, and teachers at all levels."

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The National Nanotechnology Initiative at Five Years, March 2005

knowledge of innovations across many fields. An opportunity exists for the state to improve its organization, approach, and level of coordination for encouraging entrepreneurial development of nanotechnology businesses.

The majority of nanotechnology companies in North Carolina are new startups, but not all nanotechnology is new or of benefit only to new companies. Existing companies are also beginning to incorporate nanotechnology into their operations.

Education and Workforce

Education and workforce development programs focused on nanotechnology are beginning to emerge, and North Carolina is one of the leaders on this front. For example, a joint project between UNC-Chapel Hill and North Carolina State University was one of the first in the nation to introduce middle and high school students to experiments using atomic force microscopy, a fundamental measurement technique at the nanoscale. In addition, the National Science Foundation recently named the Museum of Life and Science in Durham as a partner in a first-of-its-kind $20 MM nationwide network of museums and research centers featuring nanotechnology. In this role, the museum will collaborate with local universities as well as corporate partners to develop exhibits and programming specifically targeting the workforce. Education and workforce development programs along these lines are growing, and nationally nanotechnology is being broadly integrated throughout science curricula and public programs.

At the postsecondary level, nanotechnology is increasingly being integrated into coursework across a variety of fields such as chemistry, physics, biology, and engineering. However, nationally only a few degree programs specifically in the field have been approved. Although North Carolina universities currently offer no degree programs in nanotechnology explicitly, efforts to introduce these are underway; and in the spring of 2005, Forsyth Technical Community College became one of the first colleges in the country to offer an Associate's degree in nanotechnology.

Students conducting nanoscale experiments with viruses under an atomic force microscope. Image courtesy of Gail Jones, Nanoscale Science Education Research Group, North Carolina State University.

Public Understanding and Public Leadership

The requirement that the public understand the practical and societal impacts of nanotechnology mirrors that of science and technology in general. Although findings pertaining specifically to North Carolina are not available, a 2004 national survey found that Americans hold a generally positive view of nanotechnology and believe the potential benefits outweigh the potential risks. However, more than 80 percent of those surveyed indicated they had heard "little" or "nothing" about nanotechnology, and most could not correctly answer factual questions about it. In addition, 60 percent of survey respondents indicated they had "not much trust" that business leaders would minimize potential risks to humans.[15]

North Carolina companies using nanotechnology feel strongly that public understanding of and public leadership support for nanotechnology is critical for successful development of nanotechnology businesses in the state. To date, however, nanotechnology has received limited attention by the public, policy makers, and the media in North Carolina.

[15] Cobb and Macoubrie 2004.

IMPERATIVES:

Improving and Developing North Carolina's Nanotechnology Economy

To strengthen North Carolina's nanotechnology economy we must build upon our core strategy to advance the state's technology-based economy overall, as outlined in the imperatives of the previous section. To those we must add building blocks focused specifically on nanotechnology.

The Task force deems the 10 actions below as key elements of a framework directed toward mobilizing and equipping North Carolina to advance the state's nanotechnology economy. Nanotechnology is an emerging economic cluster in North Carolina with significant potential to contribute to the state's economy over the coming decades. Support for nanotechnology commercialization, education, and workforce development must be structured to ensure that basic nanotechnology research being conducted today in our laboratories is converted to new commercial products, new companies and jobs—and that we prepare the state's workforce to participate and benefit from the explosive growth of the worldwide nanotechnology economy.

1. **Establish a North Carolina Nanotechnology Alliance.** An alliance of representatives from the state's academic, industry, government, and non-profit sectors is critical to provide coordination and assistance to the state's nanotechnology efforts. It must work with the Department of Commerce and partners throughout the state to:

   - Increase federal nanotechnology-related research funding to North Carolina's colleges, community colleges, universities, and industry;
   - Facilitate the sharing of nanotechnology-related facilities, equipment, and resources;
   - Increase the commercialization of nanotechnology-related intellectual property from universities and laboratories and the growth of nanotechnology-related entrepreneurial companies;
   - Promote statewide education, understanding, and leadership related to nanotechnology;
   - Interface with the U.S. National Nanotechnology Initiative and related nanotechnology efforts in other states.

2. **Through the development of multiple centers of nanotechnology excellence at North Carolina's universities, develop a diverse critical mass of nanotechnology research, development, education, and outreach expertise in the state.** The state's universities, both public and private, must be encouraged and facilitated to build on their core strengths in areas related to nanotechnology such as biology, engineering, chemistry, physics, textiles, medicine, computer science, education, and policy.

3. **Establish a not-for-profit nanotechnology "Imagineering" group staffed to identify emerging nanotechnology opportunities and execution agents.** The group would promote the growth of nanotechnology-based economic development in North Carolina by serving as a "point" organization for opportunities, as an advertiser for attracting investment funds, and as a facilitator of the working partnership. For targeted nanotechnology opportunities, the group would develop a portfolio prospectus describing specific technologies and the application advantages to be derived, and distributions to venture capitalists and potential investors to attract new seed ventures. The group also would solicit execution agents from a mix of small businesses, large businesses, and universities to execute in partnership.

4. **Create an information clearinghouse about nanotechnology in North Carolina.** An information clearinghouse, including a website and other resources, is essential for providing the following types of information about nanotechnology in North Carolina:

   - General information
   - News and events
   - Resources for researchers
   - Resources for industry
   - Resources for educators
   - Resource for students
   - Funding opportunities
   - Success stories and achievements

   The clearinghouse would provide general information of use to a broad audience as well specific information targeted to nanotechnology users in the state.

5. **Convene an annual North Carolina Symposium on Nanotechnology** to:

   - Broaden awareness—in-state, nationally, and internationally—regarding North Carolina's activities, expertise, and opportunities related to nanotechnology;

   - Provide a venue in which representatives from sectors across the state can network and exchange information and ideas related nanotechnology;

   - Serve as a launching point for collaborative relationships related to nanotechnology.

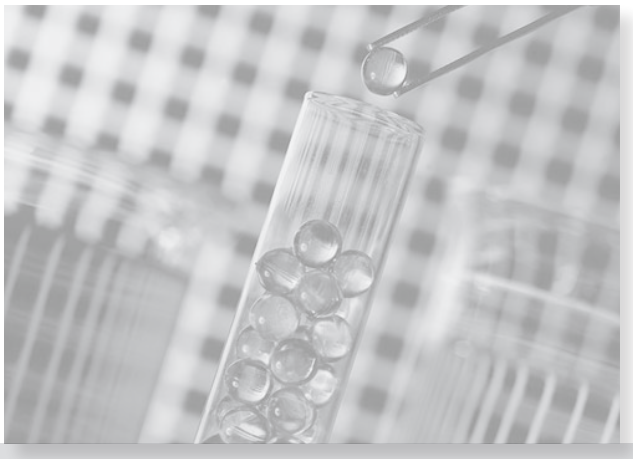
6. **Ensure that nanotechnology is explicitly considered in education and workforce development activities.** The North Carolina Department of Public Instruction, the North Carolina Community College System, and the state's colleges and universities must ensure that nanotechnology-related modules are explicitly included in science education curricula at all levels.

7. **Strengthen teacher knowledge of advances in nanoscale science.** The North Carolina Department of Public Instruction should collaborate with researchers and educators from North Carolina universities and science museums to offer professional development opportunities for teachers such as workshops on nanotechnology, summer internships in nanotechnology, and research labs. School-business partnerships should be formed to encourage researchers and scientists to visit schools and share new advancements in nanotechnology.

8. **Integrate information about nanotechnology into the North Carolina Biomanufacturing and Pharmaceutical Training Consortium.** Because much of the innovation in biotechnology in the future will occur at the nanoscale, strengthening the consortium's efforts and incorporating nanotechnology information into them will be critical to maintaining North Carolina's leadership in biotechnology. The consortium's efforts also provide an excellent venue for providing workers with the knowledge and skills necessary for working with nanotechnology across a variety of industries in addition to biotechnology.

9. **Explicitly integrate the environmental, ethical, health, legal, safety, and other societal implications of nanotechnology into the public discourse.** Researchers in North Carolina must be encouraged and be given resources to study these implications and report their findings widely to the public and state leadership. Scholars representing disciplines that might not have been previously engaged in nanotechnology-related research must be engaged, and these efforts must be integrated with conventional scientific and engineering research programs.

10. **Emphasize education of policy makers, the public, the business community, and the scientific community on issues related to nanotechnology.** A plan must be developed to increase statewide awareness and understanding of nanotechnology and its importance to society and the economy.



Methodology and Acknowledgements

When preparing this report, the authors drew upon ongoing interactions with private sector and non-profit representatives, researchers, and public sector officials involved in state-level nanotechnology economic development efforts from across the state and the nation.

The State Science and Technology Advisor, the Department of Commerce, and the Members of the North Carolina Board of Science and Technology wish to express their appreciation to the 28 members of the Task Force listed on the back cover of this report who participated in this effort. The authors also wish to acknowledge the assistance of Albert Link, Professor of Economics, University of North Carolina at Greensboro; Dawn Trembath, Research Associate, North Carolina Board of Science and Technology; and Doug Longman for their assistance with research and analysis related to this report. They also wish to thank Karen Becker for the design and layout of this report.

In addition, the authors conducted extensive secondary research when preparing this report. Research resources consulted included more than 40 reports, presentations, surveys, statistical indicators, databases, and websites produced by private and public organizations. Those resources are listed in the following section.

Finally, the authors surveyed 25 nanotechnology-related companies that have direct ties to North Carolina. The companies answered a total of 33 questions, both closed-ended and open ended, designed to learn more about the nature the companies' work with nanotechnology, the challenges and barriers they face, and their thoughts on how public policy and the private sector can help them grow and be competitive. The companies completing the survey are also listed in the final section.

Additional information used to inform the preparation of this report may be found at: www.ncnanotechnology.com.

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North Carolina Companies Surveyed for this Report

3rd Tech
Advanced Liquid Logic
Alnis BioSciences
Amphora Discovery Corporation
Asklêpios BioPharmaceutical
Centice
Coventor
Expression Analysis
Hydro-Flo
INI Power Systems
Liquidia Technologies
MEMSCAP
Nanotech Capital
NanotechLabs
Nano-Tex
Nextreme Thermal Solutions
Optotrack
QuarTek Corporation
RTI International
Semiconductor Research Corporation
SolarAMP
Tiny Technology
Umicore Semiconductor Processing
VF Corporation
Ziptronix

NORTH CAROLINA

the state of minds

Direct questions or comments to:

North Carolina Board of Science and Technology

North Carolina Department of Commerce

301 North Wilmington Street

1326 Mail Service Center

Raleigh, North Carolina 27699-1326

(Phone) 919-733-6500

(Fax) 919-733-8356

(E-mail) ncbst@nccommerce.com

(Web) www.ncscienceandtechnology.com

Members of the North Carolina Board of Science and Technology

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Governor of the State of North Carolina

The Honorable James T. Fain III
Secretary of Commerce

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Dean, College of Textiles,
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The Preiss Company

James C. Renick
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David P. Rizzo
Chief Executive Officer
NC IDEA

Paul J. Rizzo
Chairman,
Franklin Street Partners

Adam Saffer
Senior Vice President of Strategy,
RTI International

James Siedow
Vice Provost for Research,
Duke University

Mark Welker
Vice Provost for Research,
Wake Forest University

Jameson Wells
Attorney,
Wells & Daisley, P.A.

Members of the Governor's Task Force on Nanotechnology and North Carolina's Economy

Katherine Ansardi
President,
Sustainable North Carolina

Stephen Barry
President,
Alnis BioSciences, Inc.

Cynthia Bioteau
Vice President, Instructional Services,
Forsyth Technical Community College

Ken Buckingham
President,
Tiny Technology, Inc.

Rick Carlisle
Managing Director,
Dogwood Equity

David Carroll
Director, Center for Nanotechnology and Molecular Materials, Wake Forest University

Robert L. Clark
Thomas Lord Professor, Mechanical Engineering & Materials Science, Duke University

Bernadette Donovan-Merkert
Chair, Chemistry,
University of North Carolina at Charlotte

Paul L. Domanico
Vice President, Technology Development, U.S., GlaxoSmithKline

Monica Doss
President,
Council for Entrepreneurial Development

Kim Houchens
Chief Technology Officer,
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