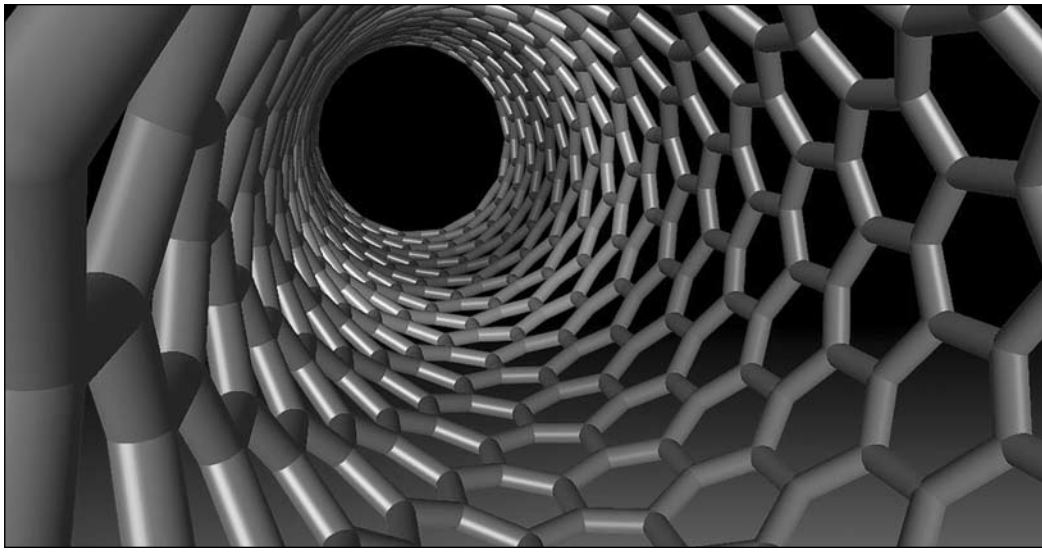
Nanobiotechnology in North Carolina



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FRONT COVER: A cluster of oysters, a model organism for studying toxicity of nanomaterials, in their natural habitat © Amy H. Ringwood, PhD *(left)* Computer-rendered view inside a carbon nanotube © Geoff Hutchison *(right)*

BACK COVER: Mounting carbon nanotube yarn samples for SEM imaging © Matt Brown

Acknowledgements

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Executive Summary

North Carolina is in a position to be profoundly affected by advances in nanobiotechnology, the field of nanotechnology specializing in creating novel nanoscale materials with desired biological, physical, and chemical properties. The state has a strong research base, with nearly $100 million in nanotechnology research already funded. Current research in nanobiotechnology portends tomorrow's advances in drug delivery, medical imaging and diagnostics, and even computer circuits.

Nanobiotechnology may have broad impacts across many sectors that are well-established in the state, including health care, textiles and electronics. Coordination of statewide research activities and development of infrastructure that serves industrial development will ensure a stronger role for North Carolina in nanotechnology, bolster existing industries, and bring new jobs to the state.

This report describes nanotechnology, nanobiotechnology and some of their applications, with a focus on North Carolina's leadership role in nanobiotechnology today and in the years to come.

What is nanotechnology?

Nanotechnology is the application of techniques to manipulate and study matter at the nanoscale—a world smaller than mere miniaturization, typically involving particles in the range of one billionth to 100 billionths of a meter in size. That's about 1/80,000 the thickness of a human hair. At this level, carefully arranged atoms and molecules in various materials have been found to have new and often unexpected properties. Drawing on the convergence of physics, chemistry, materials science, and engineering, nanotechnology allows for the creation of novel materials and products with desired properties such as increased strength or better conductivity. The ability to design nanomaterials is beginning to have broad impacts on many fields including chemistry, medicine, engineering, and computational science.

What is nanobiotechnology?

Nanobiotechnology represents the convergence of nanotechnology and biotechnology, yielding materials and products that use biological molecules in their construction or are designed to affect biological systems. Several applications of nanobiotechnology include:

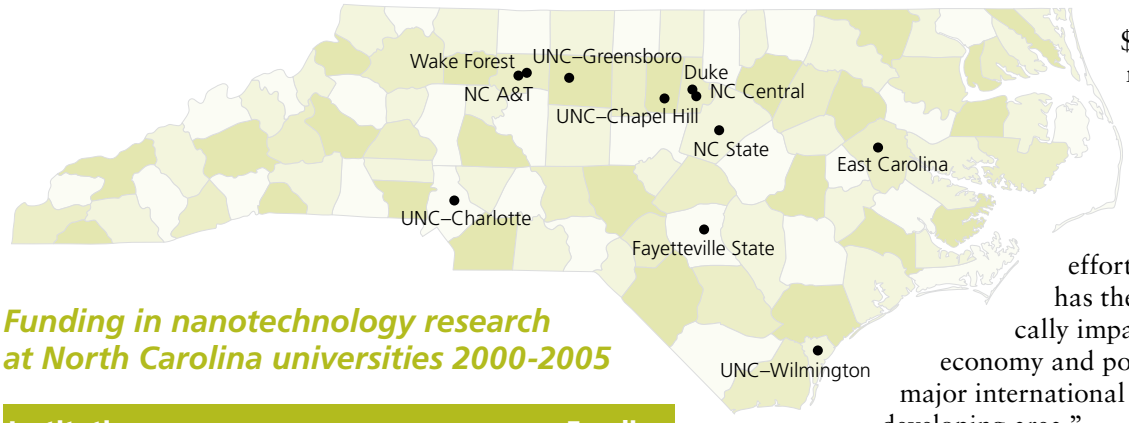
- engineering biomolecules for non-biological use, such as DNA-based computer circuits
- using nanotechnology tools such as medical diagnostic devices and medical imaging to study biology
- combining nanomaterials with biological systems for outcomes such as targeted drug therapies.

The state of nanobiotechnology in North Carolina

North Carolina is already taking part in cutting-edge nanobiotechnology research. The nanotechnology magazine Small Times in 2005 ranked the state among the top 10 regions in the country for nanotechnology research, citing strong academic nanotechnology programs and a high concentration of nanotech researchers and graduate students. The state has at least 27 university-based nanotechnology centers and institutes. The University of North Carolina-Chapel Hill was named one of the top 10 nanotechnology universities in the United States in a 2006 report by the Southern Growth Policies Board. North Carolina State University and UNC-Chapel Hill both ranked in the top 10 in industrial outreach in nanotechnology.

One measure of the strength of the university research programs is the level of nanotechnology funding. Between 1995 and 2004, the National Science Foundation awarded 139 nanotechnology grants to North Carolina researchers, totaling more $53 million, according to the Southern Growth Policies Board. NCSU, UNC-Chapel Hill and Duke University rank in the top 100 institutions nationwide based on the total funding awarded in nanotechnology.

In 2005, UNC-Chapel Hill received a $3.8 million grant from the National Cancer Institute to establish the Carolina Center of Cancer Nanotechnology Excellence. Led by principal investigator Dr. Rudy Juliano, the center is one of seven in the nation focused on applying nanotechnology to improve cancer diagnostics, imaging and therapy. Dr. Shelton Earp, director of the UNC-Chapel Hill Lineberger Cancer Center, said, "Our inclusion in this National Cancer Institute program with some of the world's premier physical science universities is a tribute



Funding in nanotechnology research at North Carolina universities 2000-2005

Institution	Funding
Duke University	$18,756,011
East Carolina University	$35,000
Fayetteville State University	$91,896
North Carolina A&T State University	$10,983,115
North Carolina Central University	$2,317,474
North Carolina State University	$33,266,273
University of North Carolina-Chapel Hill	$25,027,505
University of North Carolina-Charlotte	$5,421,875
University of North Carolina-Greensboro	$44,999
University of North Carolina-Wilmington	$498,083
Wake Forest University	$2,362,917
TOTAL	$98,805,148

to UNC's ability to put together teams across academic boundaries. This synthesis of engineering, material science and medicine is both the future of patient care and attractive to industry at all levels."

The University of North Carolina-Greensboro and North Carolina A&T State University are building a Joint School of Nanoscience and Nanoengineering to train graduate students in basic and applied nanotechnology research. The universities have secured funding for a $10 million core laboratory building. Dr. Rosemary Wander, associate provost at UNC-Greensboro, lauded the research endeavor as "a unique effort by two campuses that has the potential to dramatically impact North Carolina's economy and position the state as a major international player in this rapidly developing area."

Another way of assessing North Carolina's impact in nanotechnology is to examine scientific publications from researchers in the state. Between 1995 and 2004, North Carolina researchers published 385 articles on nanomedicine and nanobiology—categories within the field of nanobiotechnology—and more than 1,000 publications in the broader field of nanotechnology. Top-notch nanotechnology research is being conducted at institutions throughout the state including BD Technologies, Duke University, Carolinas Medical Center, East Carolina University, Fayetteville State University, GlaxoSmithKline, the National Institute of Environmental Health Sciences, North Carolina A&T State University, North Carolina Central University, N.C. State University, RTI International, Shaw University, UNC-Chapel Hill, UNC-Charlotte, UNC-Greensboro, UNC-Wilmington, and Wake Forest University.

From talented researchers, new innovations may lead to new commercialization possibilities. UNC-Chapel Hill, Duke, and NCSU already hold several nanotechnology patents, as do North Carolina companies GlaxoSmithKline and Trimeris. More than 250 nanotechnology patents were issued to North Carolina assignees between 2003 and 2005, according to the U.S. Patent and Trademark Office. Additionally, start-up nanobiotechnology companies in North Carolina are already working to develop a wide range of nanobiotechnology products.

Strengthening nanotechnology in North Carolina

North Carolina has long recognized that encouraging science and technology leads to economic prosperity. The Governor's Task Force on Nanotechnology and North Carolina's Economy has developed a strategic roadmap to promote the development of nanotechnologies and help bring new high-wage jobs in nanotechnology to North Carolina. Members of the task force came from business, academia and the public sector.

"A Roadmap for Nanotechnology in North Carolina's 21st Century Economy" details their findings including a framework for increasing collaboration between industry and universities, further developing nanotechnology research centers at North Carolina universities, improving education and workforce training, and educating North Carolina citizens and policy makers on nanotechnology issues.

Dr. Robert McMahan, executive director of the N.C. Office of Science and Technology, described the roadmap as "a very clear call to action for the political, industrial, and university communities to build the nanotechnology and bionanotechnology community in the state."

Selected nanobiotechnology companies in North Carolina

Company	Location	Area of nanobiotechnology research
Advanced Liquid Logic	RTP	Lab-on-a-chip devices
Centice Corporation	Durham	Spectroscopy sensors for molecular recognition
HyperBranch Medical Technologies	Raleigh	Nanomaterials and devices for ocular surgery; drug delivery
LaamScience	RTP	Anti-viral surface coating using nanomaterials
Liquidia Technologies	Morrisville	Engineered nanomaterials for manufacturing processes in many industries
NanoCor Therapeutics	Chapel Hill	Nanoparticles for delivering gene therapy for chronic heart failure treatment
NanoTechLabs	Yadkinville	Nanomaterials
PharmAgra Labs	Brevard	Nanomaterials for pharmaceutical and biotechnology.
Tiny Technology	Charlotte	Nanotechnology consulting and education
QuarTek International	Greensboro	Nanomaterials, devices and sensors
Xintek	RTP	Nanomaterial-based field emission technologies for X-ray imaging

Start-up companies have sprung from the strong base of nanotechnology research in North Carolina universities. The majority of nanotechnology companies are located in Research Triangle Park, the Piedmont Triad, or the Charlotte area near universities with major nanotechnology research programs. Nanobiotechnology is particularly strong in the Research Triangle region, while other regions are developing infrastructure to support research and industrial growth. With further development of its nanotechnology infrastructure, the state can position itself more favorably to nanotechnology businesses, tap its strong base of researchers and leverage its low overhead costs.

Nanotechnology clusters are developing around the nation's biotechnology "magnets," particularly in California and the Northeast. Many states already have a nanotechnology initiative in place, and are actively investing in research centers and promoting business development.

The State of North Carolina is well known for its visionary investments in biotechnology. These investments have been handsomely rewarded. Biotechnology companies in the state now employ more than 48,000 people statewide and account for a $3 billion annual payroll. North Carolina leaders are embracing nanotechnology development. Governor Mike Easley formed a Task Force on Nanotechnology to provide direction for advancing nanotechnology in North Carolina and to identify areas that need investments to ensure the state's future in the nanotechnology sector. North Carolina will build on its biotechnology, health care, and information technology sectors as nanotechnology increases in importance.

The economics of nanotechnology

In the last decade, global funding for nanotechnology research has reached $9 billion annually, according to the President's Council of Advisors on Science and Technology. The world market value for nanotech materials is estimated to be $1 trillion by 2015, and some analysts say nanotechnology may account for the creation of 2 million jobs worldwide.

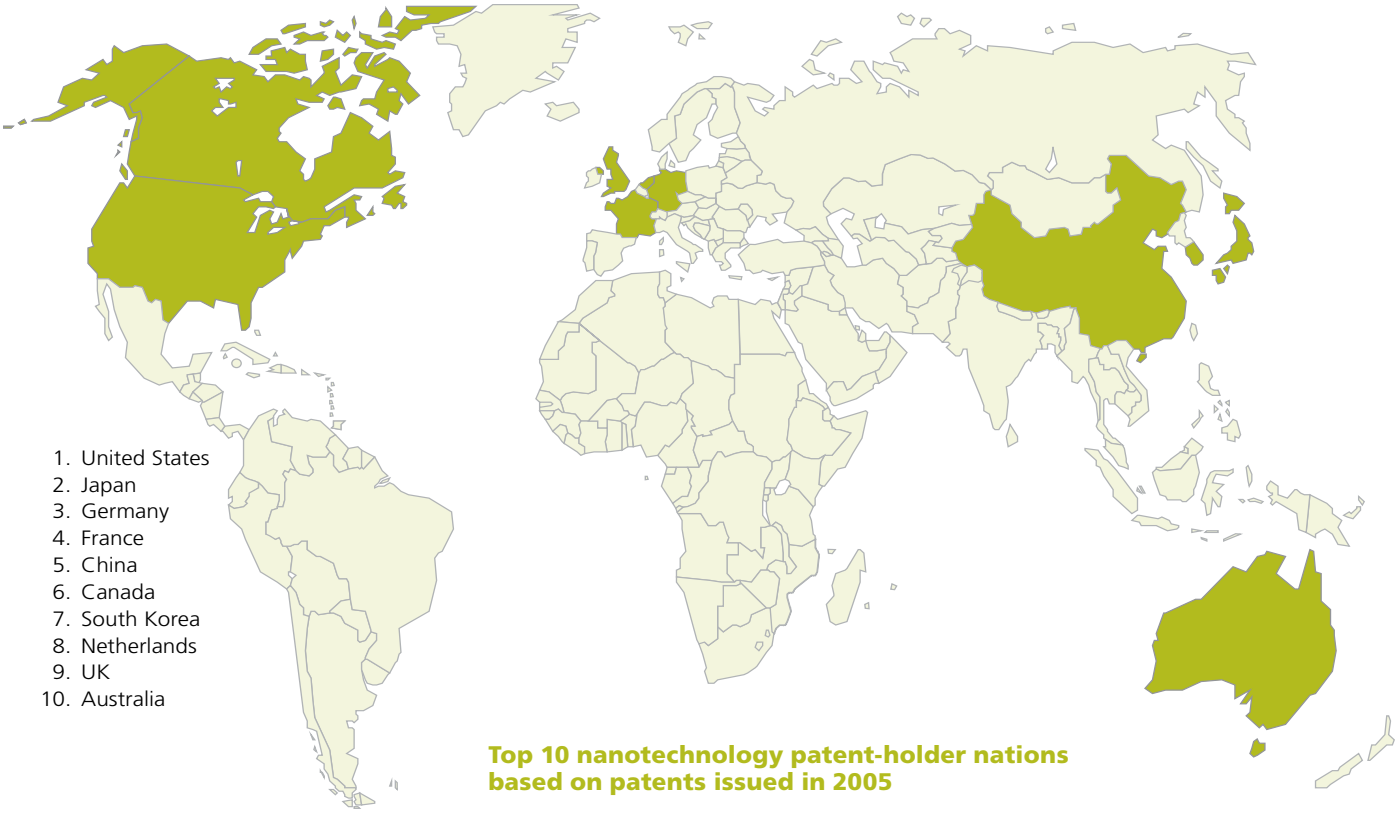
Recognizing the enormous potential impact of nanotechnology, the U.S. established the National Nanotechnology Initiative in 2001 to fund nanotechnology research.

Nanobiotechnology Conference at the Biotechnology Center

The North Carolina Biotechnology Center held its first North Carolina Nanobiotechnology Conference in 2006, drawing state policy makers, industry leaders and academic researchers from the Carolinas Medical Center, Duke University, East Carolina University, Fayetteville State University, North Carolina Central University, North Carolina State University, Shaw University, the University of North Carolina-Chapel Hill, the University of North Carolina-Charlotte, Wake Forest University, and Winston-Salem State University.

The conference gave North Carolina researchers the opportunity to present and exchange information, from toxicity studies of nanoparticles to DNA-based computer chips and the latest research on creating and selecting desired nanomaterials.

Dr. Robert McMahan, the state's science and technology advisor, and executive director of the N.C. Office of Science and Technology, called the conference participants "the embodiment of the kind of innovative strategic thinking for which North Carolina is recognized internationally."



Top 10 nanotechnology patent-holder nations based on patents issued in 2005

SOURCE: U.S. PATENT AND TRADEMARK OFFICE

Between 2001 and 2005, the federal government invested more than $4 billion on nanotechnology research. Funding for nanotechnology research has been given a high priority. The Bush Administration requested $1.45 billion in the 2008 budget for the National Nanotechnology Initiative. In addition to federal funding, private investments and state spending account for about $2 billion in annual nanotechnology investments.

The nanotechnology field is sufficiently developed that discoveries are beginning to transition from scientific novelties to commercial applications. One measure of the commercialization of nanotechnology is the number of patents issued. Between 1995 and 2004, more than 8,600 nanotechnology-related patents were issued in the United States. The majority of nanotechnology-related patents worldwide are issued to assignees in the United States, though other nations, including Japan and Germany, play a major role in global nanotechnology research.

Nanotechnology-based products are already on the market in cosmetics and sunscreens, machinery coatings, and electronic displays, and new applications may impact medicine, pharmaceuticals, genomics and proteomics in the near future. The next wave of applications is expected to include many from the nanobiotechnology field. A technical advisory group for the President's Council of Advisors on Science and Technology predicted in May 2005 improved biological sensors and portable and convenient medical diagnostic devices will be available in the next five years. Furthermore, targeted drug therapies and enhanced medical imaging are expected within five to 10 years.

Understanding the science

The field of nanotechnology took form in the early 1980s, when the development of scanning probe microscopy allowed researchers, for the first time, to observe and manipulate individual atoms. Through years of research and advances, manipulations of nanoscale objects have become less cumbersome and the field is now making rapid advances.

Nanomaterials are more than just tiny versions of bulk material. Nanoscale materials possess different physical and chemical properties than larger-scale matter because their size is sufficiently small that quantum mechanics dictates some of their properties. For example, gold is normally a solid, but at the nanoscale it becomes a liquid at room temperature. Another key property of nanomaterials is that as a particle gets smaller, its relative surface area increases and its electronic structure changes.

The unique properties of nanomaterials due to quantum effects and surface-area effects allow new applications for many materials. The ability to create and design novel materials is ultimately why nanotechnology promises to make a huge impact on so many fields.

Nanomaterials can be constructed by a top-down approach or a bottom-up approach. In the top-down approach, the nano builder reduces the size of a material of interest until it reaches nanoscale proportions. In the bottom-up approach, nanostructures are built atom by atom or molecule by molecule by either manipulating individual atoms or creating conditions where components can self-assemble. Self-assembly is much faster than building nanomaterials atom by atom; engineering new nanomaterials that self-assemble may provide a critical manufacturing solution. The field of biology provides many examples of self-assembling molecules, such as proteins that fold into a specific configuration. Studies of naturally occurring self-assembly may lend insight to designing new nanomaterials.

Designing nanomaterials differs from traditional chemistry because nanotechnology allows unequaled molecular-level control over materials. Novel nanomaterials are being developed for biotechnology and medical applications. And the marriage of nanotechnology and biotechnology has led to the emerging field of nanobiotechnology.

Research in nanotechnology, biotechnology, and information technology intersects increasingly. Multidisciplinary research involving medical researchers, biologists, chemists, physicists, materials scientists, and engineers is propelling nanobiotechnology forward. The convergence of these once-distinct fields is the essence of nanobiotechnology.

Because nanomaterials are of the same scale as biological molecules, nanomaterials may open new possibilities for monitoring and intervening in biological systems. Researchers are using nanobiotechnology to create new contrast agents for cell imaging, to deliver gene therapy, and to analyze cellular processes. Nanomaterials are being investigated as a potential scaffold for cell transplantation in the treatment of diseases such as Parkinson's and diabetes.

Nanotechnology may also play an important role in developing tissue-engineering materials that are more compatible with the body. On-site diagnostic work to assess the presence or activity of a particular molecule can be faster and more sensitive using nanoscale tags. Drug-delivery systems that use nanoparticles to carry drug molecules only to the desired location could reduce side effects and increase potency.

Interfacing nanomaterials with biomolecules may allow a wide variety of medical applications as well as analytical tools for advancing genomics—the study of all the genes in a living organism—and proteomics—the study of all the proteins in a living organism.

NanoTechLabs

Nanotechnology may some day offer treatments for neurological conditions such as Parkinson's disease, epilepsy and depression. NanoTechLabs of Yadkinville, N.C., has recently developed a new type of carbon nanotube electrode for electrical stimulation of the brain.

Implantable electrodes may some day be used to for deep brain stimulation. Analagous to a heart pacemaker, the device would emit electrical impulses to stimulate the brain.

NanoTechLabs and commercial research partners Foster-Miller and InnerSea Technology are developing nanomaterials that are biologically compatible and readily manufactured. With further research, new treatment options for neurological diseases may be possible.

Nanoparticles and gene therapy

Could nanotechnology hold the key to unlocking gene therapy for diseases such as muscular dystrophy? Researchers at the University of North Carolina-Chapel Hill are working on the next generation of gene therapy using biological nanoparticles.

For years, researchers have been studying gene therapy as a tool to treat diseases that are caused by the absence of a key protein in the body. By introducing the correct gene into cells, the therapy should enable the patient to make the missing protein. Though gene therapy is a promising concept there have been problems with expressing sufficient quantities of protein and targeting the gene to desired tissues.

UNC-Chapel Hill Professor Jude Samulski founded Asklepios BioPharmaceutical, Inc. (AskBio) to develop and commercialize proprietary biological nanoparticles for efficient, safe therapy of diseases such as muscular dystrophy, hemophilia and congestive heart failure. The North Carolina Biotechnology Center has provided $165,000 in funding for AskBio, including a 2005 pre-clinical study of biological nanoparticles in congestive heart failure treatment. The company is also conducting the first human clinical trials of a gene therapy for Duchenne Muscular Dystrophy.

Samulski

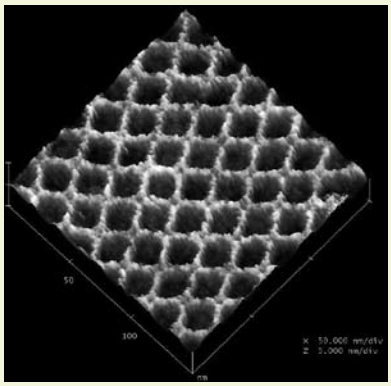
"After years of encouraging preclinical results, I'm excited that AskBio will soon be able to bring this promising new therapy into the clinic, and look forward with a great deal of optimism to offering this initial step toward hope for the Duchenne Muscular Dystrophy community," Samulski told the Muscular Dystrophy Association.

Computer processors using self-assembling DNA nanostructures

Cutting-edge research into the computers of tomorrow includes the use of DNA nanostructures in computer processors. Already, researchers have assembled DNA nanostructures for experimental use and are working toward practical applications.

Dr. Thomas LaBean, associate research professor of computer science and chemistry at Duke University, described a research project at Duke involving the use of DNA nanostructures to detect and modify faulty gene expression in a programmable manner that is analogous to a computer computation.

"A simple system has been demonstrated outside of cells," said LaBean, "but a system functioning inside cells is probably at least 10 years away." Another area of research is using DNA nanostructures as "smart glue" to direct the assembly of other materials that might have useful electronic properties or photonic properties. Photonics uses photons—the fundamental particles of light—to transfer or store information similar to the use of electrons in electricity.



Surface plot of DNA nanogrid constructed by Duke DNA nanotech group

Complex DNA nanostructures have been used to organize proteins, metals, semiconductor nanoparticles and carbon nanotubes. A reliable DNA-based assembly method for manufacturing electronic components or devices has not yet been demonstrated, according to LaBean, but "this direction could perhaps result in products within the next 10 years."

Though DNA nanostructure research is still in its infancy, this technology is promising because nature has proven DNA to be able to form well-organized, complex nanostructures that can exhibit diverse and extremely useful properties.

Though the potential impact of nanobiotechnology is very real, there are still significant hurdles that must be overcome. There are technical problems of moving from lab scale to industrial scale. Better instruments for observing, analyzing, and positioning molecules are needed. Most significantly, though, issues surrounding the impact of nanomaterials on human health and the environment, and related ethical concerns, must be explored.

Environmental safety and human health concerns

As nanotechnology moves forward, it is possible that some nanomaterials may cause toxic effects on humans and in the environment. Because of their small size, many nanomaterials are readily absorbed by the body.

For example, researchers at the North Carolina State University Center for Chemical Toxicology Research and Pharmokinetics found that carbon nanotubes can be taken up by a human skin cell line and alter protein production. The skin represents a very likely route for exposure to nanomaterials, and these kinds of studies indicate that not all nanomaterials are benign.

However, nanomaterials should not be lumped into a single category. Different nanomaterials can have vastly different properties, and therefore very different toxicology. For example, some nanoparticles can be readily broken down by the body while others may remain in the body presenting different risks associated with long-term exposure. Additionally, for some nanomaterials, changes in manufacturing conditions can dramatically influence toxicity.

ASTM International, originally known as the American Society for Testing and Materials, is developing a "Standard Guide for Handling Unbound Engineered Nanoparticles in Occupational Settings" to provide guidance for controlling exposure to nanoparticles in the laboratory, particularly for nanoparticles that have undefined risks and exposure information.

In addition to addressing human health concerns, environmental toxicology research assessing the impact, routes of exposure and potential for bioaccumulation of nanomaterials will be critical to assessing the ecological impact of these materials. More research needs to be done to answer questions surrounding the safety of different nanomaterials.

North Carolina researchers are poised to play an important role in these toxicity studies. Some of the nation's top toxicology programs are based in North Carolina including the National Toxicology Program of the National Institute of Environmental Health Sciences (NIEHS), the Environmental Protection Agency (EPA), the CIIT Centers for Health Research, in addition to strong programs in the state's universities. Clearly, a thorough understanding of the toxicology of nanomaterials, and optimization to reduce harmful effects, are essential as the field moves forward.

"To date, there are really only limited toxicity studies based on a very limited number or types of nanomateri-

als," said Dr. Amy Ringwood, an assistant professor of biology at UNC-Charlotte who uses oysters in her lab to study toxicity. "I regard it as important to consider toxicity issues in conjunction with the development of nanomaterials to understand potential problems. In doing so, we can work cooperatively and responsibly to develop safe nanotechnology strategies."

Ethical issues

Another key area of concern is the public understanding of nanobiotechnology in our society. Emerging technologies such as genetically modified foods and stem cell research have challenged people to examine their beliefs about the natural order of the world. Nanobiotechnology will present new challenges.

Researchers at North Carolina State University are investigating public concerns about nanotechnology. A 2006 study of lay people who were provided reading materials about nanotechnology showed that 62 percent of participants had low trust in the ability of the government to manage risks associated with nanotechnology. Many participants cited past examples of new technologies that were poorly managed such as dioxin, PCBs, and asbestos. The most common concerns expressed about the use of nanotechnology included: creation of new weapons of mass destruction, undesirable military use or use of such weapons by terrorists; unknown long-term health risks of nanoparticles; and environmental problems such as new pollutants and unexpected effects on the environment.

Most participants did not fear that nanotechnology would lead to negative consequences as portrayed in the popular novel *Prey* by Michael Crichton. Nor were they concerned that nanotechnology would lead to self-replicating nanobots that consume living creatures and turn them into gray goo, as envisioned by Eric Drexler. Drexler, a scientist who advocates education about the benefits and risks of nanotechnology, says now that "fears of accidental runaway replication—loosely based on my 1986 gray-goo scenario—(are) quite obsolete." He adds that "all the hype diverts attention from more important issues—research directions, development paths, and the role of advanced nanotechnologies in medicine, the environment, the economy and in strategic competition."

As nanotechnology progresses, it will be important for the public to understand the technology and be involved in discussions about how nanobiotechnology will impact medicine, the environment, public health, and the economy.

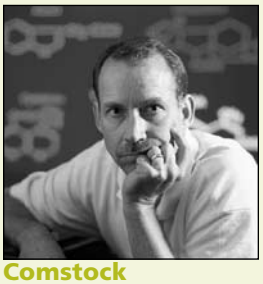
Outreach efforts are being made to inform people about this emerging technology. The National Science Foundation recognized this need in 2005 when it awarded the largest grant ever made to the museum community to create a nationwide network of informal science centers, researchers and educators dedicated to engaging the public through a wide range of learning experiences about nanoscale science, engineering and technology. As one of nine museums in the NiSE Network, the Museum of Life and Science in Durham, N.C., is offering a series of public forums on the social and ethical issues surrounding emerging nanotechnologies.

Involving North Carolina researchers in the ethical challenges of nanobiotechnology

In addition to engaging the public in understanding nanotechnology and potential risks, research scientists must also consider the ethical challenges that nanotechnology brings. At universities across the state, the next generation of researchers is being encouraged to address the ethics of nanotechnology research.

North Carolina State University is the lead institution in a national project funded by the National Science Foundation to develop a curriculum in research ethics for doctoral candidates at land grant universities. Researchers from NCSU, North Carolina A&T State University, North Carolina Central University, Fayetteville State University and other institutions across the nation are contributing to this nanotechnology ethics model curriculum. All of the lead institutions began implementing the ethics curriculum in 2006-2007.

"Today's doctoral students are tomorrow's nanotechnology leaders," said the grant's project director, Dr. Gary Comstock, a professor of philosophy and director of the research and professional ethics program at NCSU. "Our project will involve them in rigorous discussion of the broader social and ethical dimensions of nanotech, preparing them better to discern and avoid potential risks and harms. I hope that the module will provoke careful and sustained reflection on the moral ramifications of nanotechnology."


Comstock

At Duke University, professors from the Center for Biologically Inspired Materials & Material Sciences and the Center for Biological Tissue Engineering wanted to go beyond the standard required ethics training for graduate students by challenging students to confront the ethical issues surrounding nanotechnology in an essay contest. "The range and breadth of the issues that they have identified are impressive," said Dr. Daniel Vallero, who led the effort. "They include both macro and microethical issues and they related directly to real-life and real-time research challenges."

"Engaging the public right now in discussing the risks and benefits of nanoscience research and its early applications is not only the right thing to do, it could help avert greater public concern and policy issues later on," said Barry Van Deman, president and CEO of the Museum.

Barry Van Deman

Summary

Nanobiotechnology is poised to make rapid advances in the near future. North Carolina is implementing strategies to strengthen the state's role in this field. By creating a strong nanobiotechnology cluster in the state, North Carolinians will reap the economic and social benefits of this growing endeavor.

UNC-Charlotte/Carolinas Medical Center Conference

The University of North Carolina at Charlotte and the Carolinas Medical Center hosted more than 250 people at the 2005 nanotechnology conference "Nanoscale Science and Engineering: a Convergence of Top-Down and Bottom-up Approaches." The conference provided a forum for researchers to discuss national initiatives in nanotechnology, nanotechnology in medicine, and other emerging nanotechnology research.

In recent years, UNC-Charlotte and the Carolinas Medical Center have created a strong partnership to develop applications of nanotechnology for biomedical research. Their collaborative efforts have yielded promising research, such as investigating the use of nanostructures to deliver gene therapy in the treatment of muscular dystrophy and to deliver antibiotics to osteoblasts for the treatment for bone infections.

Hosting a nanotechnology conference in Charlotte has been a natural extension of such active research in nanomedicine. The North Carolina Biotechnology Center, UNC-Charlotte, and the Carolinas Medical Center also are hosting the 2007 nanotechnology conference in Charlotte focused on biomedical nanostructures.

Additional resources for nanotechnology and nanobiotechnology information

Nanotechnology reports	Web site
Southern Growth Policies Board. 2006. Connecting the Dots: Creating a Southern Nanotechnology Network	*http://www.southern.org/pubs/ConnectDots/ConnectExecSumm.pdf* Full text available at the Biotechnology Center Library or for purchase at *http://www.southern.org/pubs/pubs.shtml*
Governor's Task Force on Nanotechnology and North Carolina's Economy. 2006 A Roadmap for Nanotechnology in North Carolina's 21st Century Economy	*http://www.ncnanotechnology.com/*
President's Council of Advisors on Science and Technology. 2005. The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel	*http://www.ostp.gov/pcast/PCASTreportFINALlores.pdf*
National Science and Technology Council. 2004 National Nanotechnology Initiative Strategic Plan.	http://www.nano.gov/NNI_Strategic_Plan_2004.pdf
Government Web sites	
National Nanotechnology Initiative	*http://www.nano.gov*
National Institutes of Health Roadmap on Nanomedicine	*http://nihroadmap.nih.gov/nanomedicine/index.asp*
Nanotechnology Characterization Lab of the National Cancer Institute	*http://ncl.cancer.gov/*

Environmental Protection Agency National Center For Environmental Research: Nanotechnology Activities	*http://es.epa.gov/ncer/nano/index.html*
U.S. Food and Drug Administration—nanotechnology site	*http://www.fda.gov/nanotechnology/*
National Institute of Environmental Health Sciences—National Toxicology Program Nanotechnology Safety Initiative	*http://ntp.niehs.nih.gov/go/nanotech*
University & non-profit organization Web sites	
UNC-Chapel Hill Nanoscale Science Research Group	*http://www.cs.unc.edu/Research/nano/aims.html*
Center for Biologically Inspired Materials & Material Systems	*http://www.cbimms.duke.edu/*
Center on Globalization, Governance & Competitiveness—a research affiliate of the Social Science Research Institute of Duke University studying the societal impacts of nanotechnology	*http://www.cggc.duke.edu/projects/cns/cns.html*
NCSU—Land Grant University Research Ethics module on Nanotechnology	*http://www.chass.ncsu.edu/langure/modules/nanotechnology.html*
Wake Forest University Nanomedicine	http://www.wfu.edu/nanotech/*WFnanomeds.html*
Nanoscience and Nanotechnology Research Center at Shaw University	*http://faculty.shawu.edu/karoui/1NNRC/HomeMyNNRC.htm*
North Carolina A & T State University—Nanoscale Interdisciplinary Research Team	*http://nirt.ncat.edu/*
Foresight Nanotech Institute—a non-profit organization formed to guide nanotechnology research, public policy and education	*http://www.foresight.org/*
Johns Hopkins Institute for NanoBioTechnology	*http://inbt.jhu.edu/*
The Center for Biological and Environmental Nanotechnology	*http://cben.rice.edu/*
CIIT Centers for Health Research	*http://www.ciit.org/*
Nanotechnology news, products events and information	*http://www.nanotechweb.org/*
NISE (Nanoscale Informal Science Education) Network—Article on Nanomedicine	*http://www.nisenet.org/publicbeta/articles/nanomedicine/index.html*
Other Web sites of interest	
Small Times—Web site/magazine focused on business information about nanotechnology	*http://www.smalltimes.com/*
ASTM International—a standards development organization for technical standards for materials, products, systems, and services.	*http://www.astm.org*
Research journal articles on nanotechnology	
Halberstadt et al. Combining cell therapy and nanotechnology. Expert Opin. Biol. Ther. (2006) Vol 6 Number 10, Pages 971-981	
Nanotechnology: assessing the risks, Nano Today, Volume 1, Issue 2, May 2006, Pages 22-33, Andrew D. Maynard	*http://www.sciencedirect.com/*
International nanotechnology development in 2003:Country, Institution, and technology field analysis based on USPTO patent database, Journal of Nanoparticle Research, Volume 6, 2006, Pages 325-354, Zan Huang, Hsinchun Chen, Zhi-Kai Chen, Mihail C. Roco	*http://citeseer.ist.psu.edu/huang04international.html*
Nanotechnology: public concerns, reasoning and trust in government. Public Understand. Sci., Volume 15, 2006, Pages 221-241 Jane Macoubrie	*http://pus.sagepub.com/cgi/content/abstract/15/2/221* (abstract only)
Witzmann and Monteiro-Riviere. Multi-walled carbon nanotube exposure alters protein expression in human keratinocytes. Nanomedicine, Volume 2, 2006, 158-168.	

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