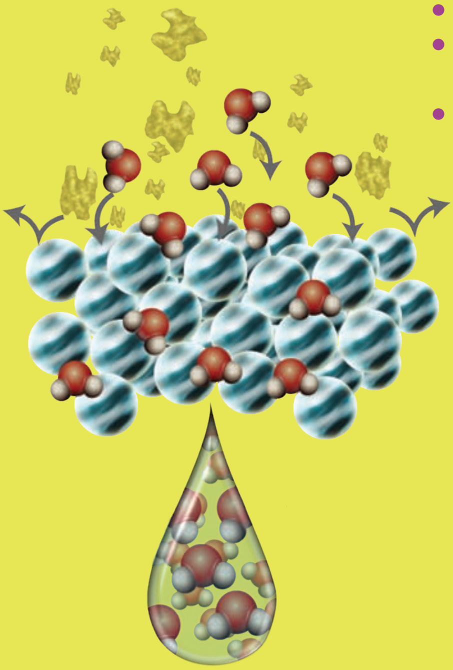
Nanotechnology

Big Things from a Tiny World

Think small. Think really, really small—smaller than anything you ever saw through a microscope at school. Think atoms and molecules, and now you're there. You're down at **the nanoscale**, where scientists are learning about these fundamental components of matter and are putting them to use in beneficial ways.

It's a relatively new area of science that has generated excitement worldwide. Working at the nanoscale, scientists today are creating new tools, products and technologies to address some of the world's biggest challenges, including

- clean, secure affordable energy
- stronger, lighter, more durable materials
- low-cost filters to provide clean drinking water
- medical devices and drugs to detect and treat diseases more effectively with fewer side effects
- lighting that uses a fraction of the energy
- sensors to detect and identify harmful chemical or biological agents
- techniques to clean up hazardous chemicals in the environment



Because of the promise of nanotechnology to improve lives and to contribute to economic growth, the Federal Government, through the guiding efforts of the U.S. National Nanotechnology Initiative (NNI), is supporting research in nanotechnology. As a result of the NNI research efforts, the United States is a global leader in nanotechnology development.

Nano *What??*

So what is nanoscience and nanotechnology?

Nanoscience involves research to discover new behaviors and properties of materials with dimensions at the nanoscale, which ranges roughly from 1 to 100 nanometers (nm). Nanotechnology is the way discoveries made at the nanoscale are put to work.

What's so special about the nanoscale? The short answer is that **materials can have different properties at the nanoscale**—some are better at conducting electricity or heat, some are stronger, some have different magnetic properties, and some reflect light better or change colors as their size is changed.

Nanoscale materials also have far larger surface areas than similar volumes of larger-scale materials, meaning that more surface is available for interactions with other materials around them.

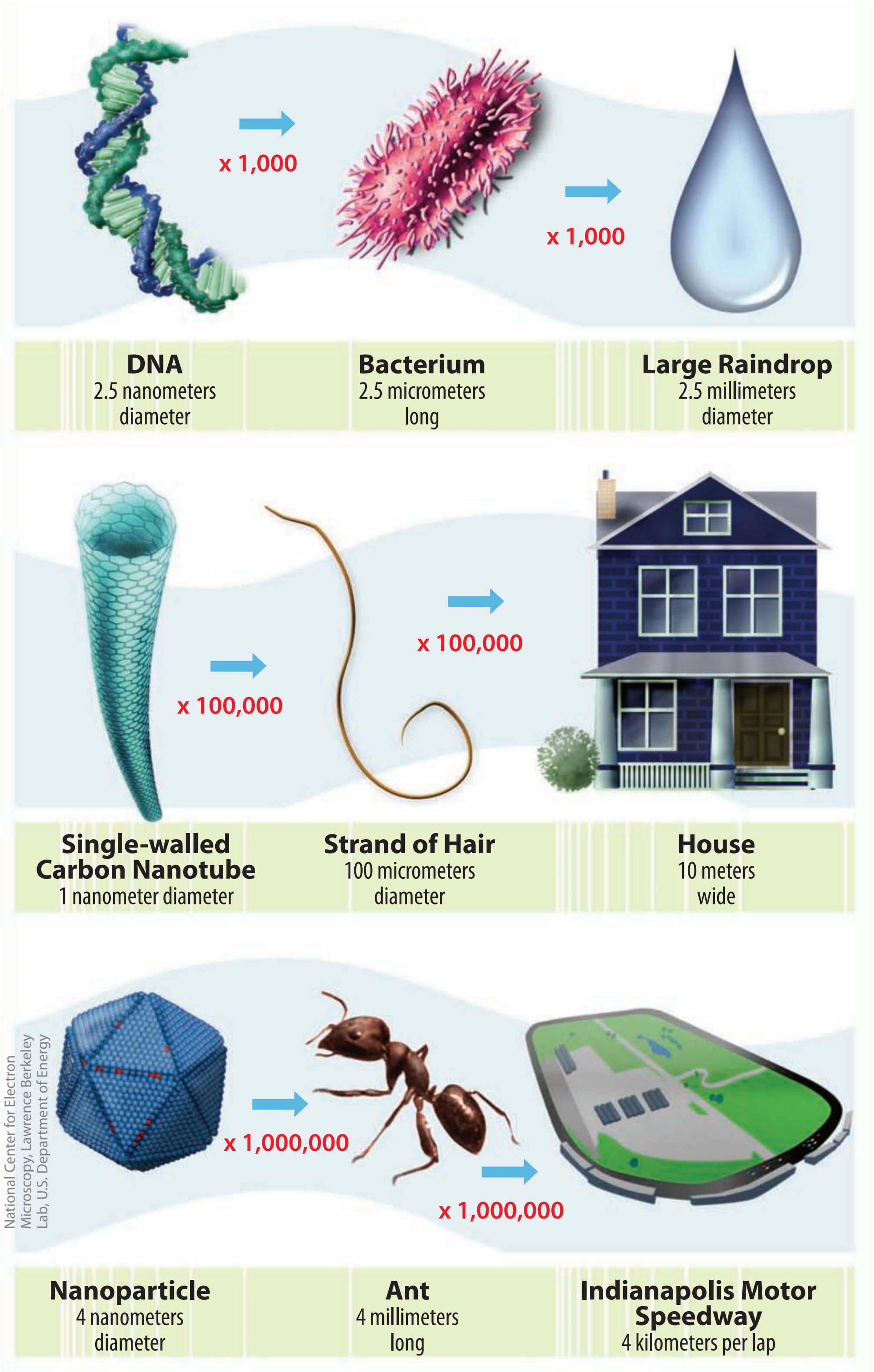
To illustrate the importance of surface area, think of a piece of gum chewed into a ball. Then think about stretching that gum into as thin a sheet as possible. The surface, or area visible on the outside, is much greater for the stretched out gum than it is for the wad of gum. The stretched gum is likely to dry out and to become brittle faster than the wad due to more contact at the surface with the air around it.

The Nanoscale in Perspective

How small is a nanometer? By definition, one nanometer is a billionth of a meter, but that's a hard concept for most of us to grasp. Here are some other ways to think about how small a nanometer is:

- **A sheet of paper is about 100,000 nanometers thick.**
- **If you're a blond, your hair is probably 15,000 to 50,000 nanometers in diameter. If you have black hair, its diameter is likely to be between 50,000 and 180,000 nanometers.**
- **There are 25,400,000 nanometers per inch.**
- **A nanometer is a millionth of a millimeter.**

NANOSCALE
3 Examples



All dimensions are approximate.

Nanoscale materials and effects are found in nature all around us. Nature's secrets for building from the nanoscale create processes and machinery that scientists hope to imitate. Researchers already have copied the nanostructure of lotus leaves to create water repellent surfaces being used today to make stain-proof clothing, other fabrics and materials. Others are trying to imitate the strength and flexibility of spider silk, which is naturally reinforced by nanoscale crystals. Our bodies and those of all animals use natural nanoscale materials, such as proteins and other molecules, to control our bodies' many systems and processes. In fact, **many important functions of living organisms take place at the nanoscale**. A typical protein such as hemoglobin, which carries oxygen through the bloodstream, is 5 nanometers, or 5 billionths of a meter, in diameter.

If scientists can create artificial spider silk economically, the super-strong, lightweight materials could be used in sports helmets, armor, tethers and other products.

Nanoscale materials are all around us, in smoke from fire, volcanic ash, sea spray, as well as products resulting from burning or combustion processes. Some have been put to use for centuries. One material, nanoscale gold, was used in stained glass and ceramics as far back as the 10th Century. But it took 10 more centuries before high-powered microscopes and precision equipment were developed to allow nanoscale materials to be imaged and moved around. **Nanotechnology is more than throwing together a batch of nanoscale materials—it requires the ability to manipulate and control those materials in a useful way.**

Putting Technology to Use

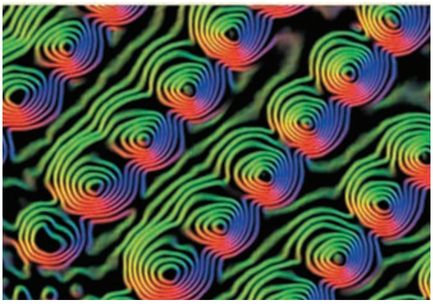
Over the past two decades, scientists and engineers have been mastering the intricacies of working with nanoscale materials. Now researchers have a much clearer picture of how to create nanoscale materials with properties never envisioned before.

Products using nanoscale materials and processes are now available. Anti-bacterial wound dressings use nanoscale silver. A nanoscale dry powder can neutralize gas and liquid toxins in chemical spills and elsewhere. Batteries for tools are being manufactured with nanoscale materials in order to deliver more power, more quickly, with less heat. Cosmetics and food producers are "nano-sizing" some ingredients, claiming that improves their effectiveness. Sunscreens containing nanoscale titanium dioxide or zinc oxide are transparent and reflect ultraviolet (UV) light to prevent sunburns. Scratch- and glare-resistant coatings are being applied to eye glasses, windows, and car mirrors.

Entirely new products could result from nanotechnology too. **Research in**

nanomedicine, for instance, is focused on finding new ways for diagnosing and treating disease.

Looking farther into the future, some researchers are working toward **nanomanufacturing and a "bottom-up" approach to making things.** The idea is that if you can put certain molecules together, they will self-assemble into ordered structures. This approach could reduce the waste of current "top-down" manufacturing processes that start with large pieces of materials and end with the disposal of excess material.



Electron microscopes create greatly magnified images by recording how a beam of electrons interacts with a sample material. Above is such an image, showing nanostructured magnetic nickel. Such materials could someday be used in data storage, electronics, biomedicine and telecommunications.
(Courtesy of Y. Zhu, Brookhaven National Laboratory.)

The Skinny on Nanoscale Behavior

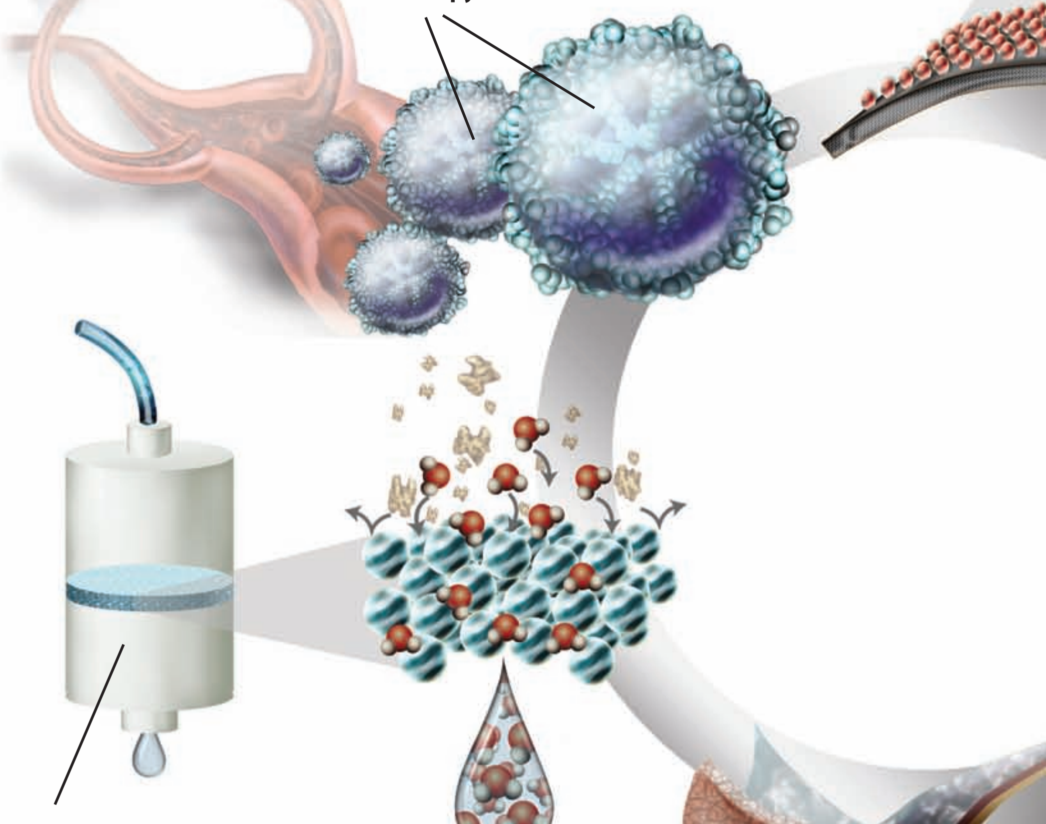
At the nanoscale, objects behave quite differently from those at larger scales. At the bulk scale, for instance, gold is an excellent conductor of heat and electricity, but nothing much happens when you shine light onto a piece of gold. With properly structured gold nanoparticles, however, something almost magical happens—they start absorbing light and can turn that light into heat, enough heat, in fact, to act like miniature thermal scalpels that can kill unwanted cells in the body, such as cancer cells.

Other materials can become remarkably strong when built at the nanoscale. For example, nanoscale tubes of carbon, 1/100,000 the diameter of a human hair, are incredibly strong. They are already being used to make bicycles, baseball bats, and some car parts today. Some scientists think they can combine carbon nanotubes with plastics to make composites that are far lighter, yet stronger than steel. Imagine the fuel savings if such a material could replace all the metal in a car! Carbon nanotubes also conduct both heat and electricity better than any metal, so they could be used to protect airplanes from lightning strikes and to cool computer circuits.

Nanotechnology Applicati

Drug-Delivery Techniques

Dendrimers are a type of nanostructure that can be precisely designed and manufactured for a wide variety of applications, including treatment of cancer and other diseases. Dendrimers carrying different materials on their branches can do several things at one time, such as recognizing diseased cells, diagnosing disease states (including cell death), drug delivery, reporting location , and reporting outcomes of therapy.



Water-Filtration Techniques

Researchers are experimenting with carbon nanotube-based membranes for water desalination and nanoscale sensors to identify contaminants in water systems. Other nanoscale materials that have great potential to filter and purify water include nanoscale titanium dioxide, which is used in sunscreens and which has been shown to neutralize bacteria, including *E. coli,* in water.

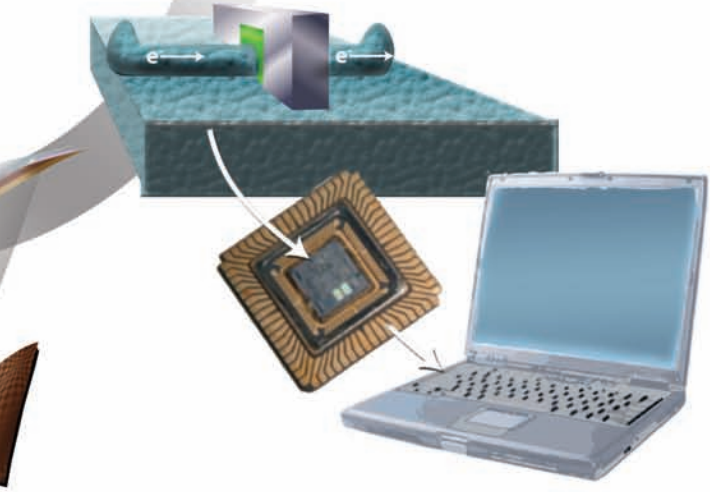
ons and Products

Nanofilms

Different nanoscale materials can be used in thin films to make them water-repellent, anti-reflective, self-cleaning, ultraviolet or infrared-resistant, anti-fog, anti-microbial, scratch-resistant, or electrically conductive. Nanofilms are used now on eyeglasses, computer displays, and cameras to protect or treat the surfaces.

Nanotubes

Carbon nanotubes (CNTs) are used in baseball bats, tennis racquets, and some car parts because of their greater mechanical strength at less weight per unit volume than that of conventional materials. Electronic properties of CNTs have made them a candidate for flat panel displays in TVs, batteries, and other electronics. Nanotubes for various uses can be made of materials other than carbon.



Nanoscale transistors

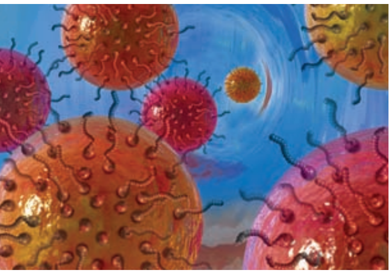
Transistors are electronic switching devices where a small amount of electricity is used like a gate to control the flow of larger amounts of electricity. In computers, the more transistors, the greater the power. Transistor sizes have been decreasing, so computers have become more powerful. Until recently, the industry's best commercial technology produced computer chips with transistors having 65-nanometer features. Recent announcements indicate that 45-nanometer feature technology soon will be here.

Solar Plastics

Thin, flexible, lightweight rolls of plastics containing nanoscale materials are being developed that some people believe could replace traditional solar energy technologies. The nanoscale materials absorb sunlight and, in some cases, indoor light, which is converted into electrical energy. Thin-film solar cells paired with a new kind of rechargeable battery also are the subject of research today. This technology will be more widely used when researchers learn how to capture solar energy more efficiently.

Technological IMPACTS

All technologies have impacts on our lives, and along with the benefits, there may be risks. The NNI funds research to help identify positive as well as negative impacts of nanotechnology, so that the benefits can be realized and steps can be taken to avoid undesirable or unintended impacts. Research on environmental, health, and safety impacts, as well as other societal impacts, are important areas of funding for the NNI.



Researchers at Rice University in Houston, Texas, believe magnetic interactions of nanoscale rust could lead to the development of a revolutionary, low-cost technology for cleaning arsenic from drinking water. (Courtesy of CBEN/Rice University.)

Work funded by agencies such as the National Institutes of Health, the National Science Foundation, and the Environmental Protection Agency is helping scientists to better understand nanoscale materials and to identify unique safety concerns that may be associated with them.

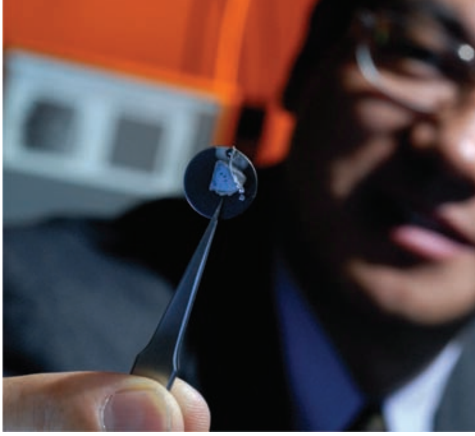
Knowledge like this can guide researchers and engineers in creating handling and disposal guidelines. Such knowledge also can help them to avoid using certain materials in products or to modify the materials to make them safe. Researchers have found, for instance, that special coatings can make potentially hazardous nanoscale materials safe for use. Research will continue in both government and industry to determine if there are unintended impacts from the use of specific nanoscale materials, including those that could occur, for instance, in recycling or disposal.

A few words about risk. **Risk, according to experts, involves two factors—hazard and exposure.** If there is no exposure, even a hazardous material does not pose a risk.

Scientists have found indications, however, that **certain nanoscale materials need to be handled with caution**. The National Institute of Occupational Health and Safety has recommended that employers take appropriate precautionary measures for handling new materials—including engineering controls, administrative controls, and personal protective equipment—to avoid worker exposure to nanoscale materials.

At the same time that some precautions are necessary, researchers are finding that nanomaterials could provide potential solutions to risks from other technologies and materials. With government funding, for instance, Rice University researchers recently discovered that magnetic interactions between ultra small (nanoscale) specks of rust could help to remove arsenic from drinking water. Thousands of cases of arsenic poisoning are reported each year worldwide and are linked to well water.

Social scientists, ethicists, and others are studying the broader implications of nanotechnology. How might products created through nanotechnology be used? Could some technological benefits also have downsides? Consider cell phones, for example. They make it possible to communicate from places where we couldn't before, but they also make it difficult to escape the conversations of others in a restaurant, in the movies, or when you're riding a train, a bus, or the subway. Research into the societal implications of nanotechnology will help to identify the positive and potentially negative impacts, so that, again, we can realize the benefits and minimize or avoid undesirable effects.



Z.L. Wang, a researcher at Georgia Tech, is using nanowires to generate electricity. Such nanowire systems, assembled on surfaces as small as 2 square centimeters, could some day be used to power implantable medical devices.

(Courtesy of Z.L. Wang, Georgia Institute of Technology.)

Into the Future

Today, many of our nation's most creative scientists and engineers are finding new ways to use nanotechnology to improve the world in which we live. These researchers envision a world in which new materials, designed at the atomic and molecular level, provide realistic, **cost-effective methods** for harnessing renewable energy sources and keeping our environment clean. They see doctors detecting disease at its earliest stages and treating illnesses such as cancer, heart disease, and diabetes with **more effective and safer medicines**. They picture new technologies for protecting both our military forces and civilians from conventional, biological, and chemical weapons. Although there are many research challenges ahead, **nanotechnology already is producing a wide range of beneficial materials and pointing to breakthroughs in many fields. It has opened scientific inquiry to the level of molecules—and a world of new opportunities.**

Sam Stupp and colleagues at the Feinberg School of Medicine at Northwestern University are using nanotechnology to engineer a gel that spurs the growth of nerve cells. The gel fills the space between existing cells and encourages new cells to grow. While still in the experimental stage, this process could eventually be used to re-grow lost or damaged spinal cord or brain cells.

About the
National Nanotechnology Initiative

Twenty-six departments and agencies of the U.S. Government participate in the National Nanotechnology Initative (NNI), which provides coordination to research and development efforts funded by the government. The NNI works to ensure U.S. leadership in nanotechnology innovation for improved human health, economic well being, and national security. The NNI agencies invest in fundamental research to further understanding of nanoscale phenomena and to facilitate technology transfer. Manufacturers are responsible for the safety of their products; however, U.S. Government regulatory agencies are responsible for protecting public health and the environment through regulation. Regulatory agencies that will be involved in maintaining public safety for nanoscale materials, as they do for materials at larger scales, include the Consumer Product Safety Commission (CPSC), Department of Agriculture (USDA), Department of Transportation (DOT), Environmental Protection Agency (EPA), Food and Drug Administration (FDA), and Occupational Safety and Health Administration (OSHA).

For more information on the NNI, see **www.nano.gov**.

For additional information on NNI participating agencies:

Department of Agriculture

Cooperative State Research, Education, and Extension Service
http://www.csrees.usda.gov/ProgView.cfm?prnum=6188

Forest Service
http://www.fpl.fs.fed.us/

Department of Commerce
http://www.commerce.gov/

Bureau of Industry and Security
http://www.bis.doc.gov/

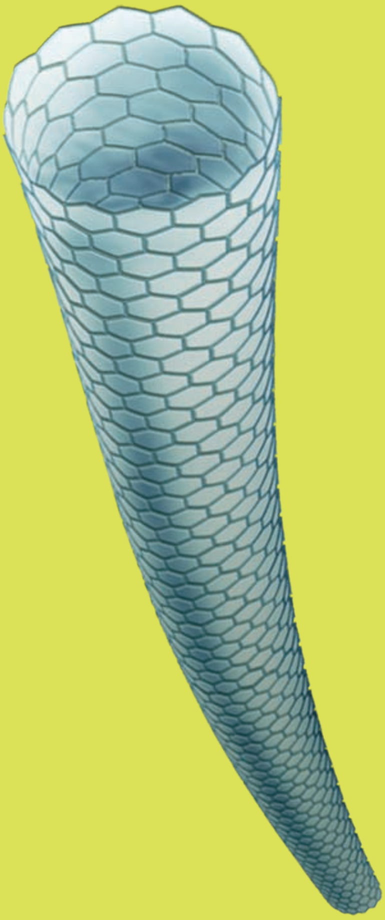
National Institutes of Standards and Technology
http://www.nist.gov/public_affairs/nanotech.htm

Technology Administration
http://www.technology.gov/

Consumer Product Safety Commission
http://www.cpsc.gov/

Environmental Protection Agency
http://es.epa.gov/ncer/nano/

Department of Defense
http://www.nanosra.nrl.navy.mil/



Department of Education
http://www.ed.gov/index.jhtml

Department of Energy
http://nano.energy.gov

Food and Drug Administration
http://www.fda.gov/nanotechnology/

U.S. Geological Survey
http://www.usgs.gov/

Department of Homeland Security
http://www.dhs.gov/index.shtm

Intelligence Community
http://www.intelligence.gov/index.shtml

International Trade Commission
http://www.usitc.gov/

Department of Justice
http://www.usdoj.gov/

Department of Labor
http://www.dol.gov/

National Aeronautics and Space Administration
http://www.ipt.arc.nasa.gov/

National Institutes of Health
http://www.becon.nih.gov/nano.htm

National Institute for Occupational Safety and Health
http://www.cdc.gov/niosh/topics/nanotech/

National Science Foundation
http://www.nsf.gov/crssprgm/nano/

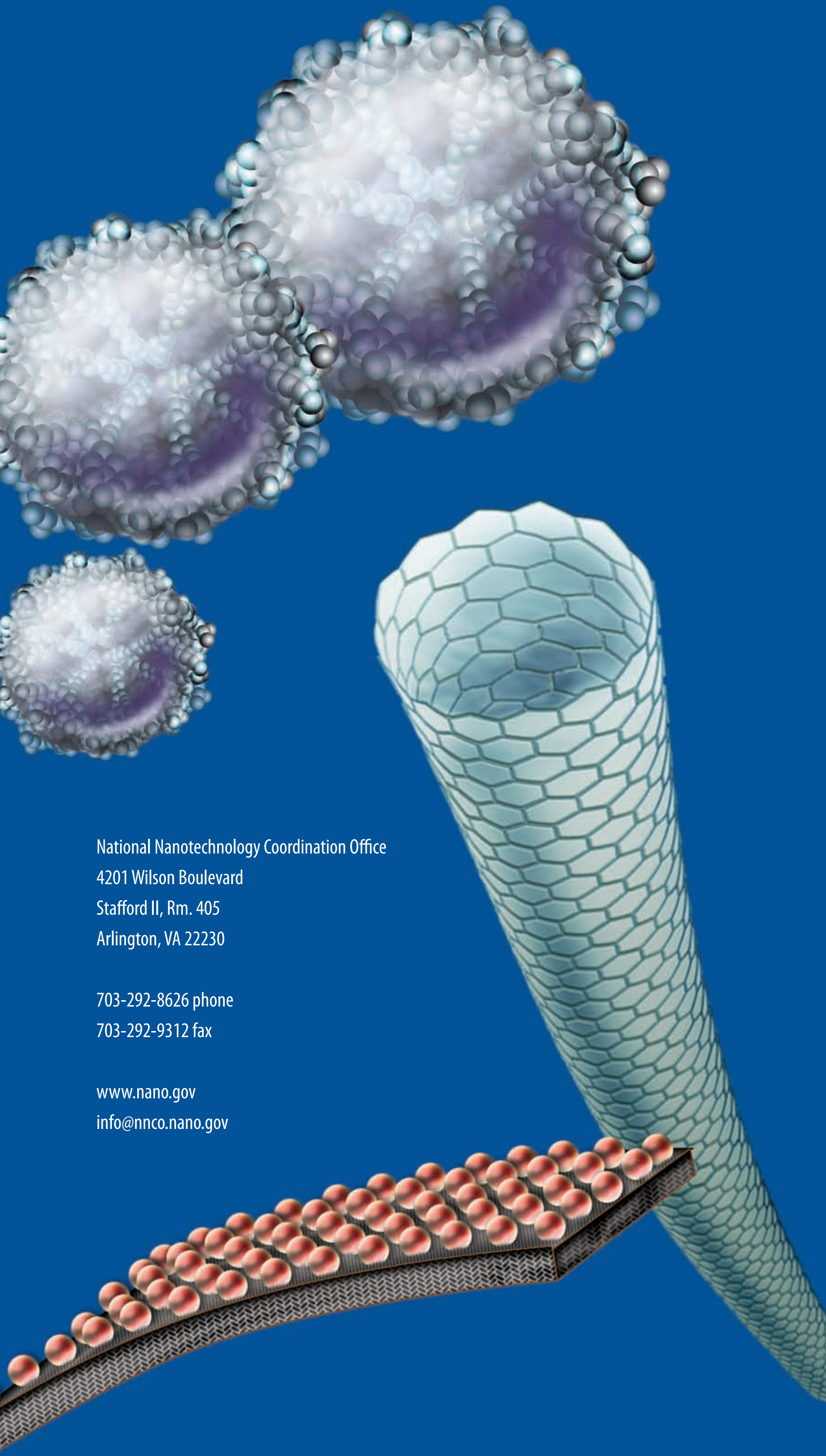
Nuclear Regulatory Commission
http://www.nrc.gov/

Patent and Trademark Office
http://www.uspto.gov/

Department of State
http://www.state.gov/

Department of Transportation
http://www.dot.gov/

Department of the Treasury
http://www.ustreas.gov/



National Nanotechnology Coordination Office
4201 Wilson Boulevard
Stafford II, Rm. 405
Arlington, VA 22230

703-292-8626 phone
703-292-9312 fax

www.nano.gov
info@nnco.nano.gov