Nanotechnology: Basic Information

Nanotechnology

Nanotechnology is the art and science of manipulating matter at the atomic or molecular scale and may lead to significant improvements in technologies for protecting the environment. Nanoscale structures are already being used for enhanced sensing, and treatment and remediation of environmental contaminants. On the bright side, future developments in nanotechnology may lead to greater control over the design of chemical and engineering technologies, such that pollution may be prevented in the first place. On the other hand, the novel characteristics of nanotechnologies may also lead to unforeseen environmental problems.

While many definitions for nanotechnology exist, EPA uses the NNI definition.

The NNI calls it "nanotechnology" only if it involves all of the following:

1. Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometer range.
2. Creating and using structures, devices and systems that have novel properties and functions because of their small and/or intermediate size.
3. Ability to control or manipulate on the atomic scale.

Nanometer

One nanometer (nm) is10^{-9} meter (a mμ or 10 Å) – the size of atoms and molecules   It takes about 3-10 atoms to span the length of a nanometer. In comparison, the diameter of a human hair is about 20,000 nm wide and a smoke particle is about 1,000 nm in diameter.

Click here for size comparison chart.

Highlights

February 12, 2008 - Read the Federal Register notice about EPA's Nanotechnology Research Strategy and meeting to review public comment:

- FR Notice Requesting Public comment on EPA's Nanotechnology Research Strategy and comment review meeting (PDF) (3 pp, 53 K)
- EPA's draft Nanotechnology Research Strategy (PDF) (76 pp, 1.10 MB)

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Structures that are made on a nanoscale level

Nanoscale structures are familiar to environmental scientists and engineers. Nanometer sized colloidal dispersions of solids, liquids, and gases in liquids (sols, emulsions, and foams, respectively) and solids and liquids in gases (smokes and fogs, or aerosols) are commonly encountered in the environment. For instance, natural weathering of minerals such as iron oxides and silicates, and microorganisms such as bacteria and algae can produce colloids,. In the environment, colloids can be also important in the fate, transformation, and transport of metals, toxic organic compounds, viruses, and radionuclides.

The structures of nanotechnology are important in how they are made and how their atoms are ordered. That is, a *nanoparticle* (a collection of tens to thousands of atoms measuring about 1-100 nanometers in diameter) is created atom by atom, and the size (and sometimes shape) of the particle is a controlled by experimental conditions. *Nanocrystal* is also used to describe these particles because the atoms within the particle are highly ordered or crystalline. A synthesized nanoparticle, however, is often called colloidal or a *colloidal crystal* because it is nanosized, and because it is typically dispersed or suspended in a stabilizing medium.

Nanoparticles can also be arranged or assembled into ordered layers, or *nanolayers*. Such self-assembly is due to forces such as hydrogen bonding, dipolar forces, hydrophilic ("water loving") or hydrophobic ("water hating") interactions, and surface tension, gravity, and other forces are involved in making such "self-assembly" happen. Many naturally occurring biological structures like membranes, vesicles, and deoxyribose nucleic acid (DNA) are formed by self-assembly. Repeating structures with a tailored periodicity are also important in applications of nanotechnology, like photonics and improved catalysts. Understanding and building nanostructures through self-assembly is at the core of creating nanotechnologies.

Nanotubes, most notably the fullerene-like "chicken-wire" construction of carbon atoms (carbon nanotubes or CNTs), are another important group of nanoscale structures. CNTs are stronger than steel while at the same time very flexible and lightweight. In addition to the remarkable mechanical properties, nanotubes could replace copper as an electrical conductor or replace silicon as a semiconductor. CNTs also transport heat better than any other known material. Together, these characteristics make nanotubes useful for a variety of applications, including super-strong cables, chemical sensors, nano-wires and active components in electronic devices, field emitters for flat-screen televisions, charge storage for batteries, "tips" for scanning probe microscope, or additives in nanofabricated materials.

Nanotechnology is really something new

Many things we are already familiar with are nanoscale and analogous to applications of nanotechnology. For instance, living organisms from bacteria to beetles rely on nanometer-sized protein machines that do everything from whipping flagella to flexing muscles. All biological cells are comprised of smart materials that self-assemble. Nanometer-sized carbon (carbon black) that improves the mechanical properties of tires, nanometer silver particles that initiate photographic film development, and nanometer particles that are the basis of catalysts critical to the petrochemical industry have contributed to commercial products for many years. However, all of the above examples of technologies are not considered nanotechnology because they do not involve specific atomic manipulations to achieve desired properties and functions of materials or products. Nanotechnology does involve purposeful atomic manipulations and structural assembly to achieve predetermined properties and functions.

Nanotechnology relate to existing disciplines like chemistry or biology

Nanotechnology overlaps significantly with many disciplines with chemistry, physics, and materials research are at the core of nanotechnology. These are the fields that discovered the atom and understood its inner workings, developed the science of combining them in precise structures, and developed tools with which these nanostructures are probed and visualized. Manipulation of atoms and nanostructures is what nanotechnology is all about.

Nanoparticles and other nanostructured materials are often synthesized using chemical methods. However, nanotechnology is fundamentally different from traditional chemistry because it deals with manipulation and physical control at the atomic level of chemicals. Synthesizing a chemical with nanotechnology could actually mean building it atom by atom. Traditional chemistry in contrast works on a bulk scale. Chemical syntheses typically result in poor yields of desired products with many unwanted by-products. Using nanotechnology to synthesize chemicals would result in 100% yield of the desired products and no by-products. It could also mean using a nanostructured catalyst in a traditional chemical reaction to improve the rate or yield of products.

For biologists, studying molecular-level structure and function is also nothing new. Applying nanotechnology, however, significantly alters the work of biologists. Traditional biology involves the study of living systems, ranging from bacteria to beetles to humans. All of these organisms rely on nanometer-sized protein machines (molecular motors) to do everything from whipping flagella to flexing muscles. An application of nanotechnology would be isolating one of these molecular motors from a living system and using it to construct a nanoscale device. A nanotechnology derived molecular motor might be fueled by sunlight and produce a rotational force that could pump minute volumes of fluids (e.g. pharmaceuticals) or open and close valves in nanomechanical devices.

U.S. government spending on nanotechnology

Federal funding for nanotechnology R&D has increased from $116 million in 1997 to an estimated $1.08 billion in 2005. The 2006 budget request calls for a total NNI budget of $1.054 billion.

Click here for the NNI 2006 budget supplement (PDF) (1 pp , 139 K) EXIT Disclaimer.

Other countries spending on nanotechnology

The United States is not the only country to recognize the tremendous economic potential of nanotechnology. While difficult to measure accurately, worldwide government funding is estimated to exceed $2 billion in 2002. Asian countries, including Japan, China and Korea, as well as several European countries, have made leadership in nanotechnology national priorities.

Funding research in nanotechnology

Nanotechnology has the potential to profoundly change our economy and to improve our standard of living, in a manner not unlike the impact made by advances over the past two decades by information technology. While commercial products are starting to come to market, some of the major applications for nanotechnology are five to ten years out. Consequently, government support for basic research and development in its early stages is required in order to realize nanotechnology's full potential and to maintain a competitive position in the worldwide nanotechnology marketplace.

EPA’s mission to protect the environment and human health calls for funding in the responsible development of new technologies. In other words, EPA’s research addresses how nanotechnology can help improve the current environment, prevent future environmental problems, and clean up the legacy of past pollution. In addition, EPA has responsibility for addressing the risk associated with new technologies and conducts research in the areas of toxicity, fate/transport of nanomaterials, and exposure routes to these new materials.

EPA's role in nanotechnology research

Nanotechnology is a revolutionary science and engineering approach that has the potential to have major consequences – positive and negative -- on the environment.

Nanotechnology can be *of benefit* to environmental protection in applications such as reducing use of raw and manufactured materials (dematerialization), minimizing or eliminating the generation of wastes and effluents, and reducing toxics. The environment is also protected in applications that more effectively treat waste streams and remediate existing polluted sites.

At the same time, *potentially harmful* effects of nanotechnology may exist. These effects might relate to the nature of nanoparticles themselves, the characteristics of the products made from them, or the aspects of the manufacturing process involved. For instance, nanoscale colloidal particles are involved in the fate, transformation, and transport of metals, toxic organic compounds, viruses, and radionuclides in the environment. Some nanomaterials have been found to cause toxic responses in test organisms.

It is also possible that nanotechnology and its products could lead to *societal changes* that influence transportation, urban development, information management, and other activities of our society that directly or indirectly effect the quality of the environment.

Because nanotechnology is an emerging area, however, it is still very much possibleto anticipate both the potential positive and negative impacts it might haveon the environment and then act to enhance what is beneficial and prevent orminimize what is harmful.

Products available today that have resulted from nanoscience

Over 700 nanoproducts are current available on the US market as of April, 2005. Most of these are nanoscale materials and instruments to characterize the materials. However, many materials are finding their way into consumer products. For instance, computer hard drives contain giant magnetoresistance (GMR) heads with nano-thin layers of magnetic materials that allow a significant increase in storage capacity. Non-volatile magnetic memory, automotive sensors, metal detectors and solid-state compasses are examples of electronic products.

Also in the marketplace are:

- Burn and wound dressings
- Water filtration devices
- Industrial catalysts
- A dental-bonding agent
- Step assists on vans.
- Coatings that allow for easier cleaning glass
- Bumpers and catalytic converters on cars
- Protective and glare-reducing coatings for eyeglasses
- Sunscreens and cosmetics
- Longer-lasting tennis balls
- Light-weight, stronger tennis racquets
- Stain-free clothing and mattresses
- Ink

Read more about Products and Applications.

Engineered/manufactured nanoparticles

Engineered/manufactured refers to those nanoparticles that do not occur naturally but are purposefully made. These are in contrast to incidental particles such as combustion ultrafine particles or occupational fumes like beryllium or welding fumes.

The number of researchers that are working in nanotechnology today

The current estimate is about 20,000 worldwide.

Future workforce needs

The National Science Foundation has estimated that 2 million workers will be needed to support nanotechnology industries worldwide within 15 years.

See:
University Education. What is nanotechnology?