Nanotechnology

by: Leslie Wood

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Preview
Nanotechnology is one of the most potentially world changing fields of research going on today and provides manufacturers with the ability to construct things such as electronic circuits and mechanical devices by assembling them molecule by molecule. This is referred to as molecular nanotechnology, or molecular manufacturing. Traditionally, things have been manufactured by cutting, scraping, and bending. Nanotechnology will allow things to be built with molecular precision by molecular machines called assemblers, much in the same way that plants and animals are put together by molecular machines called proteins.

In this report:

Executive Summary
Nanotechnology, or, as it is sometimes called, molecular manufacturing, is a branch of engineering that deals with the design and manufacture of extremely small electronic circuits and mechanical devices built at the molecular level of matter. This technology holds promise in the quest for ever-more-powerful computers and communications devices. But the most fascinating applications are in medical science. So-called nanorobots might serve as programmable antibodies. As disease-causing bacteria and viruses mutate in their endless attempts to get around medical treatments, nanorobots could be reprogrammed to selectively seek out and destroy them. Other nanorobots might be programmed to single out and kill cancer cells.

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When K. Eric Drexler, Co-founder, Chairman, Foresight Institute, popularized the word 'nanotechnology' in the 1980's, he was talking about building machines on the scale of molecules, a few nanometers wide —motors, robot arms, and even whole computers, far smaller than a cell. Drexler spent the next 10 years describing and analyzing these incredible devices, and responding to accusations of science fiction. Meanwhile, mundane technology was developing the ability to build simple structures on a molecular scale. As nanotechnology became an accepted concept, the meaning of the word shifted to encompass the simpler kinds of nanometer-scale technology. The U.S. National Nanotechnology Initiative was created to fund this kind of nanotech and their definition includes anything smaller than 100 nanometers with novel properties.

Much of the work being done today that carries the name 'nanotechnology' is not nanotechnology in the original meaning of the word. Nanotechnology, in its traditional sense, means building things from the bottom up, with atomic precision. This theoretical capability was envisioned as early as 1959 by the renowned physicist Richard Feynman.

While most uses of nanotechnology are highly speculative, such as using carbon nanotubes to create a ‘space elevator,’ some practical applications have emerged. However, concerns exist about possible unanticipated health and environmental risks, but several organizations are taking steps to preclude such hazards.

Today, nanomaterials are often combined with conventional materials to improve product functionality. Products benefiting from the unique properties of nanoscale materials include:

- Step assists on vans.
- Paints and coatings to protect against corrosion, scratches, and radiation.
- Protective and glare-reducing coatings for eyeglasses and cars.
- Metal-cutting tools.
- Sunscreens and cosmetics.
- Longer-lasting tennis balls.
- Stain-free clothing and mattresses.
- Dental-bonding agents.
- Burn and wound dressings.
- Automobile catalytic converters

A little more than a decade old, the nanotechnology market is growing at a rate of at least 30 percent a year, or twice as fast as the bio-tech market, and is expected to reach more than $28 billion by 2008 and $1,000 billion by the end of 2010.

Description

Nanotechnology is a field of science whose goal is to control individual atoms and molecules to create computer chips and other devices that are thousands of times smaller than current technologies permit. Current manufacturing processes use lithography to imprint circuits on semiconductor materials. While lithography has improved dramatically over the last two decades -- to the point where some manufacturing plants can produce circuits smaller than one micron (1,000 nanometers) -- it still deals with aggregates of millions of atoms. It is widely believed that lithography is quickly approaching its physical limits. To continue reducing the size of semiconductors, new technologies that juggle individual atoms will be necessary. This is the realm of nanotechnology.

Nanotechnology derives its name from the tiny size of the constituent components, which are measured in nanometers, or billionths of a meter. ‘Tiny’ means billionths of a meter, or about 1/500th the width of a human hair. In other words, a nanometer is one billionth of a meter, roughly the width of three or four atoms. The average human hair is about 25,000 nanometers wide.

Just how small is a billionth of a meter? It is:

- The thickness of one drop of water spread over a square meter.
- The approximate amount fingernails grow in a second.
- The slippage on the San Andreas fault in half a second.
- Ten times the diameter of a single hydrogen atom.
- Around 1/10th the thickness of the reflective coating on sunglasses.

Nanotechnology is sometimes referred to as a general-purpose technology. That's because in its advanced form it will have significant impact on almost all industries and all areas of society. It will offer better built, longer lasting, cleaner, safer, and smarter products for the home, for communications, for medicine, for transportation, for agriculture, and for industry in general.

Imagine a medical device that travels through the human body to seek out and destroy small clusters of cancerous cells before they can spread. Or a box no larger than a sugar cube that contains the entire contents of the Library of Congress. Or materials much lighter than steel that possess ten times as much strength

Like electricity or computers before it, nanotech will offer greatly improved efficiency in almost every facet of life. But as a general-purpose technology, it will be dual-use, meaning it will have many commercial uses and it also will have many military uses—making far more powerful weapons and tools of surveillance. Thus it represents not only wonderful benefits for humanity, but also grave risks.

A key understanding of nanotechnology is that it offers not just better products, but a vastly improved manufacturing process. A computer can make copies of data files—essentially as many copies as you want at little or no cost. It may be only a matter of time until the building of products becomes as cheap as the copying of files. That's the real meaning of nanotechnology, and why it is sometimes seen as 'the next industrial revolution.'

The power of nanotechnology can be encapsulated in an apparently simple device called a personal nanofactory (PN) that may sit on your countertop or desktop. Packed with miniature chemical processors, computing, and robotics, it will produce a wide-range of items quickly, cleanly, and inexpensively, building products directly from blueprints.

What could nanofactories produce?

- Lifesaving medical robots or untraceable weapons of mass destruction.
- Networked computers for everyone in the world or networked cameras so governments can watch our every move.
- Trillions of dollars of abundance or a vicious scramble to own everything.
- Rapid invention of wondrous products or weapons development fast enough to destabilize any arms race

Nanoscience research is pursuing the ability to assemble materials one molecule at a time, creating substances not found in nature -- substances featuring:

- Superlative strength to weight ratios.

- Dramatically increased electrical conductivity.
- Tremendous physical and chemical stability.
- Other properties which enable a vast array of aerospace, automotive, energy, and medical applications. For example, medical nanoscience is synthesizing cancer therapies that preferentially attack only cancer cells, leaving healthy tissue intact.

Stairway to the Stars
To illustrate the possible--but ‘far-reaching’ -- applications of nanotechnology, NASA envisions the use of carbon nanotubes (cylinder-shaped molecules of carbon 50,000 times thinner than a human hair) to fashion super-long, super-strong ‘space elevator’ cables. (Nanotubes are about six times lighter and 100 times stronger than steel.)

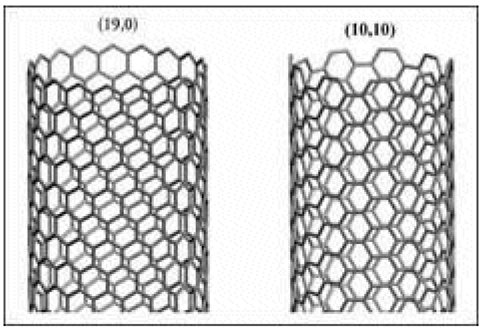

Figure 1 depicts two nanotubes.
Source: Carbon NanoTechnologies

First popularized by Arthur C. Clarke in his 1978 novel ‘Foundations of Paradise’, the concept of a space elevator is relatively simple: Put a platform is space (in geosynchronous orbit) and attaches two cables. One cable goes to the Earth and the other is attached to a captured asteroid, which acts as a counterbalance to keep the platform from being pulled out of orbit. Now put the equivalent of an elevator car on the cable and presto, a space elevator.

It sounds like a crazy idea, but if a super cable could be developed (say, with carbon nanotubes), the cost of hoisting cargo in space could decrease (in a November 2000 estimate) from $22,000 per kilogram to as little as $10 per kilogram.
According to a recent Purdue University research study, the carpet like growth of nanotubes has been shown to outperform conventional thermal interface materials. Purdue scientists found that unlike conventional thermal interface materials, the nanotube layer does not require elaborate clean-room environments, representing a possible low-cost manufacturing approach to keep future chips from overheating and reduce the size of cooling systems.

However in a not so far away place, scientists at Purdue University recently discovered that the carpet like growth of nanotubes has been shown to outperform conventional *thermal interface materials*. Like those materials, the nanotube layer does not require elaborate clean-room environments, representing a possible low-cost manufacturing approach to keep future chips from overheating and reduce the size of cooling systems.

Researchers are trying to develop new types of thermal interface materials that conduct heat more efficiently than conventional materials, improving overall performance and helping to meet cooling needs of future chips that will produce more heat than current microprocessors. The materials, which are sandwiched between silicon chips and the metal heat sinks, fill gaps and irregularities between the chip and metal surfaces to enhance heat flow between the two.

The method developed by the Purdue researchers enables them to create a nanotube interface that conforms to a heat sink's uneven surface, conducting heat with less resistance than comparable interface materials currently in use by industry.

In 2006, the University of Bath began an international £555,000 three-year project to develop a system which could cut out the need for wiring to carry electric currents in silicon chips.

Computers double in power every 18 months or so as scientists and engineers develop ways to make silicon chips smaller. But in the next few years they will hit a limit imposed by the need to use electric wiring, which weakens signals sent between computer components at high speed.

The new research project could produce a way of carrying electric signal without the need for wiring. Wi Fi internet systems and mobile phones use wireless technology now, but the electronics that create and use wireless signals are too large to be used within individual microchips successfully.

The research project, which involves four universities in the UK and a university and research center in Belgium and France, will look at ways of producing microwave energy on a small scale by firing electrons into magnetic fields produced in semi-conductors that are only a few atoms wide and are layered with magnets.

If this research is successful, it could make computers with wireless semi-conductors a possibility within five or ten years of the end of the project. Then computers could be made anything from 200 to 500 times quicker and still be the same size.

And, the University of Houston is working on a project that just may remove semiconductors from the world stage. Just as compact discs all but wiped out vinyl records, semiconductors could be on their way out, too. A University of Houston professor recently developed a similar ‘disruptive technology,’ using magnetic cellular networks, that could yield such benefits as increased computing power that rivals what is possible with semiconductor integrated circuits.

Integrated circuits, which are a microscopic array of electronic circuits and components that have been implanted on the surface of a single chip of semiconducting material, have become the principal components of almost all electronic devices. Compared to the vacuum tubes and transistors that preceded them, integrated circuits have provided a low-cost, highly reliable way for computers to respond to a wider range of input and produce a wider range of output.

Dmitri Litvinov, associate professor of electrical and computer engineering and of chemical and biomolecular engineering in the Cullen College of Engineering at UH, is working with specially arranged assemblies of nanomagnets, or magnetic cellular networks, to replace conventional circuitry and significantly improve computing operations. His research involves a system of interacting magnetic nanocells that could combine logic, random access memory and data storage in a single nanomagnetic computing system.

Working from logic gates, which are at the heart of a computer's ability to add, subtract, multiply and divide, Litvinov wants to demonstrate that the magnetization of adjacent magnets is possible and can be used to perform specific logic and computing operations, reversing the repulsive and attractive poles of magnets.

Current View

While, today, a number of devices, such as computer hard drives, are nano-enabled, the nanotechnology industry is considered by some to be "pre-competitive", meaning the application of nanotechnology, while viable, is still commercially limited.

Nanotechnology Applications

Improved nano-engineered ferroelectric crystals could realize a 50-year-old dream of creating nonvolatile random access memory (NVRAM). The first fruits of it can be seen in Sony's PlayStation 2 and in smart cards. A simple wave of a smart card identifies personnel or pays for gas or public transportation.

Random Access Memory (RAM) is used when someone enters information or gives a command to the computer. It can be written to as well as read but - with standard commercial technology - holds its content only while powered by electricity.

However, today scientists have already created materials and are studying nanoscale crystals of ferroelectric materials that can be altered by an electrical field and retain any changes. (Ferroelectric materials behave similarly to ferromagnetic materials even though they don't generally contain iron and consist of crystals whose low symmetry causes spontaneous electrical polarization along one or more of their axes. The application of voltage can change this polarity. Ferroelectric crystals can also change mechanical to electrical energy– the piezoelectric effect – or electrical energy to optical effects.)

A strong external electrical field can reverse the plus and minus poles of ferroelectric polarization. The crystals hold their orientation until forced to change by another applied electric field. Thus, they can be coded as binary memory, representing "zero" in one orientation and "one" in the other.

Because the crystals do not revert spontaneously, RAM made with them would not be erased should there be a power failure. Laptop computers would no longer need back-up batteries, permitting them to be made still smaller and lighter. There would be a similar impact on cell phones.

And, if Fujitsu's latest hard-drive research bears fruit, we could soon be looking at 2.5-inch hard drives capable of storing as much as 1.2TB each.

Figure 2: 1 Terabyte laptop drives will by ready for production by 2010
Source: Fujitsu

The breakthrough in cramming terabyte-class storage into laptop drives is courtesy of perpendicular recording combined with nanotechnology. This creates ordered, tightly packed 'nanoholes' capable of storing bits of information. The result is a higher density of data per unit of surface area and up to 1.2TB on just two 2.5-inch platters. By contrast, current 1TB 3.5-inch drives require five platters to reach that mark.

Fujitsu estimates the new drives will by ready for production by 2010, although it still has to address several issues, including warming the drive before writing and magnetic flux requirements.

In developing the new drive, various Fujitsu arms worked together with Japan's Kanagawa Academy of Science and Technology.

Since the Project on Emerging Nanotechnologies launched the world's first online inventory of manufacturer-identified nanotech goods in March 2006, the number of items has increased 175 percent—from 220 to 580 products. There are 356 products in the health and fitness category—the inventory's largest category—and 66 products in the food and beverage category. One of the largest subcategories is cosmetics with 89 products. All are available in shopping malls or over the Internet. The list includes merchandise from such well-known brands as Samsung, Chanel, Black & Decker, Wilson, L.L. Bean, Lancôme and L'Oreal.

According to Andrew Maynard, science advisor with the Project on Emerging Nanotechnologies the use of nanotechnology and nanomaterials in consumer products and industrial applications is growing rapidly, and the products listed in the inventory are just the tip of the iceberg. Maynard says that how consumers respond to these early products—in food, electronics, health care, clothing and cars—will be a bellwether for broader market acceptance of nanotechnologies in the future.

Government Regulation

As with any new technology, nanotechnology has its share of detractors, including those who fear the proliferation of near-invisible--potentially self-replicating--devices. Recognizing a potential public backlash, leaders of the nanoscience research and development community have joined forces to form The Foresight Institute, an organization that advocates voluntary industry regulation. Based on the successful self-regulation model pioneered by the biotech industry, The Foresight Institute has articulated a set of research guidelines designed to forestall crippling government regulation.

Foresight research guidelines include:

- Artificial replicators must not be capable of replication in a natural, uncontrolled environment.
- Evolution within the context of a self replicating manufacturing system is discouraged.
- Any replicated information must be error free.
- Device design should specifically limit proliferation and provide traceability of replicating systems.
- Developers should attempt to systematically consider environmental consequences of the technology, and to limit these consequences to intended effects. This requires significant research on environmental models, risk management, as well as the theory, mechanisms, and experimental designs for built-in safeguard systems.
- Industry self-regulation should be designed in whenever possible. Economic incentives could be provided through discounts on insurance policies for development organizations that certify Foresight Guidelines compliance.
- Willingness to provide self-regulation should be one condition for access to advanced forms of the technology.
- Distribution of molecular manufacturing development capability should be restricted, whenever possible, to responsible actors that have agreed to use the Guidelines. No such restriction need apply to end products of the development process that satisfy the guidelines.

Health Concerns
While nanotechnology shows promise in many areas, such as converting waste water into palatable water and "eating" industrial waste, some fear that such technologies might produce "nano-pollution" that have health repercussions for mankind--a microscopic equivalent of acid rain. Scientists at the University of Rochester Medical Center has conducted studies that show that, when inhaled by rats, nano-particles travel quickly to several areas of the rats' brains. The results of such build-ups are not yet clear, but are of concern.

Two nanotechnology organizations are working together to take a proactive approach to the health risks of nanotechnology. The International Council on Nanotechnology (ICON) and Rice University's Center for Biological and Environmental Nanotechnology (CBEN) together have created a database marshalling research on nano-related health risks and benefits. The database is called the Environmental Health and Safety (EHS) Database, and can be accessed through the ICON website.
Outlook

Burgeoning Market
The global market for nanotechnology was estimated at $7.6 billion in 2003. Analysts at Business Communications Company forecast a growth rate of at least 30 percent a year, reaching $28.7 billion in 2008, or twice the growth rate of the bio-tech market. The National Science Foundation estimates that nanotechnology industries will employ two million workers worldwide within 15 years.

Venture capitalists have increased their investments in nanotechnology 600% over the previous two years. About 600 companies worldwide are active in nanotechnology, as well as 300 major university research teams in 28 countries. In 2004, technological industry leaders such as IBM, Intel, and Samsung, spent $3.8 billion on nanotechnology. In 2005, $410 billion was spent

The US, along with Japan, China, Korea, and Europe have established nanotechnology research as a major priority. The National Nanotechnology Initiative, a federal research and development program established to coordinate efforts in nanoscale science, engineering, and technology, has established a $982 million fund for research and development in the field for 2006.

The dark side of a burgeoning market entails the possible dangers of nanotechnology being implemented in developing countries that do not have the ability to instill government regulations and practical policies that are needed to safeguard either their populations or the global environment from unanticipated repercussions from nanotechnology. A report by UNESCO this year raised the concern that poor countries might not have the access to scientific information that is necessary to minimize risks. To prevent this situation from developing, UNESCO recommends that the international scientific community find ways to end the knowledge gap both between and inside nations. The report also recommends that global regulatory frameworks be put into place.

Military Applications

Military applications are the greatest driver of nanotechnology. Currently, the US government is the world leader in nanotechnology funding and research, with a special emphasis on military applications. To illustrate:

- The CombiMatrix Group won a $5.9 million contract to enhance its micro-array technology to detect biological agents, including various viruses, toxins, and bacteria.
- The US Army wants uniforms that turn into lightweight body armor on command; a development that many nanotechnologists predict will be achieved within 10 years.

Nanotechnology could be used to create more powerful and accurate surveillance systems. The increased amount of data gathered by the sensors could be processed through nano systems to identify viable threats. Intelligent sensors and barrier systems could be tailored to local terrains in order to control the movement of enemies. Nanotechnology could be used to create small and inexpensive anti-tank systems, reducing the number of infantry required to defeat large armored forces. Nuclear weapons could be replaced by nano-guided systems that could surgically destroy targets, reducing the amount of damage to nearby civilians and buildings.

The risk, however is that the technology could fall into the hands of enemies of the state. To combat this risk, the Foresight Institute was founded. The Foresight Institute is a think tank created in 1986 to prepare for the advent of nanotechnology; today, the Foresight Institute focuses on advancing beneficial nanotechnology by guiding nanotechnology research, public policy and education to address the major challenges created by nanotechnology. The Foresight Instititute works with governments, multi-national organizations, non-governmental organizations, environmental organizations, and other entities to develop usage and security policies relating to nanotechnology.

Future Applications

According to the National Nanotechnology Initiative, "the pharmaceutical and chemical industries are being impacted greatly by nanotechnology. New commercial applications of nanotechnology that are expected in two to five years in these and other industries include:

- Advanced drug delivery systems, including implantable devices that automatically administer drugs and sensor drug levels.
- Medical diagnostic tools, such as cancer tagging mechanisms and lab-on-a-chip, real time diagnostics for physicians.
- Cooling chips or wafers to replace compressors in cars, refrigerators, air conditioners and multiple other devices, utilizing no chemicals or moving parts.
- Sensors for airborne chemicals or other toxins.
- Photovoltaics (solar cells), fuel cells, and portable power to provide inexpensive, clean energy.
- New high-performance materials.

Future nano-enabled computing elements are expected to be so inexpensive that they can be deployed in fabrics (for smoke detection, for instance) and other materials.

Recommendations

There is nothing to suggest that nanotechnology simply can't be done as real research is going on today, and real progress has been made.

Analyst David Forrest advises corporations to adopt strategies to avoid being "blindsided" by nanotechnology development (as were pharmaceutical companies by advances in biotechnology). "Industry can cooperate with government institutions, professional societies, and standards organizations to:

- Focus research priorities appropriately
- Insure the adequate training of scientists, engineers, and technologists.
- Address public safety and environmental concerns.
- Address national security concerns
- Look for Nanotechnology Investment Opportunities

The National Nanotechnology Initiative contends that 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. Forward-thinking companies should consider:

- Investment in nanotechnology firms.
- The role that nanotechnology can play in improving their own products and services.
- How nanotechnology could impair the demand for their own products or services.

Conclusion

Nanotechnology is one of the most potentially world changing fields of research going on today. Broadly speaking, it's any technology involving devices at the nanometer scale. Ultimately it will lead to the ability to manufacture things by assembling them molecule by molecule. This is referred to as molecular nanotechnology, or molecular manufacturing. Traditionally, things have been manufactured by cutting, scraping and bending. Nanotechnology will allow things to be built with molecular precision by molecular machines called assemblers, much in the same way that plants and animals are put together by molecular machines called proteins.

The ability to build things on a molecular scale will give the human race absolute control over matter. Firstly, very small things can be made. Computers can be made several orders of magnitude smaller and faster, storage devices can have a single molecule per bit of data. Secondly, large things can be made with near perfect structures. Tall buildings, long bridges, and efficient spacecraft can be built out of a single piece of carbon crystal. Anything that can be designed on a computer could be prototyped instantly - in much the same way that software is designed, with small changes being implemented, then tested - all within a few minutes. The cost of manufacturing will become insignificant. Design costs will become all important.

About the Author

Leslie C. Wood is a freelance technology and business writer based in Philadelphia, PA. She specializes in white papers, case studies, articles, user guides, training manuals, online help, educational courses, and software documentation. She also writes lifestyle articles for several local and national publications. Her email address is lcw@writer4u.com. Her Web site address is www.writer4u.com.

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