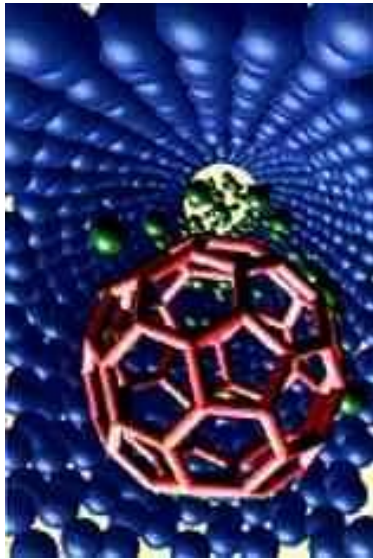


Technology Topics for Investors

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Nanotechnology in a Nutshell

Nanotechnology has been a hot topic on the scientific circuit for many years, but the buzz of nano is finding its way into the mainstream press, and the possibilities are washing unchecked over a wider audience. What is nanotechnology, and what does its development mean for our future? This article by technology analyst David J. Roughley spells out the key ideas—without the hype.

Actor Robin Williams popularized the word *nano* in his late 1970s comedy TV series *Mork & Mindy* (about the adventures of a naïve alien who lands on earth). But most scientists track the beginning of nanotechnology to a 1959 presentation "There's Plenty of Room at the Bottom" by visionary Cal Tech physicist Richard Feynman. In his lecture, Feynman talked about a future in which superior mechanical, electronic, and biological systems might be created by manipulating materials at the atomic and molecular scale. And though the tools to achieve such manipulations were not yet available, he noted that—in principle—no fundamental reason existed why they could not one day develop. Feynman had identified the seeds of a powerful trend that during the next 40 years helped launch the field of electronics, the PC, the Internet, genetics, and biotechnology and enabled many of the everyday objects we now take for granted—all through improving control of materials at the micro scale. As Feynman anticipated, scientists are now on their way to creating a suite of tools and technologies that will enable them to interact at the nano scale too

What Is Nanotechnology?

Nanotechnology has become an umbrella term for a wide range of technologies and processes that can manipulate or exploit materials with an organized structure at the nanometer scale (1 nanometer is 10^{-9} meter). A typical atom is 1/5 nanometer (nm) in diameter (viruses vary from 25 nm to 300 nm) and the smallest features on a leading-edge microprocessor chip are about 130 nm. By comparison, the diameter of a human hair is massive—about 100,000 nm. Influencing the behavior of materials at the atomic scale may seem a curious scientific pursuit, but in many applications

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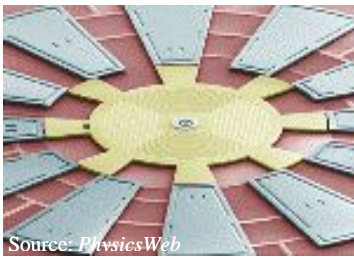
of technology the macroscopic behavior of a system is determined by the atomic structure. To illustrate: Quantum physics may seem irrelevant in everyday life, yet a thorough understanding was first necessary before engineers could reliably fabricate the sandwich of atomically precise semiconductor layers that formed the laser at the heart of a compact-disc player. Without a basic scientific foundation and years of commercial development, this ubiquitous device would never have emerged. Nanotechnology is taking some of the same ideas a step further; in quantum dots, for example, that could help to authenticate bank notes or credit cards "invisibly" or even to tag biomolecules to aid research. The materials to achieve these advances are commercially available now, and the applications and business opportunities will no doubt follow shortly. Many other unexploited nanoscale capabilities still await discovery, research, and subsequent development efforts, which helps explain the excitement that now surrounds the technology. Perhaps the most easily visualized nanosystems are biological ones in which researchers are learning to identify—and then manipulate—the genetic codes locked in long-chain DNA molecules and to alter their subsequent behavior. Scientists have figured out how to pick up and move single molecules or atoms using a scanning tunneling microscope, thus allowing them to "build" atomic arrangements. For example, in one famous experiment, IBM spelled out the company's acronym in rows of single atoms that it had placed in order.



Source: PhysicsWeb

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Source: PhysicsWeb

The semiconductor industry that produced increasingly powerful computers, cell phones, and electronic devices of all kinds has applied its skills to machine and form silicon and other materials into microscopic mechanical devices that can measure pressure changes (illustration) and acceleration and even do mechanical work on a tiny scale. Most are still too large to be nanodevices, but some developers think that today's processes and techniques will eventually become capable of creating nanoelectromechanical systems (or NEMS). Some researchers talk about atomic assemblers that are themselves submicron in size (1 micron is a thousand times bigger than 1 nanometer). The ideas can be intoxicating, but the truth is that nanotechnology has different meanings to different groups, and the term has become

a buzzword encompassing a range from fundamental and theoretical studies on the nature of material to devices and applications that could have come straight from the pages of a science-fiction novel. All nanotechnology is not the same.

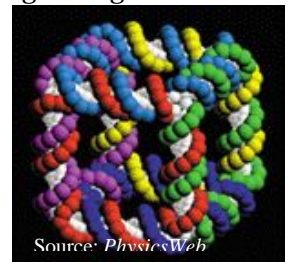
A Generic Name for Diverse Capabilities

Field	Applications	Comments
Materials	Quantum wells and quantum dots, nanocrystals, nanoparticles, nanotubes, NEMS, self-assembled monolayers	Devices/systems that can exploit nanoscale mechanical, electrical, magnetic, atomic, and quantum effects to improve functionality
Energy/Storage	Advanced batteries, capacitors, photovoltaics, fuel cells. Micro-power supplies might also be included	Devices/systems that enhance power storage and delivery through control of materials and surfaces at the atomic level
Biotechnology	Biochips, biosensors, drug-delivery and drug-discovery products, diagnostics, nanosurgery	Devices/systems that localize or target biological processes to improve diagnostics, drug delivery, or synthesis
Electronics	Smart goods, nanoelectronics, pervasive electronics, imaging systems	Electronic (or optical) systems that are so tiny that they are virtually invisible and can be deployed anywhere and in new ways
Computing	Quantum computers, molecular computers, optical computers, DNA computers	Systems that aim to use alternative (non-electronic) methods to represent and process data at higher rates or in new ways

Source: David J. Roughley

How Do Scientists "Do" Nanotechnology?

Basically two methods of manufacturing exist: top-down and bottom-up. In top-down manufacturing, researchers selectively reform, add to, chip away, or modify the starting material to create a material with new functionality at a smaller scale. Both humans and nature use top-down processes: The erosion of raised geological regions to form mountains is one of nature's examples; the formation of a statue from a block of marble is a human example. Bottom-up manufacturing approaches from the opposite direction, building larger and more complex systems from elementary (smaller) subcomponents. So far, scientists have had little access to bottom-up processes at the nano scale, but all natural construction follows this model (for example, think of the formation of a strand of DNA from four chemical bases: adenine, cytosine, guanine, and thymine). A human approach to bottom-up manufacturing might be the creation of the Egyptian pyramids or the creation of a book from sheets of paper covered in symbols. It is clear that both top-down and bottom-up processes can occur at the macro and micro scales. And though this observation may seem academic, it becomes important when we try to think about the future of nanotechnology in context. Clearly, two ways exist of approaching nanotechnology. The first way is for engineers to continue improving current top-down semiconductor (and related) technologies until they can work in the nano range. The second way is for



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engineers to find ways to exploit the nano-scale components and mechanisms already provided by nature in order to fabricate devices or structures (or to conceive tools that can simulate nature's processes). This distinction that separates nanotechnology into two threads with very different starting points, ambitions, threats, and opportunities is very important (see **Approaches to Nanotechnology**).

Approaches to Nanotechnology		
	Pros	Cons
Top-Down	Some top-down approaches are already well developed and are exploited at the micro scale, and their incremental trend to function at smaller dimensions is feasible. Near-term commercialization is possible due to predictable cost/time of achieving evolutionary advances.	Top-down approaches will eventually reach limits imposed by the technology, unacceptable cost, or inadequate ROI. Some nanoscale processes may never be feasible at all by top-down approaches. Bottom-up solutions may eventually outrun top-down solutions.
Bottom-Up	Bottom-up approaches have the potential to allow fundamentally new assembly and manufacturing processes at the atomic and molecular level. The opportunities for exploitation will expand, rather than narrow, as the basic principles of operation and tools are developed.	Bottom-up processes are less well developed in terms of their application, are less well understood, require more fundamental scientific study, and have far less certain outcomes in commercial terms. Some key processes under debate may never be realized. At best, their exploitation cycle will be relatively long.

Source: David J. Roughley

An example of the scale of technological and commercial forces that drive nanotechnology comes from the microelectronics industry. Significant challenges are looming in the next decade as technologists continue to miniaturize the basic transistor for reasons of improved economy and performance. As the devices become smaller, control of the intricate flow of electrons with existing top-down processing becomes harder. At present, engineers can handle the onset of these problems through clever designs, new materials, and the adaptation of process technology. But at some point these fixes will become increasingly difficult to achieve because of the rising importance of quantum effects in devices that have features just tens of nanometers in size (quantum effects have always been present, but they begin to dominate as the devices grow smaller). Theoreticians, scientists, engineers, and industrialists are all debating what will follow. Some nanotechnologists are flirting with the idea that bottom-up approaches could eventually enable tiny machines that could "self-assemble" computer chips, making the existing semiconductor infrastructure redundant. Are such ideas realistic? Though new ideas are plentiful, the established silicon technology infrastructure is likely to remain the foundation on which any new paradigms are built. And though the concepts of data representation and processing are under scrutiny, alternative approaches will still need to meet the performance and economic standards established by the resident technology. In fact, top-down and bottom-up approaches may not conflict at all and could both be necessary for scientists to achieve the most significant advances. In addition, the presence of several alternative approaches to future electronics—that are diverse in terms of application and maturation time—leads to the possibility of extended opportunity windows, where each technology first leapfrogs, incubates, and then becomes the springboard for subsequent progress. The bottom line is that in the last 40 years, chip companies have invested billions of dollars to develop their existing infrastructure—much of it based on constant renewal and innovation. So if any technology shift is to occur, they have the greatest incentive and the necessary resources to implement it.

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How Important Is Nano?

In a recent presentation here in Vancouver, Richard Lipsey—professor emeritus of economics at Simon Fraser University—talked about general-purpose technologies (GPTs) and the role that they have played in the development of human civilization and society for millennia. The wheel, the printing press, and (in more recent times) the silicon transistor all qualify as GPTs, and in each case their wide application revolutionized society in a lasting way. However, Dr. Lipsey notes that with each passing century GPTs have been arriving with increasing speed and that fact presents unique threats and opportunities to society and commerce in the modern age. The best recent example of a GPT is the Internet, which has not only changed the way people exchange information, but has begun to alter the very fabric of society (at least in electronically dependent nations). Some people see nanotechnology as the next GPT that will leave its mark on the face of technology and society. Nanotechnology certainly has the potential to enable many technological hopes. Embedded sensors that are no bigger than a pin head might constantly monitor air quality in a building, detect fire hazards before any real danger occurs, or unobtrusively track the migratory paths of birds. Tiny drug delivery systems might function intravenously or subcutaneously, delivering precise doses of drugs to specific targets in the body. Novel forms of neurosurgery based on nanobioelectronics might one day offer a chance to help patients with dysfunction. Conversely, nanotechnology also has the potential to create new challenges. "Nanophobes" warn of a future in which out-of-control nanorobots wreak havoc inside our bodies, a world without privacy, and the ultimate synthetic viral infestation. Reality will differ from both these visions. Extreme opinions frequently accompany new technological capability; in all cases, the diversity of opinion itself ensures that the future unfolds in more digestible doses.

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Funding and Growth

Nanotechnology is still very much in the melting-pot stage, but already developers are pursuing a range of opportunities that they believe will provide some key advantage over existing systems or processes (see **Selected Nanotechnology Areas and Developers** for a few examples—many more exist). Even while they are thinking about the tools they will need to build nanosystems, nanotechnologists are visualizing the applications and potential opportunities that could follow. So an intense mixture of creativity, innovation, entrepreneurship, and urgency exists in the world of nanotechnology. However, all this effort is not toward a single goal or application—which presents its own challenges, because although the broad topic of nanotechnology provides many potential opportunities for success, to attract the critical mass of resources necessary to realize a specific positive commercial outcome is also more difficult (and even harder if the aim is long-term theoretical research). Somehow, having raised public attention to nanotechnology in general, developers next have to focus attention on their specific ambitions. Typically, much of the precommercial work in broad-use technologies takes place in universities and academic institutions. Regional or federal funding is often the only source that can meet the significant costs of R&D projects at this stage. The United States in particular has made full use of its defense infrastructure to research and develop many technologies for both military and civilian applications. In November 2003, the U.S. Senate approved \$3.7 billion over four years for nanotechnology R&D. In addition, at least 12 States have initiated local funding programs ranging

Different Viewpoints

Nanofuturist: Nano is a revolutionary set of technologies that will allow us to move physically, biologically, mentally, and socially closer to the products of our technology and to each other (symbiosis).

Antinanoist: Nano means insidious, hidden technology, with the potential for runaway self-replication as dangerous to society as—and even less controllable than—biotechnology.

Nanorealist: Aims to exploit the unique properties that come from knowing the precise size, form, or position of atoms and molecules in products and processes that customers are virtually guaranteed to pay premium prices for within the normal business cycle.

Source: Brock Hinzmann, SRI Consulting Business Intelligence

in size from \$0.5 million to \$50 million per year. The European Union has also martialed its advanced research projects infrastructure to support burgeoning nanotechnology topics, as have other regions, including China, Russia, Switzerland, Australia, and Israel (see **Federal Funding for Tiny Technologies**). Total estimated global government funding in 2003 was US\$2.5 billion, with expectations as high as US\$4.5 billion for 2004

Selected Nanotechnology Areas and Developers

Products	Ventures	Major Players
Bulk Inorganics	Nanophase Technologies	DuPont
Fullerenes and Carbon Nanotubes	ONI, Hyperion, Carbon Nanotechnologies NanoMix Inc.	Mitsubishi
Nanomaterials, Industrial Applications	Komarka, Eikos, Five Star Technologies, Nano-Tex	Dow Chemical, Samsung, Mobil Oil
Tools, Metrology and Manufacturing Software	Imago, Nanoink, nPoint, Zyvex	Veeco, IBM
Energy Storage	Altair Nanotechnologies	ABB
Nano-life Science and Diagnostics	Nanofluidics, Nanosphere, Nanogen	Roche
Nano-biotherapeutics	C-Sixty, iMedd	Bayer
Information Storage	Nantero, Nanochip, D-Wave Systems, Mitre	IBM, Seagate
Nanoelectronics	CALMEC, MatElec, Molecular Electronics Corp.	IBM, Hewlett-Packard, Infineon
Optical Nanocommunications	NanoOpto, NeoPhotonics, Nanoco	Lucent
Displays	Optiva. Inc., Applied Nanotech Inc., CSIRO	Samsung Advanced Institute of Technology

Source: Ardesta, David J. Roughley

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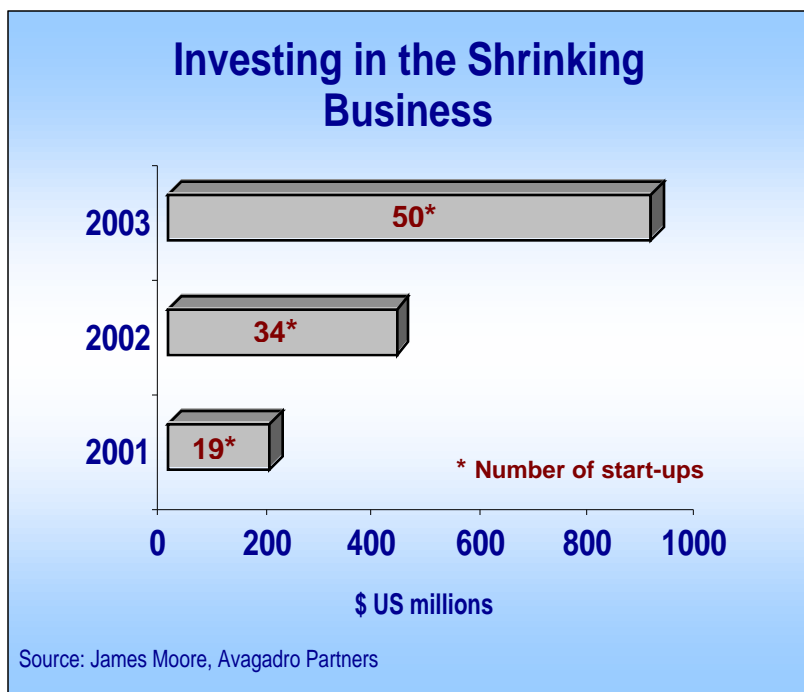
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The second phase of technology growth is usually characterized by increasing private-sector support through angel and venture-capital (VC) investors. Young companies spin off from their academic roots or from their parents/incubators to establish early territory through intellectual-property (IP) positions (patents and licensing), and much value attaches to strong patent positions in emerging technologies. Although federal funding has been gravitating strongly to

...visionary technologies have a habit of attracting visionary investors who are not always content to wait for the future to come to them.

Federal Funding for Tiny Technologies	
Canada:	US \$120 million over five years
EU:	Announced EU700 million from 2002-2006 as part of the 6th Framework Programme. Excludes manpower and Infrastructure costs. Fixed budget.
Japan:	Approved US \$650 million FY 2003
Taiwan:	Reported investments of US \$685 million from 2003-2009
USA:	The Senate recently approved the US \$3.7 billion 21st Century Nanotechnology Research and Development Act over four years. Includes manpower and infrastructure costs. Excludes medical and military projects. Flexible budget.

nanotechnology during the past few years, VCs are also beginning to find a few opportunities in the nanotechnology space, though—according to James Moore of Avagadro Partners—the volume is still comparatively modest (see **Investing in the Shrinking Business**). Nonetheless, VC funding is likely to grow at more than 30% a year. Moore further notes that from the VC perspective, nanotechnology is currently at a development stage similar to that of biotechnology in the 1980s, which characterizes it as high risk and with little scope for short-term exit strategies. Therefore, investors will need patience—not to forget courage. Nonetheless, visionary technologies have a habit of attracting visionary investors who are not always content to wait for the future to come to them. For example, NanoTex (not to be confused with Nano-Tex—a textiles company in **Selected Nanotechnology Areas and Developers**) is a Houston, Texas-based organization that aims to raise funding directly from wealthy individuals to support research in Texas universities. This initiative is one of several now under way that aims to establish Texas as the global



nanotechnology leader. Dozens of other locations likely have similar ambitions, though not all are as well positioned. Other funding routes are also possible. In Canada, AMR Technologies Inc. has signed agreements with Singaporean agencies to apply its expertise in nanotechnology to rare-earth materials—effectively exporting its know-how. Reportedly, more than 1500 start-ups have already formed to exploit various nanotechnology-based positions—more than half of them in North America. All these start-ups cannot succeed, but this kind of frenetic growth is not unusual and is an important generator of IP resources in any emerging field. Start-ups aside, many nanotechnology champions are established organizations seeking to exploit a "nanoangle" of their existing business in the hope of increasing investor enthusiasm, attracting consumer attention, or staying ahead of the competition (for example, IBM claims world leadership in nanotechnology). For young and mature companies alike, a large part of strategic technology development is to understand and defend their corporate position in a changing external environment, often through buying,

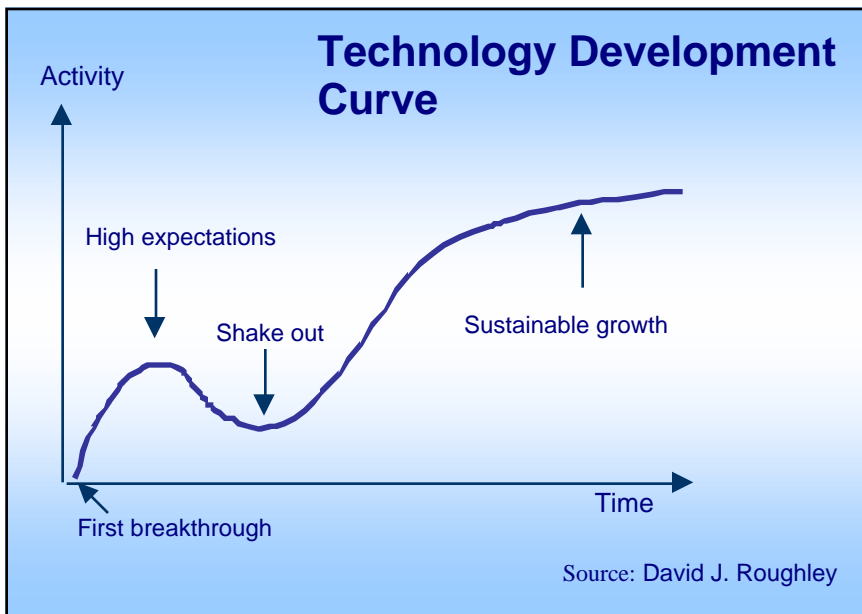
selling, or circumnavigating IP positions established by competitors. In this pursuit, early entrants have a noticeable advantage. So right now, much of the action is about defining territory that may (or may not) lead to workable

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businesses later. Accompanying this phase is a buzz of interest that is typical of the technology-push phase of emerging technologies.

The Development Curve: Opportunities and Hype



More than a decade ago business analysts—including consultants at SRI Consulting Business Intelligence (SRIC-BI)—began looking at the way new technologies emerged in terms of their actual technical progress versus their apparent commercial success. Using topical technologies (including superconductivity and nanotechnology), they began to observe common patterns. Their analysis suggested that business enthusiasm did not necessarily track the technical development curve in the early years of growth. In fact, after the first significant innovation or breakthrough, commercial appetite often exceeded the scientific foundation to support it, leading to rapid growth and equally rapid decline. This process resulted in short-term financial losses and waning business interest—creating the so-called hype curve (see **Technology Development Curve**). The model also indicated that technical progress often continued at a

steady pace until business confidence returned in a more predictable and controlled way to provide increasing support in the later stages of research and early market commercialization. Plunges in business confidence were accompanied by market shakeouts, leaving fewer (but more committed) companies to develop their application areas. The exact nature of the curve is still under discussion and varies according to the measured characteristics and the time period (for example, a typical time scale for the schematic **Technology Development Curve** might be 10 to 20 years). Regional, financial, and market factors can also influence the shape of the curve. But the basic observation that

...commercial appetite often exceeded the scientific foundation to support it, leading to rapid growth and equally rapid decline.

business interest and technological capability do not match well in the early stages is now established. One can view nanotechnology as a collection of discrete processes and technologies at different states of maturity and having different levels of impact so the overall picture is better represented as a superposition of multiple development curves. All these technologies will experience different growth rates—some will be relatively mature in their own field; others will be purely theoretical or barely proved, underscoring the considerable limitations implicit in collecting these diverse topics under a single defining title.

Though hype is most commonly associated with commercialization efforts, scientists also occasionally fall prey to hype, as demonstrated by the cold-fusion debate in 1989: Leading researchers short-circuited the traditional peer-review process and went directly to the public with their discovery of "free" energy. The dot-com bust in early 2000 also demonstrated a hype-curve characteristic. Will the same happen to nanotechnology? According to James Moore, that outcome is unlikely. Equipment is expensive, and IP positions are complex. In addition, the technology-adoption cycle is much longer, which also acts like a brake on unwarranted commercial exuberance. Nonetheless, at all levels, decision makers are concerned about the impact of hype on "real technology." Nanotechnology will likely see both positive and negative fluctuations on its way to maturity. From an investor's point of view, some careful analysis and good appreciation of the longer-term trends and wider perspectives becomes crucial. Analysts at SRI Consulting Business Intelligence (SRIC-BI) search constantly for signals of change in technology and business practices through their Scan and Explorer programs. A few areas that SRIC-BI identified as candidates for nanotechnology breakthroughs in early 2003 are in **Nanotechnology Opportunity Topics**.

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Nanotechnology Opportunity Topics

Cosmeceuticals:

- L'Oreal and Revlon are major patent holders
- British Telecom is developing "active skin"
- One company is putting caffeine in make up

Identifiers:

- DNA inks for anticounterfeiting
- Tracking genetically modified foods
- Privacy issues over invisible surveillance

Smart Materials:

- Tissue engineering
- Biomimetic materials

Defense:

- Biosuits that seal out biological agents
- Biosensors and tiny IR detectors
- Fuel reformers the size of pencil erasers

Power Sources:

- Microbatteries for remote nanoelectronics
- Nanoparticles to improve battery technology
- Thermoelectric generators powered by body heat

Neurotechnology:

- Neural chips to restore brain functions
- New noninvasive or low-invasive therapies

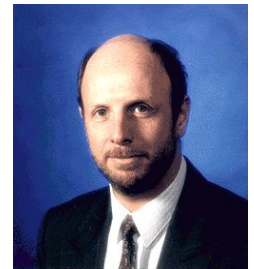
Source: SRI Consulting Business Intelligence

Summary

Although both entrant and established companies are busy staking territory and promoting their particular view of nanotechnology, most advanced economies have recognized an important underlying trend and are funding efforts to establish regional capabilities during the next few years. Though much uncertainty currently exists, venture capitalists are feeling their way into a complex area, and some are already making cautious investments—a trend that will likely continue in the next few years. Mainstream investors can expect to hear increasingly about nanotechnology capabilities from both start-ups and established enterprises. But they should be aware that much falling under this heading has been under development for many years, may not be nanotechnology at all, and in some cases may never become feasible! At the same time, genuinely novel capabilities are also finding increased visibility on the platform of nanotechnology and—though perhaps years away from commercialization—could indeed eventually change our lives. But don't expect the dawn of a new civilization overnight. Ron Eisses, Business Development executive for IBM in Canada, observed recently, "Nanotechnology is not a sudden revolution." Most people within the technical community agree with that view. Nanotechnology has been coming for decades. And weaving its unique threads into the technological tapestry will take decades more. But do expect a crescendo in nanotechnology "noise." When the hoopla subsides, good science and good business opportunities will still be ahead.

About the Author

David J Roughley is an independent technology development consultant living and working in Vancouver, Canada. He has experience in the semiconductor, chemical, and high-tech manufacturing industries and has held various research, engineering, and consulting positions. He began his consulting career in the European offices of SRI Consulting Business Intelligence and continues to work closely with that and other organizations internationally in the field of strategic analysis of technology. He is a Chartered Physicist and a member of the British Institute of Physics. You can contact him at djrstc@shaw.ca SRIC-BI is an employee-owned spin-off of the former Stanford Research Institute, and taps into a history of technology innovation that nurtured the computer mouse and the Internet. It combines content-based research programs with consulting expertise bringing an optimistic view of opportunity coupled with a realistic view of the difference between hype and reality. More information is at <http://www.sric-bi.com>.



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