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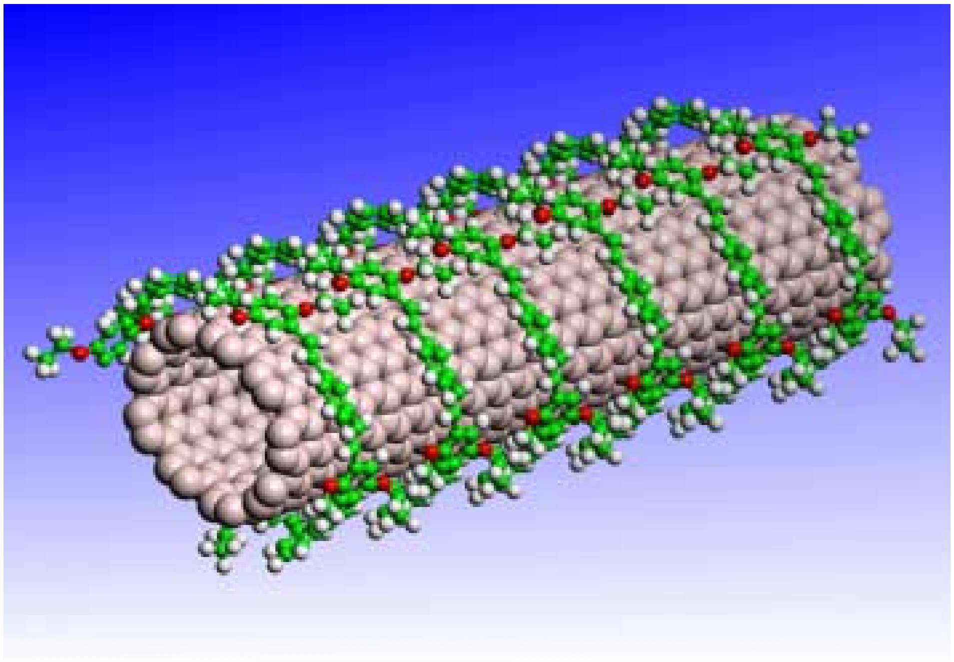
Investment Strategy

Big Money in Thinking Small

Nanotechnology—What Investors Need to Know



Source: Nanotech-Now.

- **Nanotechnology is a revolutionary technology that could obliterate current business models and restructure vast parts of the economy.**
- **Nano-enabled products are just starting to come to market.**
- **The market for nanotechnology is expected to reach $1 trillion by 2015.**
- **Nanotechnology is an early-stage, general-purpose technology that will generate a massive wave of creative destruction.**
- **We believe it is important to develop a knowledge base and remain informed about advances in this burgeoning technology.**

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Executive Summary

References to nanotechnology are popping up everywhere. If you're like most businesspeople, you probably have only a vague idea of what nanotechnology is—and certainly perceive that other issues are more topical and pressing. To many, nanotechnology and its promises are too futuristic given today's economic and political challenges.

But now is time to learn about what nanotechnology is and what it might mean for business. Nano-led innovation will likely obliterate many of today's business models and will lead to huge gains and losses in shareholder wealth. Because of weak equity markets, many investors perceive that innovation has slowed. But innovation in the *real world* continues to be strong, and nanotechnology is playing a central role.

This report seeks to introduce investors to nanotechnology and what it means for them. Key ideas include the following:

- *Nanotechnology in a nutshell.* Nanotechnology is about manipulation at the atomic level, and looks like a classic, general-purpose technology (GPT). Other GPTs, including steam engines, electricity, and railroads, have been the basis for waves of creative destruction and major economic revolutions. GPTs typically start as fairly crude technologies with limited uses, but then rapidly spread into new applications. We provide specific details, and timelines, for nanotechnology research.
- *Industries in the scope.* A few industries, including materials, healthcare, and electronics, are squarely in nanotechnology's development path. Successful product commercialization in these areas will lead to significant creative destruction.
- *Follow the money.* We examine the sources of funding for nanotechnology research. Today, much of the research is funded by governments and carried out within the university system. Translating nanoscience into nanotechnology is a great challenge and opportunity.
- *Investing in nanotechnology today*. Although we are in the early days, we identify three broad ways to invest in nanotechnology today: Nanotechnology startups, nanotechnology enablers, and major companies working on nanotechnology (an attempt to capture what we call the "nano option".) So investors seeking exposure to nanotechnology can chose an investment strategy in-line with their risk tolerance.
- *Other pertinent nanotechnology topics*. Appendix A provides a timeline of the major developments since Richard Feynman introduced the concept in 1959. We offer a very detailed accounts of how materials, healthcare, and electronics are likely to change as the result of nanotechnology in Appendix B. We address concerns about nanotechnology's potential perils in Appendix C. And, finally, Appendix D walks through the effort each company in the Dow is devoting to nanotechnology, and the potential impact that nano advances could have on their businesses.

Introduction

The world has changed more in the past 100 years than in any other century in history. The reason is not political or economic, but technological—technologies that flowed directly from advances in basic science.

Stephen Hawking

Today's investors have an acute sense of uncertainty, as the result of a murky economic and earnings outlook, a post-bubble market, and geopolitical events. Innovation and fundamental business change is not near the top list of concerns for most. But a general-purpose technology that could change our lives, not to mention our investment portfolios, looms large on the horizon: nanotechnology.

You've probably heard of nanotechnology—it's worked its way into pop culture, from movies to novels—and some companies are discussing it. But because nanotechnology research and applications are so disparate, most investors have not fully contemplated what nanotechnology is and how it will reshuffle the investment landscape. If you have an investment interest in healthcare, information technology, or basic materials (to name just a few broad areas), you can be sure that nanotechnology will significantly reshape those industry structures over the next decade or two. Consider the following:

- The National Science Foundation predicts that by 2010, half of all pharmaceuticals will be developed through nanotechnology. [1]
- Nanotechnology-based computer chips will have 100 times the storage density of current chips at a fraction of the cost.
- Nanotube-enhanced batteries may lead to the eventual destruction of the disposable battery industry and allow for electric cars, putting an end to the 100-plus reign of the combustion engine.

Why take notice today of a technology that may not come into its own for some time? Stock prices reflect the present value of future cash flows. If you take a look at the market-implied future cash flows for most businesses, you realize that the market is taking a long-term view (even if much of the value is lodged in the nebulous terminal value). So investors need to be aware today of the factors that will change—and possibly eviscerate—the cash flows of tomorrow.

So what is nanotechnology? Nanotechnology is "the ability to design and control the structure of an object at all lengths from the atom up to the macro scale." [2] Our breathtaking technological advancements in recent centuries have all relied on reshaping the world's raw materials—oil for energy or sand for semiconductors. In contrast, nanotechnology starts from nature's basic unit, the atom, and builds from there.

Nano comes from the Greek nannos, meaning dwarf. A nano is one-billionth of a unit. For example, one nanometer is approximately the length of three to six atoms placed side-by-side, or the width of a single strand of DNA. To put it in more human terms, a nanometer is the distance your fingernails grow in a second, and the thickness of a human hair is between 50,000 and 100,000 nanometers. [3]

But nanotechnology is not simply about manipulating small things. A technology must meet one of two criteria to be considered nanotechnology.

The first is molecular level assembly, which allows for unparalleled efficiency. For production today, we basically carve what we need from a large piece of material. Nanotechnology reverses this method, and instead builds from the molecular level up. Building atom by atom enables increased product complexity, exact composition, and eliminates virtually all waste.

The second criterion is the use of nanosized materials to enhance the physical properties of a manufactured product. For example, steel makers can use nanosized materials to greatly improve the strength of steel.

UCLA researcher Carlo Montegmagno classifies nano through precision assembly:

> *Precision assembly is a cornerstone metric that defines nanotechnology. If you're not doing that you're not doing nanotechnology. So, yes, my mantra is precision assembly of individual molecules. Place molecules, where you want when you want and with the functionality you want.* [4]

In some ways, the ideas behind nanotechnology are not new. In 1959, Nobel laureate physicist Richard Feynman discussed nanotechnology in his famous speech "Plenty of Room at the Bottom":

> *The principles of physics as far as I can see, do not speak against the possibility of maneuvering things atom by atom, it is not an attempt to violate any laws; it is something, in principle, that can be done; but in practice, it has not been done because we are too big.*

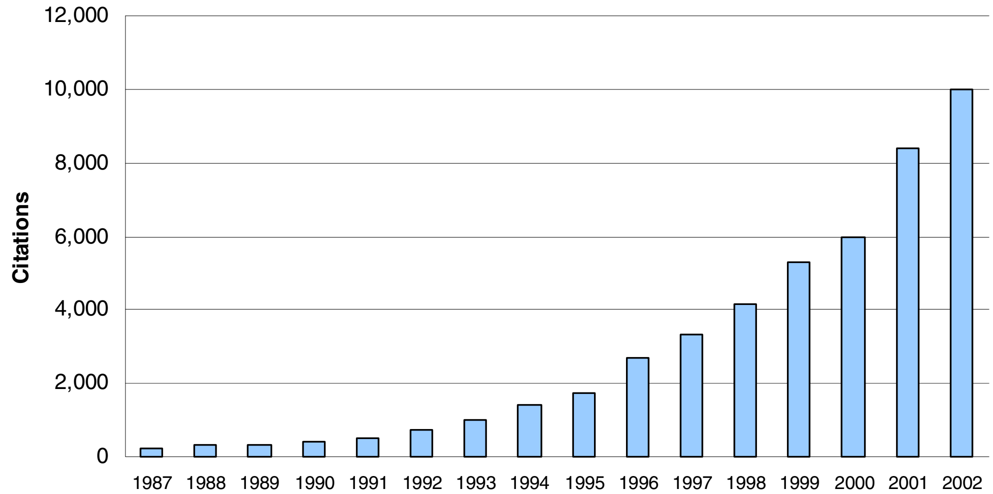
Given that Feynman had this figured out 45 years ago, why is nanotechnology only coming of age now? To go from the theory of nanotechnology to the actual implementation, we needed three things: a better understanding of the physics on this level, computational power, and sophisticated instruments.

At the nanoscale, different physical rules govern. Nanotechnology development requires a fundamental understanding of quantum physics—the rules that govern the atomic world. Physical laws that are part of our everyday life and that govern macroscale design (like gravity) are not major factors at the nanoscale. [5] While scientists have made numerous advances, we still do not fully understand quantum physics. A better understanding of these laws will propel additional nanotechnology advances.

A second factor driving rapid advances in nanotechnology research is the increase in computing power. The steady march of Moore's Law allows scientists unprecedented calculation power at a cheaper-and-cheaper price.

Finally, we are now developing the necessary sophisticated equipment to operate on the nanoscale. Advances in equipment will be important in going from the lab to commercial production for many nano products. Appendix A documents nanotechnology milestones, and Exhibit 1 shows the gaining momentum of nanotechnology research over the past decade and a half.

Exhibit 1: Number of Scientific Publications with "Nano" in the Title

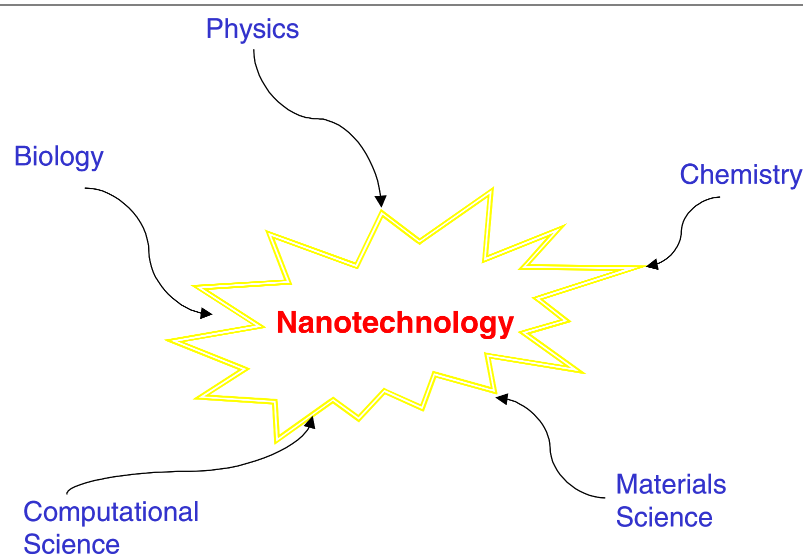


Source: Stephen R. Waite, *Quantum Investing* (New York: Texere, 2003), 67.

While we have made extraordinary scientific advances, two pieces must still fall in place for us to transition from nanoscience to nanotechnology. The first is that we must learn to successfully, and cost-effectively, manipulate material at the molecular and atomic level. Second, we need to develop self-replicating technology, because to be feasible for everyday use, nano devices require vast quantities.

One of the reasons investors are not fully aware of nanotechnology is the very nature of the research and science. Nanotechnology is the convergence of several disciplines. (See Exhibit 2.) Researchers from disparate academic fields, including chemistry, biology, physics, material science, and computational science, are all actively involved in nanotechnology.

Exhibit 2: Convergence of the Sciences



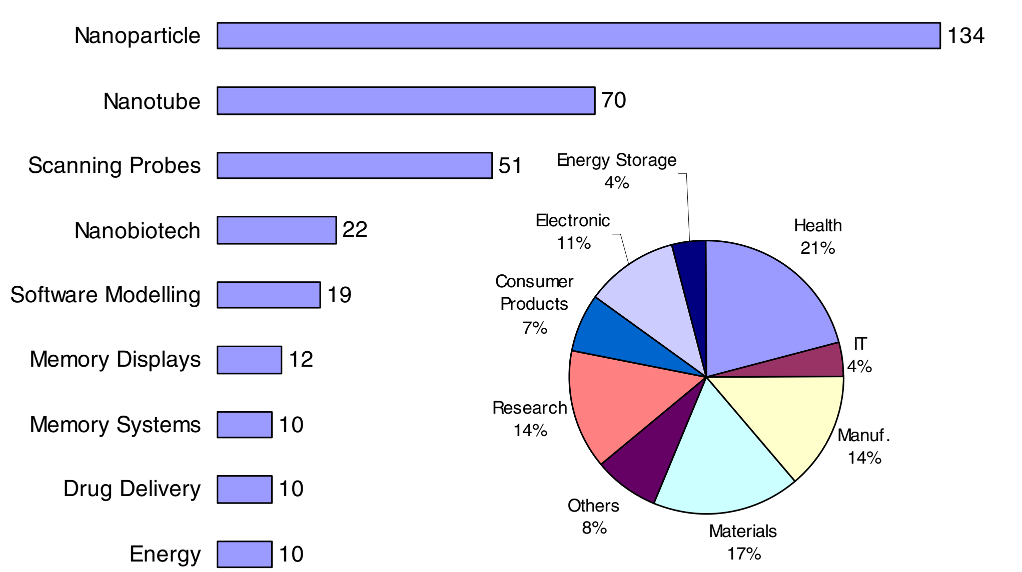
Source: CSFB.

This, too, makes investing in nanotechnology tricky. The vast majority of nanotechnology researchers are at universities and large companies. In 2002 alone, governments and corporations worldwide invested over $4 billion in nano research. Today, there are basically three ways to invest in nanotechnology (from least to most risky):

- *Major corporations that are investing in nanotechnology.* We call this capturing the "nano option."
- *Companies that make nanotechnology equipment.* These are the suppliers to the universities and companies doing the nano research.
- *Nanotechnology startups.* The leading startups are basically trying to capture as much of the intellectual property as possible, with an eye toward future commercialization.

Exhibit 3 shows that the bulk of the current research and spending is going into healthcare, materials, and manufacturing. We can be sure, though, that nanotechnology will spill into other fields. Very few businesses will be ultimately immune from nanotechnology's direct or indirect touch.

Exhibit 3: Nano Startups by Area



Source: Terry Turney, "Small Wonders: Nanotechnology in Perspective," *CSIRO Manufacturing Science and Technology.*

Nanotechnology is a classic, general-purpose technology (GPT). Other GPTs, including steam engines, electricity, and railroads, have been the bases for major economic revolutions. GPTs typically start of as fairly crude technologies, with limited uses, but then rapidly spread into new applications.

All GPTs have four characteristics: [6]

1. *Scope for improvement*. This means that the technology evolves, and that over time the technology improves and costs fall.
2. *Wide variety of uses.* A new GPT typically has a very few uses, but businesses discover many additional applications as the technology evolves. Inherent in GPTs are major opportunities for improvements, adaptations, and modifications.
3. *Wide range of use.* This refers to the proportion of an economy's productive activities that use the technology. For example, use of the light bulb spanned the economy—a wide range—but it only had one purpose.
4. *Strong technological complementaries with existing or potential new technologies.* This is the degree to which the new technology works with, and enhances, current and future technologies.

All prior GPTs have lead directly to major upheavals to the economy—the process of creative destruction. And nanotechnology may to be larger than any of the GPTs that preceded it. Creative destruction is the process by which a new technology or product provides an entirely new and better solution, resulting in the complete replacement of the original technology or product. [7] Investors should expect that creative destruction will not only continue, but will also likely accelerate, and nanotechnology will be at the core.

Nanotechnology and Creative Destruction

Creative destruction is the result of the discontinuity between corporate survival techniques and innovation. Managers frequently manage for longevity first and foremost, and the resulting survival tactics are poor at coping with the pace and scale of innovation. Corporations seek survival, whereas markets thrive on upheaval and change.

For many companies, survival implies strict control and a relentless focus on profitability. Indeed, this focus is reinforced by market expectations. But the rigidity of corporate structures often quashes efforts to lead innovative waves, and limits business growth and development in times of changing markets.

What does this mean from a practical standpoint? Because of the advent of nanotechnology, we believe new companies will displace a high percentage of today's leading companies. The majority of the companies in today's Dow Jones Industrials Index are unlikely to be there 20 years from now.

Investors who want to understand the breadth of change should spend time with Appendix B, where we provide a very detailed account of how three industries—materials, medicine, and electronics—are likely to witness significant and revolutionary change as the result of nanotechnology. For now, we will provide only three examples of the potential for creative destruction.

Medicine

Cancer is the second leading cause of death among Americans today. Cancer treatment is currently very blunt. Nanotechnology may offer an entirely new approach to cancer treatments.

One approach uses viruses, which the patient can ingest with a simple pill, to target individual cancer cells to eradicate them. Basically, the cancer-fighting viruses travel through the blood stream, and find cancer cells. Once they find a cancerous cell, they bind with it, and then inject the cell with antibodies that destroy it. Unlike radiation, which kills good and bad cells, this treatment destroys only cancerous cells while leaving healthy cells unharmed.

Computing

Nanotechnology may provide the means to produce semiconductors so cheap and abundant that they could be disposable. Scientists are working on making plastic semiconductors through a process similar to ink-jet printing. The device precisely sprays nanoscale particles onto a thin plastic film. Plastic has several advantages over silicon—it is less rigid, does not require ultra clean fabs, and requires no toxic chemicals. As a result, plastic semiconductors are much less expensive than silicon ones.

Plastic transistors are larger then silicon transistors, so they will not replace silicon at the high end of the market. But their low-cost, light-weight, and flexible structure make them ideal for lower-end applications. One example is electronic paper. Scientists will likely be able to design electronic paper devices that maintain the reader's tactile experience—the same texture and feel of a regular newspaper or magazine— while allowing for customization and updates through quick downloads.

Materials

The U.S. Department of Defense hopes to further protect soldiers by implementing nanosensors into lightweight-material uniforms. The goal is a lighter and more flexible combat uniform, including enhancements in protection, performance, and injury intervention.

As a result of the nano enhancements, these uniforms will not only be bulletproof, but they will also detect and filter harmful chemical and biological agents. The material includes actuators, which can apply force with an electrical signal. As a result, the uniform creates an exoskeleton that allows the material to alternate between flexibility and rigidity. This feature allows the uniform to function as a cast or bandage when a soldier is injured. The uniform also monitors the soldier's physiological state, including heart rate, blood pressure, hydration level, and chemical signs of stress.

Exhibit 4 provides a list of nano advancements and notes the primary and derivative impact the technology is likely to have. Each of these technologies is reasonably well established.

Exhibit 4: Nano Advancements

Nano Advancement	Primary Impact	Derivative Impact
nanofabrics	fabric manufacturers clothing manufacturers	detergent manufacturers dry cleaners stain removers washing machine/dryer manufacturers
self-repairing fabric	fabric manufacturers clothing manufacturers	sewing machine manufacturers tailors
military enhanced clothing	military current chemical sensor manufacturers brace/sling manufacturers	fewer casualties hospitals/medical supplies
nanothermometor	traditional thermometer	
light-induced ignition	other energy sources current solar cell technology	electronics photography
nano-enhanced plastics	traditional plastic manufacturers packaging companies component manufacturers (for cars, planes, buses, etc.)	autobody shops tires insurance sporting good manufacturers other building materials (I.e. cement, steel, metals, ceramic)
artificial leaves	current smokestack scrubber manufacturers	refining industries manufacturers
sunscreen	current sunscreens	aloe vera dermatologists plastic surgeons
coatings	current coatings stain repellents water repellents	upholstery cleaners cleaning products repair kits stain remover manufacturers
tissue and organ generation	doctors (orthopedic, surgeon, dentist, etc) prostheses manufacturer	pharmaceuticals medical device manufacturers (I.e. pace maker manufacturers, dialysis machine manufacturers)
drug-delivery	pharmaceuticals chemo and radiation therapies	doctors hospitals managed-care providers labs test manufacturers

Source: Company data, CSFB estimates.

Exhibit 4: Nano Advancements *continued*

Nano Advancement	Primary Impact	Derivative Impact
quantum-dots	traditional dyes	traditional scans (MRI, CAT, X-ray) tests labs
genetic testing	doctors (obstetricians and geneticists as well as surgeons, neo-natal, pediatrics)	pharmaceuticals hospitals assisted living medical device manufacturers (i.e. pace maker manufacturers, dialysis machine manufacturers)
microprocessors	current technology silicon manufacturers hard drive manufacturers	IT departments back-office processors retailers manufacturers (everything from food to tires to paper) etching chemical producers vacuum facilities
memory	Silicon manufacturers RAM manufacturers hard drive manufacturers enterprise storage	IT departments physical storage space router manufacturers switch manufacturers
electronic displays	current LED producers television manufacturers computer monitor manufacturers	packaging manufacturers retailers advertising printing companies newsstands schools (textbooks automatically download updates) electronics manufacturers (mobile phones, PDAs, cameras, printers) film companies light bulb manufacturers
fuel cells	batteries electric companies gas companies	portable electronics light bulbs auto manufacturers engine manufacturers transportation providers environmental groups

Source: Company data, CSFB estimates.

Timing and Development

Where are we in the development of nanotechnology? By all accounts, we are still in the very early stages. To be more specific, we can break the development process into three phases: [8]

1. *R&D phase*. In this phase, the focus is on research and development. There are no real products or revenues to speak of.
2. *Pre-initial public offering (IPO) phase*. Companies in this phase are pre-IPO and are just beginning to sell their products. Most are still not profitable.
3. *Public phase*. In the final phase, companies are profitable. At this point, most companies have come public.

Currently, the majority of pure nanotechnology companies are in phase one, with a few in phase two. (Some experts expect the first major nanotechnology IPO in 2003. [9]) We might view some public companies branching into nanotechnology as in phase three.

How long will it take for various technologies to get to the third phase? We can group nanotechnology initiatives into three time-horizon categories:

The next five years. The more rudimentary technology will likely emerge in the very short term. Already, companies are generating, or are close to generating, revenue in a host of areas, including (examples in brackets):

- nanotechnology tools (lithography),
- materials (nanopants, nanotubes),
- powders/nanoparticles (chemical production, cosmetics),
- absorbent drugs (drug delivery),
- composites (super bumpers),
- sensors (disease detection), and
- fuel cells.

Five to ten years. A little further out, a partial list of what we should expect includes:

- hierarchically nano-structured materials (precision building),
- two-dimensional nanoelectronics (Intel Itatanium processor),
- hybrid bio-nano functionality (merging nano and biotechnology),
- drug delivery systems (implantable devices, no need for pharmacy), and
- sensor proliferation (DNA sensors on your toothbrush).

Ten years and beyond. Some of these concepts still sound more like science fiction than reality. While scientists are developing some of these technologies now, they remain far off opportunities.

- self-replicating machinery (growing electronics),
- three-dimensional nanoelectronics (computers with three dimensional displays), and
- tissue and organ regeneration.

The popular press loves to focus on these far-reaching conceptual applications. Yet, while these longer-term initiatives are more distant revenue opportunities, the likelihood of watershed technological advances is almost certain. For most investors, phase three is where the bulk of investment opportunities—both on the long and short side—exist.

Investors should not come away with the sense that nanotechnology is either too small or too distant. According to the NanoBusiness Alliance, nanotechnology is already running at about $45 billion in annual sales. The National Science Foundation predicts that nanotechnology sales will reach $1 trillion by 2015. [10] Similarly, In Realis predicts $100 billion by 2005, $800 billion by 2010, and up to $2 trillion by 2015. Evolution Capital estimates that yearly nano sales are currently $20-50 billion, and that growth will be to $150 billion in 2005 and $1 trillion by 2010. The National Nanotechnology Initiative estimated that 2001 sales were $30 million, and that 2015 sales would reach $1 trillion—a 110% compound annual growth rate.

Over the next decade or so, we can expect hundreds of nanotechnology-related IPOs as companies cycle from phase one to phase three. And just as the information technology IPOs of the past 20 years yielded some of today's most valuable companies, investors should expect that some of the most valuable companies in the year 2020 are those that have yet to go public today.

Follow the Money

While we only touched on three industries, the breadth of nanotechnology developments suggests that dynamic change is in store for many industries. So who is going to drive nanoscience—with its current $4 billion annual research budget producing only a handful of potential commercial applications—to nanotechnology and its estimated $1 trillion market opportunity? When in doubt, follow the cash.

Government Investment

Because of the risk and uncertainty that surrounds this nascent industry, government agencies throughout the world currently provide most of the funding for nanotechnology research and development. The strong financial support of governments around the world demonstrates the perceived importance that nanotechnology will play in our future.

United States

Initially, the United States was underspending other economic rivals. For example, both Europe and Japan provided more financial support for nano research than the United States in 1998. In 1999, the National Science and Technology Council (NSTC) reported that worldwide nanotech spending was still at least twice that of the United States. With the establishment of the National Nanotechnology Initiative (NNI) in 1999, the United States has significantly increased its funding for nano research.

Support for the effort has been bipartisan. The NNI was founded during the Clinton administration. Newt Gingrich was one of the backers of the NNI, and is now co-chairman of the NanoBusiness Alliance. According to Gingrich:

> *Those countries that master the process of nanoscale manufacturing and engineering will have a huge job boom over the next 20 years, just like aviation and computing companies in the last 40 years, and just as the railroad, steam engine and textile companies were in decisive in the 19th century. Nanoscale science will give us not dozens, not scores, not hundreds, but thousands of new capabilities in biology, physics, chemistry and computing.* [11]

However, 2003 budget estimates place the United States once again in second place to the Japanese. The U.S. government's nano-spending estimate for 2003 is $776 million, up 28% from 2002. [12] The new 2004 budget shows a 9.5% year-over-year increase in nano spending, to $847 million. [13] Exhibit 5 shows the breakdown of U.S. government spending.

Exhibit 5: U.S. National Nanotechnology Initiative Funding

US$ in millions

	2001A	2002A	2003E	2004 Proposed	Percentage Change 2003-2004
Nat'l Science Foundation	$150	$199	$221	$247	12%
Defense	125	180	243	222	-9%
Energy	88	91	133	197	48%
Nat'l Institues of Health	40	41	65	70	8%
Commerce	33	38	69	62	-10%
NASA	22	46	33	31	-6%
Agriculture		2	1	10	900%
EPA	5	5	6	5	-17%
Homeland Security			2	2	0%
Dept. of Transportation	0	2	2	0	-100%
Dept. of Justice	1	1	1	1	0%
Total	**$464**	**$605**	**$776**	**$847**	9%

Source: National Nanotechnology Initiative.

Asia

Excitement for nanotechnology and money raised to fuel ongoing research has been extremely strong in Asia as a whole. Some experts equate Asian investment and interest in nanotechnology to the boom Asian nations had in the 1980s' auto market. [14] Exhibit 6 summarizes the spending in Asia.

Japan

Japanese government funding for nanotechnology in 2003 is estimated at approximately $1 billion. [15]

Taiwan

Taiwan's nanotechnology investment is a distant third. Taiwan is expected to spend $679 million over the next six years. In addition, Taiwan's Industrial Technology Research Institute spent $290 million to establish the Center for Applied Nanotechnology Institute. The Taiwanese look for nano business to generate 2004 sales of $2 billion.

Singapore

Despite its size, Singapore is investing $37 million annually in nanotechnology.

South Korea

South Korea, which has an economic focus primarily on microelectronic applications, massively ramped up its nanotechnology spending between 2001 and 2002. Government funding increased 93% to $145 million in 2002. The South Korean government has also pledged $10 million per year to memory-chip nanotechnology.

China

China wraps up the majority of Asian nano spending. Over the next five years, approximately $240 million from the central government and $240-360 million from local governments will go toward funding nanotechnology. Most of China's research efforts focus on semiconductor fabrication technologies, the development of nanotech-based electronic devices, and archeological artifact preservation. China estimates that 50 universities, 20 institutes, and 100 companies have already instituted nanotechnology research.

Exhibit 6: Far East Nanotechnology Funding

US$ in millions

Country	2002
Japan	$650
China	200
Taiwan	150
Korea	150
Singapore	40
Total	**$1,190**

Source: CMP Cientifica.

Europe

European countries have also devoted research effort to nanotechnology, and many of the near-term opportunities for investment will likely come from Europe. While Austria, Finland, France, Italy, and Sweden all have notable programs, Germany is by far the most committed to nanotech development. [16] Exhibit 7 summarizes the spending in Europe.

Germany has focused its efforts on materials, which offer near-term revenue opportunities. One example is Nanogate Technologies, a protective coating business. German research is focusing on ultrathin layers, lateral nanostructures, ultraprecise handling of nanostructures, measurement and analysis of nanostructures, and nanomaterials, and molecular analysis.

Exhibit 7: European Nanoscience and Nanotechnology Spending

in millions of euros

Country	1997	1998	1999	2000
Austria	€ 1.9	€ 2.0	€ 2.2	€ 2.5
Belgium	0.9	1.0	1.1	1.2
Denmark		1.9	2.0	2.0
Finland	2.5	4.1	3.7	4.6
France	10.0	12.0	18.0	19.0
Germany	47.0	49.0	58.0	63.0
Greece	0.2	0.2	0.3	0.4
Ireland	0.4	0.4	0.5	3.5
Italy	1.7	2.6	4.4	6.3
Netherlands	4.3	4.7	6.2	6.9
Portugal	0.2	0.2	0.3	0.4
Spain	0.3	0.3	0.4	0.4
Sweden	2.2	3.4	5.6	5.8
United Kingdom	32.0	32.0	35.0	39.0
European Commision	23.0	26.0	27.0	29.0
Total	**€ 126.6**	**€ 139.8**	**€ 164.7**	**€ 184.0**

Source: Third European Report on S&T Indicators, 2003.

Private Investment

Venture Capital

Since the majority of nanotechnology intellectual property resides at universities and is funded by the government, finding investment opportunities is difficult. The largest part of private investment in nanotechnology is via venture capital. There are currently over 95 investment companies involved in nanotech. That number is sure to grow as more companies reach phase two of the development cycle.

As most nanotechnology companies are still in phase one, private investment is a significantly smaller source of funding for nano startups and research think tanks than government spending. In 2002, venture capitalists only committed $282 million to nano deals, a tiny fraction of the total $17 billion in venture money spent last year. [17]

While the private sector is providing limited funding, investment firms are beginning to show more interest, with some attempting to specialize in the research. Early-stage investors play the odds—most nanotech startups will not make it, but those that do are likely to reap disproportionately large rewards.

How to Invest in Nanotechnology Today

We believe there are three broad approaches to investing in nanotechnology today (from least to most risky):

- *Major corporations that are investing in nanotechnology.* We call this capturing the "nano option."
- *Companies that make nanotechnology equipment.* These are the suppliers to the universities and companies doing the nano research.
- *Nanotechnology startups.* The leading startups are basically trying to capture as much of the intellectual property as possible with an eye toward future commercialization.

Many major corporations fund their internal research and development in an effort to keep up with technological change. In recent years, nanotechnology has become a more important part of the R&D for many companies, and some are now devoting up to a third of their research budgets to nanotechnology. In most cases, however, it's difficult for an outsider to determine exactly how much any given company is dedicating to nano research.

The easiest and safest way to incorporate nanotechnology into your portfolio is through a large company that is actively involved in nano research. These companies are typically large, established, and profitable, and the nano spending is not making a dent on the bottom line. But is these companies are on the nanotechnology cutting edge, they might have embedded, valuable nano options.

The good news is that, in most cases, investors appear to place little or no value on these nano options. The bad news is that many of these companies have large capitalizations, so the option would have to be sizable to materially change shareholder value. Exhibit 8 provides a list of global companies, with brief descriptions of their nano initiatives.

Exhibit 8: Large Companies with Nano Options

Company	Ticker	Development Areas	Funding/Research Centers
BASF	BF	Polymer Research, Nanocubes (for hydrogen storage), Nanofiltration, Nanoscratching (scratch-tests with AFM), Crystalline Organic Nanoparticle Pigments, Nanocoatings, Nanostructured Materials and Surfaces, Synthetic Nanofabrics	Institut de Science et d'Ingénierie Supramoléculaires (ISIS)
DOW Chemical	DOW	Nano Generators (for cancer treatment), Nano-Structured Particles, Drug Delivery, Nanotube Field Emission Displays, Polymer Research	
DuPont	DD	Nano-coatings, Color Technologies, Nano-electronics and technologies	Partner in the Institute for Soldier Nanotechnologies
General Electric	GE	Biomimetics, Nanotubes, Nanowires, Nanocomposites, Nanostructured Optoelectronics	GE Global Nano Research
General Motors	GM	Nanocomposites, Hydro-Carbon Fuel-Cells	
Hewlett-Packard	HPQ	Molecular Electronics, Nanowires, Self-Assembly, Semiconductors and Equipment, Nanodevices, Nanocomputing Architectures, Biochips, AFM	Quantum Science Research Center. Over half of long-term R&D devoted to nanotechnology.
Hitachi	HIT	Advanced Semiconductor Materials and Equipment, DNA Chips, Electronic Device Systems, Life Science, Information Systems & Electronic Components, Advanced Industrial Products, Environmental Applications, Electron Beam Lithography	Estimated nanotech funding $280M per year.*
Intel	INTC	Advanced Semiconductor Components and Systems	
IBM	IBM	Microscopy (STM, AFM), Cantilever Sensors, Chemical AFM, Magnetic Resonance Imaging, Dynamic Force Microscopy, Bottom-Up Nanomachines, Nanoscale Integrated Circuits, Assembly Tools for Molecular Structures, Thermomechanical Storage, Ultrathin Magnetic Structures, Quantum Computing, Self-Assembly	Millipede
Lucent	LU	Nanoelectronics, Organic Semiconductors, Nanotransistors, Nanocrystal Fabrication, Optical Physics Research, Materials Research (including polymers and biological tissues)	New Jersey Nanotechnology Lab, Bell Labs
Merck	MRK	Bioinformatics, Designer Drugs, Molecular Modeling	
Mitsubishi	MSBHY. PK	Nanocarbon Products (fullerene and nanotubes for use in pharmaceuticals, cosmetics, batteries, hydrogen storage fuel cells, super conductive materials, and superfine artificial diamonds for industrial grinding), Nanoparticles, Nanocrystal Separation, Colloidal Nanodot Films by SPM, Semiconductor Nanocrystals	National Institute of Advanced Industrial Science and Technology (AIST)
Motorola	MOT	Biochips, Molecular Electronics, Gallium Arsenide Chips, Nanotubes, AFM, Self-Assembly	Partnership with Rice University. Motorola Physical Research Labs (France and Japan)
NEC	NIPNY	Carbon Nanotubes, Fuel Cells,	Estimated nanotech funding $15M per year.* NEC Fundamental Research Laboratories
Xerox	XRX	Nanoparticles, Nanomagnets, Nanoelectronics	Palo Alto Research Center

* Estimate from May 21, 2002 Nanoelectronics News Archives "Hitachi Dives Further Into The Nanotechnology Realm."

Source: Company data, CSFB estimates.

The next way to play nanotechnology is through companies that enable the nano research, development, and manufacturing process. These companies represent a play on nanotechnology in general, although they also offer different technologies that the market is likely to greet with varying degrees of enthusiasm.

Here is a list of the enablers and their positions:

Exhibit 9: Nanotechnology Enablers

Microscopy	Nanomaterials	Production Tools
FEI (FEIC)	Altair International (ALTI)	Intel (INTC)
Hewlett-Packard (HPQ)	DOW Chemical (DOW)	Molecular Imprints
IBM (IBM)	Materials and Electromechanical Research Corporation	Veeco (VECO)
Technical Instruments		Zygo (ZIGO)
Veeco (VECO)	Nanomat	Nanometrics (NANO)
Molecular Imaging	Nanophase Technologies (NANX)	Nanopierce (NPCT)
Advanced Surface Microscopy	Symyx (SMMX)	NPoint

Source: CSFB.

The final, and riskiest, group is the early-stage investment companies. Many of these companies are working to build their intellectual property portfolios.

Exhibit 10: Nanotechnology Pure-Plays

Companies	Sector
Elan (ELN)	healthcare
Flamel Technologies (FLML)	healthcare
Harris & Harris (TINY)	venture capital
Nanogen (NGEN)	healthcare
Nanophase Technologies (NANX)	materials
Nexia Biotechnologies (NXB.PK)	materials
Pharmacopia (PCOP)	healthcare
SkyePharma (SKYE)	healthcare
Symyx (SMMX)	materials

Source: CSFB.

Investors can participate in nanotechnology today. But the main lesson for investors at this juncture is that they must be diligent in evaluating how technology will change various business models. Many of the businesses, and business practices, we take for granted today will be obsolete in the next 5-15 years. The value migrations are likely to be profound.

Conclusion

Nanotechnology is becoming part of our everyday life. Technological advancements, coupled with financial capital, will drive significant change across a broad range of industries. It is still early, but it is clear that this wave of creative destruction is coming, and more rapidly than most businesspeople and investors may realize.

Appendix A: The Journey Thus Far—Nanotechnology Milestones

You may be asking yourself, "Why now?" Nanotech is just entering the commercial markets. The journey began with Feynman's speech almost 45 years ago. Along the way we have passed numerous significant milestones.

Fifteen years after Feynman's famous speech, researchers built the first molecular electronic device plant. The invention of Scanning Probe Microscopy (SPM) at IBM's Zurich research lab in 1981 remains one of the main breakthroughs to allow for today's creation and measurement at the nanoscale.

SPM measures and identifies structures through touch. The concept is based on the idea that different materials exert different forces. Just as we can identify whether we are touching silk or cement by sliding our fingers across the surface, the SPM drags a measurement tip or probe across the target and measures the force. The probe itself is of nanoscale dimension—the tip that comes in contact with the target surfaces is often the size of only one atom.

Atomic Force Microscopy (AFM) and Scanning Tunneling Microscopy (STM) are two examples of SPM. AFMs, invented in 1986, measure the force exerted on the probe through electronics. STM measures the amount of electrical current between the probe and the target. Depending on the manner of measurement, STM may measure the geometry of the structure or the electrical conducting characteristics. STM also provides the ability to precisely place individual atoms and molecules by using the sharp tip to push the atoms around a smooth surface. [18]

Besides the advances in measuring at the atomic scale, SPM also allows for manipulation at the atomic level. Scientists can use the probe of the scanning probe microscope to scratch, dimple, score, or move individual atoms and molecules. By using SPM, IBM researchers wrote out the letters "IBM" with 35 Xenon atoms in 1989. [19] This was the first time scientists had manipulated individual atoms with SPM.

While the concept of scanning probe microscopy is revolutionary and has enabled many developments at the nanoscale, SPM suffers from two primary limitations. It is extremely expensive and very time consuming. SPM is not yet suitable for use in mass production.

Among all the microscopy developments, scientists also discovered new molecular level structures. In 1985, Robert Curl, Jr., Harold Kroto, and Richard Smalley found buckyballs, extremely stable molecules containing 20 to over 500 carbon atoms, among the byproducts of laser-vaporized graphite. (The scientists dubbed them buckyballs because their structure is reminiscent of architect Buckminster Fuller's domes. [20]) Their unique structure, heat resistance, and electrical conductivity, fuel speculation about possible buckyballs applications in high-temperature lubricants, filters, semiconductors, and manufacturing processes.

Microscopy also allowed researchers to observe the quantization of electrical conductance in 1987. That same year, Theodore Fulton and Gerald Dolan of Bell Labs invented the first single electron transistor, a concept that Moscow State University's Konstantin Likharev originally proposed in 1985. Likharev anticipated that scientists would be able to control the movement of a single electron on and off a "coulomb island"—the name Likharev uses for a conductor on a nanocircuit. [21]

The ability to control the movement of a single electron on a circuit allows for an entirely new transistor. Traditional computing requires a countless stream of electrons to make a counting device "flop" or change state. At the nanoscale, a device can flop when a single electron is fed into it. [22] Bell Labs first produced single electron charging in 1987. With reduction in scale, the single electron charging effects can completely dominate current flow. The smaller the transistor, the more robust are the physical effects of the electron. Eventually researchers may even be able to produce computing devices that flop with a single photon—creating a cooler, faster, and more efficient form of computing.

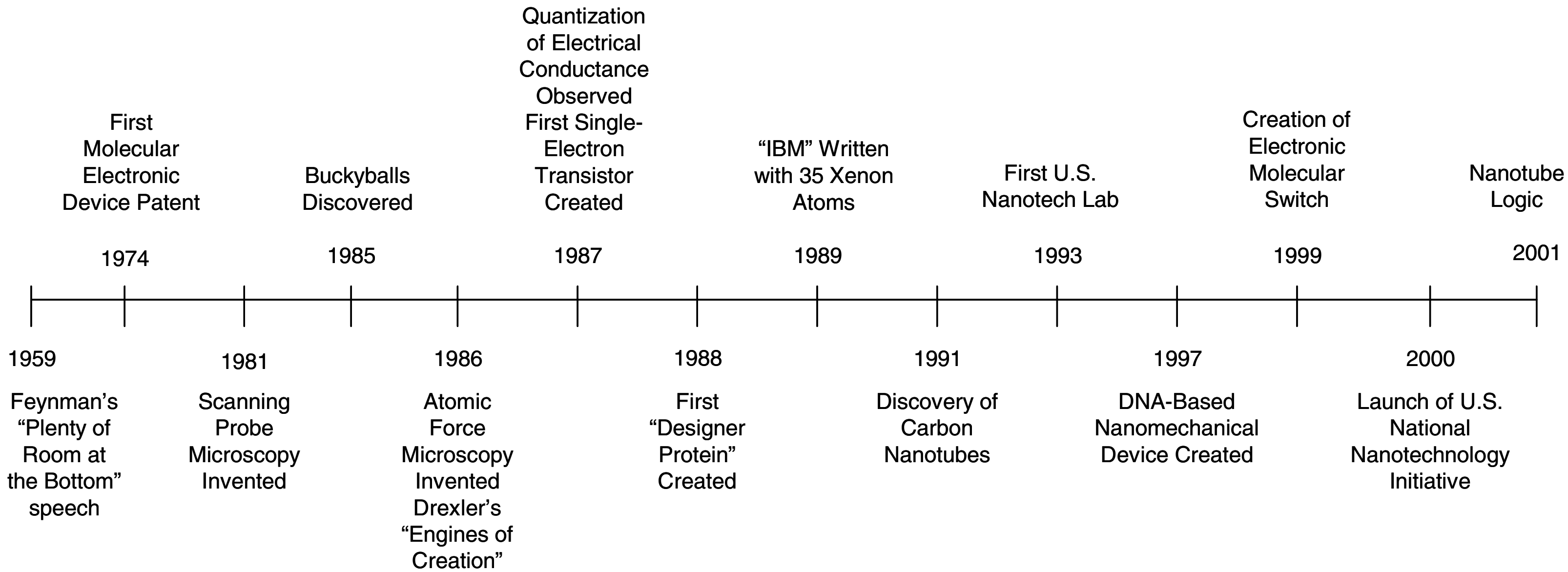
One of the most important milestones in nanotechnology was the discovery of carbon nanotubes in 1991 by NEC's Sumin Iijima. Carbon nanotubes are often seen as one of the most promising near-term nanotechnologies because of their strength, structure, and conducting and thermal characteristics. Nanotubes are an arrangement of carbon atoms in a hexagonal pattern, which creates a cylindrical structure that resembles a tube of rolled-up chicken wire.

In 1993, Rice University built the first U.S. research lab devoted entirely to nanotechnology. The early 1990s saw a ramp of interest from the scientific community, but the true validation of nanotechnology and its potential came from the launch of the United States' National Nanotechnology Initiative in 2000.

The purpose of the NNI is to provide funding to promote the scientific and engineering developments in nanoscience. The agency receives funding from a variety of groups, including the National Science Foundation, the Department of Justice, the National Institutes for Health, the Department of Defense, the Environmental Protection Agency, and a number of other government agencies and departments. [23] As Josh Wolfe noted in *Forbes* magazine (October 10, 2002), "The NNI will be the most significant U.S. government-funded science project since the Space Program. Federal nanotechnology research funding has surged nearly six-fold in the past six years, starting from $116 million in 1997." [24]

Despite all these developments, we should consider most of today's work as more nanoscience than nanotechnology. While writing "IBM" at the atomic level is impressive, companies cannot yet tap these rudimentary manipulation techniques on a sufficient scale for commercial use.

Exhibit 11: Nanotechnology Milestones



Source: CSFB.

Appendix B: What to Look for in Nanotechnology

Nanotechnology could fundamentally change how companies produce many goods, and hence usher in new companies and technologies while ushering out those that don't keep pace. Some changes will be invisible but will allow for increased efficiency, less pollution, more accuracy. This new approach to production will likely spur an entirely new industrial revolution.

While it is clear that nanotechnology will reshape various industries in different ways, investors will feel the ripples of the innovation wave throughout the market value chain. For instance, improvements in automotive parts through the use of nano-enhanced plastics will result in fewer replacements and repairs (stronger, more durable components) and better gas mileage (lighter components). In addition, fewer repairs lead to lower revenue not only for auto-parts manufacturers, but also for auto-body shops, car dealers (cars look new longer), and insurance companies (better cars result in customers filing fewer accident claims). Nano advancements will have a trickle-down influence on the economy, so industries will experience both the direct *and* indirect effects.

Here's a summary of some of the more exciting, and realistic, commercial technologies:

Materials

Some of the first commercial applications are now coming to market. Nano-enhanced materials are the first items consumers can buy today. Currently, most available nano-enhanced products are simple concepts using basic advancements in nano engineering.

Textiles

You may have seen the commercials for Eddie Bauer and Dockers khakis. Dubbed nanopants by Eddie Bauer, the pants are available for $10 more than regular khakis, and are both water-repellant and wrinkle-resistant. [25]

Even though nanopants have the look and feel of normal khakis, the manufacturers have literally incorporated nanotechnology in the very fibers of the pants. The manufacturers dip the pants in a "nanowisker," which contains 10-nanometer-long fibers (about one-ten-thousandth the size of a grain of sand), and bake the pants to set the solution. These nanofibers create fabric that is so dense that water cannot penetrate it. While not yet indestructible, the technology in nanopants lasts through approximately 35 washes.

While the unique properties of this material do not yet last forever, further advances in nanotechnology should allow for pants that maintain their water-repelling capabilities. In fact some nano believers propose a day when clothing will be self-cleaning, and even eventually self-repairing, with the advancement of self-replicating nanotechnology.

Nano-Tex, which has partnered with textile giant Burlington Industries, is the leading nano-enhanced textile manufacturer. Burlington, currently in the throes of bankruptcy, counts on nano innovation to remain a viable business in the future.

Nano advancements will naturally affect all clothing manufacturers, as clothing sales will be driven even more by fashion then by replacement. Beyond the fabric and clothing industries, detergent companies, tailors, dry cleaners, and washing machine and dryer manufacturers will feel derivative effects. Fewer washes mean less cleaning and fewer repairs.

While nanopants are one example of innovation in textile production, we are only on the cusp of what is in store for all materials. The Department of Defense (DoD) is spending a great deal of time and money on the development of innovative products. With a budget of almost $380 billion for 2003, the DoD has some serious financial heft. The Department of Defense's committed contribution represents over a quarter of the NNI's 2003 budget of $710 million.

While nano-electronics, magnetics, and detection and protection against chemical, biological, radiological, and explosive threats are all areas of interest; the DoD has also earmarked funds for materials by design. [26] The DoD is hoping to use nanotechnology to better protect soldiers. The DoD has given $50 million in funding to MIT's Institute for Soldier Nanotechnologies (ISN) for the "Objective Force Warrior Program." The 153 researchers from MIT's ISN are working to implement nanosensors into lightweight material uniforms.

The goal is the development of a lighter and more flexible combat uniform, which will include enhancements in protection, performance, and injury intervention. In terms of protection, beyond being bulletproof, these new materials will also be capable of detecting and filtering harmful chemical and biological agents. Performance enhancements include actuators in the material, which can apply force with an electrical signal. The resulting uniform creates a sort of exoskeleton, with dynamic material properties allowing transfer from and between flexibility and rigidity. With these capabilities the uniform could function as a cast or bandage almost instantaneously when injuries occur. The uniforms could also monitor physiological characteristics of soldiers, such as heart rate, blood pressure, hydration level, and chemical signs of stress.

Nanotubes

One of the most important milestones in nanotechnology was the discovery by NEC's Sumin Iijima of carbon nanotubes in 1991. Carbon nanotubes (often just nanotube) are often seen as one of the most promising near-term nanotechnologies. Nanotubes are created through the arrangement of carbon atoms in a hexagonal pattern, producing a cylindrical structure that resembles a tube of rolled-up chicken wire.

An individual nanotube is just one hundred thousandth the width of a human hair. Despite their small size, they are extremely stable, exhibit extraordinary strength, and are very flexible. Due to the stability of their molecular bonds, carbon nanotubes are tougher than diamonds and have over one hundred times the tensile strength of steel. They are also remarkably flexible. Manufacturers can braid or arrange nanotubes in groups to form rope-like structures. Beyond their strength, nanotubes are also exceptional electrical and thermal conductors, with better capabilities than any other substance known today. The lack of electrical resistance could lessen the chip design problem of heat build-up from tightly packed components.

Nanotubes may prove to be a disruptive technology in the production of many materials. Researchers manipulating and integrating nanotubes into everyday technologies are grabbing many of the new technology and innovation headlines.

Nanotube production is still too expensive for commercial use. But production costs should drop dramatically. In fact, the cost of producing single-walled nanotubes fell 20-fold from 1996 to 2001. [27] Carbon Nanotechnologies, a pioneer in nanotube production, began selling nanotubes for $2,000 per gram in 1999. [28] Two years later, worldwide production was over three kilograms of single-walled nanotubes, with an average selling price of $300 per gram (versus approximately $10 per gram for gold). [29] Nanotube prices should eventually fall below $1 per pound, making them much more commercially attractive. [30]

The Carbon Nanotech Research Institute (a subsidiary of Japan's Mitsui & Co.) has already opened the first nanotube fabrication plant. The plant is expected to produce 10 tons of multiwalled nanotubes a month, retailing at approximately $80/Kg. [31] (However, these are multiwalled nanotubes, which have more limited functionality than the single-walled tubes.)

Where will we find nanotubes? The applications are widespread. Here are some examples:

Batteries. The atomic structure of carbon nanotubes will allow a battery to store many more lithium ions than graphite, today's material of choice for rechargeable batteries. The enhanced lithium storage will speed the recharging process and dramatically lengthen battery life.

Researchers expect nanotube-enhanced batteries to be on the market by next year. This advancement could not only signal the eventual destruction of the disposable battery industry, but should also have major effects on the electronics industry. Longer-lasting, quicker-charging batteries may be the key to producing a commercially viable electric car. (Owners have to recharge current models every 50 miles.)

Nanothermometer. On February 7, 2002, researchers Yihua Gao and Yoshio Bando, of the National Institute for Materials Science in Ibaraki, Japan, announced that they had created a carbon nanothermometer. The thermometer, which functions like a conventional thermometer, is a column of carbon 10 micrometers in length, and it can measure temperatures ranging from 50 to 500 degrees Celsius. [32] The scientists constructed the column by filling carbon nanotubes 150nm in diameter with a column of gallium. This thermometer will increase the range of temperature measurement at the nanoscale. The ability to monitor temperatures at the nanoscale will help scientists understand quantum physics.

Light-Induced ignition. By happenstance, scientists mistakenly discovered that single-walled carbon nanotubes also serve as a means of ignition. [33] When the scientists tried to photograph some nanotubes, the flash ignited the tubes. When placed in vacuum-eliminating oxygen, the flash doesn't ignite the nanotubes, but it does rearrange their atomic structure, creating new nanomaterials. These findings are spurring researchers to explore ways to create new actuators and sensors from carbon nanotubes.

Ultrafast oscillators. Because nanotubes are hollow, it is possible to conceive of creating a nest of tubes at the nanoscale that can act as a gigahertz oscillator. [34] These oscillators are potential tools for use in nanosized mechanical devices. Researchers predict that there would be very little friction between the nestled tubes. Scientists have hypothesized that these oscillators may act as optical filters in fiber optic systems.

Additional Nanomaterial Advancements

Nanotubes, while significant, are not the whole story behind advances in materials. Here are some other active areas of research and opportunity:

Plastics

Scientists are using nanocomposite plastics—which incorporate clay nanoparticles—as lightweight replacements to more traditional plastics. [35] The enhanced plastics are just as strong as the traditional materials, but they exhibit enhanced durability and are 12 times lighter. Auto manufacturers, tennis balls producers, and food packagers already all use these revolutionary plastics. [36]

For example, Toyota uses a combination of nanoscale rubber and polypropylene in its bumpers, which have the same rigidity of a normal 4mm bumper but are only 60% of the size. [37] Wilson has incorporated InMat LLC's Ari D-Fense nanocomposite product into its Wilson Double Core tennis balls. [38] For $1.50 more per can, the balls last for four weeks. The additional coating inside the tennis ball, composed of clay polymer nanocomposites that are 1nm thick layered to 20 microns, creates the lasting bounce. Because the coating is thin, it does not change the ball's weight or bounce but prevents air from escaping. Manufactures can apply the technique to other products, including basketballs and tires.

The use of enhanced plastics has some far-reaching implications. Longer-lasting materials result in trickle-down effects to the retail level. For example, the beverage bottling industry is looking at ways to use nanotechnology to create more airtight plastic bottles. Until recently, beer was only available in glass bottles or cans. But the new technology will make beer in plastic bottles viable. The result is a longer-lasting product and cheaper packaging costs for the industry. Further, the lighter-weight packaging reduces transportation costs.

Artificial Leaves

Scientists have demonstrated that artificial leaves remove carbon dioxide from the atmosphere, just as photosynthesis does. Work by Oak Ridge National Laboratory's Ligen Wang suggests that we may be able transform carbon dioxide into oxygen without light. [39]

Light-independent photosynthesis means that we could remove harmful carbon dioxide before companies release it into the atmosphere, especially where it is dark. This technology would result in lower costs in order to meet environmental regulations, fewer Environmental Protection Agency regulators, less cost in environmental clean-up, and potentially affect the law industry through fewer environmental lawsuits.

Sunscreen

Nanophase Technologies makes a number of basic products at the nanoscale. [40] One product is zinc oxide in 50nm crystals—one-forth the size of the crystals in the traditional white zinc oxide sunscreen. These crystals provide the same protection against the sun's harmful UV rays, but they are small enough to let normal light pass through, making the sunscreen transparent. The crystals are also used in some antifungal foot powders. In 2000, Nanophase shipped 250 tons of zinc oxide powder.

Nonattention grabbing, but more powerful, sunscreen will likely increase use. Increased sunscreen use will reduce burning, creating a negative effect on aloe vera sales, and lower instances of wrinkles and skin cancer, thereby lessening the demand for dermatologists.

Coatings

Nanogate Technologies, of Germany, produces nanotech-enhanced protective coatings that are approximately 100 nanometers thick. [41] Nanogate's technology may become the Scotchgard of the 21st century. Nanogate's coating, Sol-Gel, makes surfaces such as tile and sinks stain- and scratch-resistant. Sol-Gel also makes surfaces significantly easier to clean: Some describe treated surfaces as practically self-cleaning. Sol-Gel comprises two layers: the first is an adhesive layer of nanoparticles, and the second is a nonadhesive layer of the particles that dirt cannot bind to. Consumers can buy coated fixtures and tile, or purchase the coating in a wax form and apply it themselves. While Nanogate 2001 sales were only about $2 million, the company expects to be profitable in 2003. DuPont is late to this game but is working to catch up.

Advances in coatings result in lower replacement rates of the materials they protect, as well as reduced sales of cleaning agents. If less cleaning is necessary, sales will decline in industries such as maid services, dishwasher manufacturers, upholstery and rug cleaners, and plumbing services.

Healthcare and Medicine

Healthcare is the fastest-growing industry in the United States. Pharmaceuticals, biotechnology, surgery, and patient care have grown tremendously, resulting in a significant increase in lifespan. However, our current methods of treatment are still crude. We are still unable to treat medical disorders on a molecular level, which limits our ability to treat many medical problems. Nanotechnology opens the doors to more effective and accurate treatments by developing a way for doctors to treat patients on a molecular level. Nanotechnology medical research is focusing on advancements to aid in tissue repair, drug delivery, and biological testing and screening.

The increase in longevity through medical advancements will affect the medical community of healthcare providers, insurance industries, pension plans, and financial planning industries. The growing population will also have carry-through effects on city planning, the housing market, food suppliers, and manufacturers. While still in the conceptual stages, if a pill can solve all ailments, people will no longer worry about the effects that a lack of exercise and high fat diets will have. The implications of this extend well into the multibillion-dollar fitness and diet markets. Health clubs, diet supplements, plastic surgeons, support groups, fitness products and magazines will likely experience dramatic business decline.

Tissue and Organ Generation

Through nanotechnology researchers are attempting to reverse engineer the way that "Mother Nature" produces substances and materials like bone and tissue. One aim of nanotechnology is biomimicry. Tissue and organ failure accounts for half of total U.S.

health care expenditures. [42] Current estimates are that 80,000 people nationwide are waiting for donor organs, and every day an average of 63 people receive their much-needed transplants.

Scientists are beginning to talk of generating skin and cartilage in a dish within the next decade. [43] Today, hundreds of companies are engineering tissue, 12 of which are publicly traded, with a total of four FDA-approved products on the market. The struggle for these companies is slower-than-expected adoption, FDA approval, less-than-anticipated success rates in testing, and the problems inherent in early-stage companies.

The concept of tissue engineering has been around since the mid-1960s when scientists developed artificial skin for burn victims. Through advances in microscopy, scientists now better understand how tissues bind and interact with biomaterials at the nanoscale. Further insight may make feasible the design of nanomaterial to replace bone, tissue, and blood vessels. Other developments in this area include Angstrom Medica's bone-like inserts, which replace the use of medical screws in orthopedic surgery. These screws are less painful and gradually dissolve with new bone growth.

Artificial tissue and organs will reduce the need for medical care providers, medical device manufacturers (such as dialysis machines), and drug manufacturers.

Drug Delivery

Researchers studying virus behavior seek to mimic the way a virus takes over a cell for use in drug delivery and imaging. [44] Scientists are trying to recreate the viral capsid without the nucleic acid that a virus carries to inject into a cell. In place of the nucleic acid, scientists instead plan to use the space to carry drugs to targeted cells. These capsids are very versatile, and doctors can easily modify them. In addition, empty capsids self-assemble in yeast cells that are genetically engineered to produce subunits. Doctors seek to engineer viral-inspired capsids that can target, and destroy, cancerous cells by releasing the drugs the capsids carry.

Scientists can also use these viral shells to improve imaging techniques, thus improving cancer detection. For example, scientists place atoms of the imaging agent gadolinium into the capsid and genetically reengineer the capsids by placing docking sites for cancerous cells on the shell. These docking sites bind with proteins expressed on the surface of cancer cells. The result is a collection of the gadolinium cells on the cancer site that a magnetic resonance imaging (MRI) machine can pick up.

The docking sites can also be modified to detect varying forms of cancer. Doctors are investigating how the capsid would know to release the anticancer agent once it finds the cancer cell. While viruses normally use pH levels to trigger the opening of the ducts, scientists are looking into using redox potentials (the differences in electrical charge, or the affinity for an additional electron) as the trigger to opening the release gates.

Less harmful cancer treatments will restructure not only the medical professions such as oncology, surgery, and chemotherapy and radiation doctors and technicians, but also nutritionists, pain-killer pharmaceutical makers, support groups, and beauticians that specialize in cancer patients.

"Quantum Dots" and Labeling in Imaging

Advances in semiconductor nanocrystals have led to what researchers call "quantum dots." Quantum dots may one day replace conventional dye molecules that doctors currently use for imaging techniques. While originally developed for electronic and optical purposes, scientists now use quantum dots in drug development and disease diagnosis. [45] Quantum dots obey the laws of the quantum scale, resulting in a set of properties unique to the crystals.

Unlike the traditional organic dye molecules, quantum dots can absorb all light particles above a given energy threshold (organic dyes only absorb a specific wavelength). The size of the quantum dot determines the color of light that it emits. Quantum dots have several other advantages versus traditional dyes. The largest advantage is the range of colors that they can emit. This range allows for several observations at one time, whereas with traditional methods doctors have to direct a variety of light wavelengths at the area they are examining. The quantum dots are capable of performing more cycles of light emission than organic materials, which often decompose quickly. This allows researchers to track cellular activity for extended periods.

Arrangements of quantum dots, in the form of bar codes, tagged to specific genes in DNA have been used to monitor reactions of cells to certain drugs or viruses. The tagging technique used is known as "bead-based genotyping." This technique may allow blood samples to be quickly screened for certain proteins that indicate a higher propensity for diseases such as diabetes, HIV, and cancer. Quantum dots will have an effect on traditional medical dye manufacturers, testing and lab companies, and medical screening (MRI, CAT-Scan) companies and the technicians that operate the equipment.

Genetic Testing

Scientists are currently working to develop a means of quickly detecting specific genetic sequences through the use of atomic force microscopy techniques. IBM researchers have attached strands of DNA to arrays of probes like those used in AFM. The DNA sequences are arranged to bind to specific genetic coding. When the probes move across a sample of genetic material and the sample binds, it induces a surface stress that bends the arms that the probes are attached to by a few nanometers, which is just enough to be detected. [46]

Computing and Electronics

It would appear we have reached the limits of what is possible to achieve with computer technology, although one should be careful with such statements; they tend to sound pretty silly in five years.

John von Neumann, 1949.

The computing and electronics industry is the final major area of current nanotechnology research. Current predictions are for technology to reach the limits of what we can fit on a microchip using current technology by the year 2020. [47] Moore's Law will succumb to overheating if researchers do not develop new processes. Nanotechnology will provide the necessary innovation to propel computing to new levels of power at even smaller scales.

According to researcher, inventor, and futurist Raymond Kurzweil:

> *We will have the raw computing power of the human brain—about 100 billion neurons and 100 trillion connections—in a 1,000 (USD) PC by around 2019 . . . By 2030, a 1,000 (USD) computer system will have the power of a thousand human brains; by 2050, a billion human brains.* [48]

Nanotechnology is already fundamentally changing much of electronics and computing. Researchers are also exploring nanotechnology's potential in everything from circuitry and storage to flat-panel screens in computing.

Advances in computing that decrease size and cost will result in the integration of computer chips and nanocomputers into products and materials, which previously had no computing capability. Not only will chips be used in electronics, toys, automobiles, and appliances, but also computing could bring about additional enhancements in materials.

One day your jacket may be able to automatically adjust its wind resistance and waterproof properties based upon the external conditions, with internal computer chips stimulating electronic fibers. There may be a day when your orange juice carton contains a chip that not only monitors the freshness and level of your juice, but that also interacts remotely with your PDA to tell you that you need to pick up more orange juice when you are at the store. Advances in electronics will bring cheap computing power to everyday things, revolutionizing the way we experience the world.

Circuitry

Likharev's proposed coulomb island and single-electron transistors could form the basis for a new nanocircuit that is increasingly robust as its size diminishes. Cornell scientists have already created a single-atom transistor, comprised of a molecule positioned between two gold electrodes. When voltage is applied, electrons flow through the molecule creating a circuit. [49]

A research team at Harvard University is leading the production of "nanowires." [50] Nanowires are slivers of semiconductors that are so small that 20 million can fit into a strand of 2-lb.-test fishing line. These nanowires may enable the next generation of computing devices. Engineers need nanowires to connect nanocomputers to the larger devices that they communicate with and operate.

In October 2002, IBM researchers announced that they had created the world's smallest working computer circuit. [51] The circuits are made of a precise pattern of carbon monoxide molecules on a copper surface. The carbon molecules are aligned like dominos, so moving one molecule triggers a cascade of motion in a particular sequence. The researchers combined this with structures capable of performing the OR and AND digital-logic functions, data storage and retrieval, and the wiring for the circuitry. The most complex circuit was only 12nm by 17nm. At this size, 190 billion could fit within a 7mm diameter circle.

Researchers are also making plastic semiconductors through a process similar to ink-jet printing. The device sprays nanoscale particles precisely onto a thin plastic film. Plastic provides several benefits over silicon—it is less rigid and does not require the ultraclean fabrication facilities, nor the toxic chemicals, used to etch silicon, making plastic semiconductors much less expensive. The plastic transistors are larger then silicon transistors, so they will not replace silicon at the high end of the market, but their low-cost, lightweight, and flexible structure make them ideal for lower-end applications. The application that is proposed most frequently is a form of electronic paper. The design of the electronic paper devices will maintain the reader's experience (same texture, feel of a regular newspaper or magazine) while allowing for customization and updates through quick downloads.

Electronic paper could revolutionize not only the printing and publishing industries, but also advertising (billboards that can change throughout the day and personalized adds in downloaded magazines and papers). Retailers will be able to eliminate the time-consuming and costly process of changing display signs, and eventually electronic paper could make its way into interior design (changing customized wallpaper and paint).

Storage

Chip technology costs are expected to skyrocket—by 2010, a major fabrication facility is expected to cost approximately $50 billion. [52] Nanotechnology and self-replication hold the potential to scale costs down dramatically.

IBM has announced that it has been able to use nanotechnology for data storage at a density of a trillion bits per square inch. This is 20 times the magnetic storage density available today and it is still very early stage. [53] Currently, the technology utilizes about 1,000 probes to create and read the data, the number of probes is expected to scale to 1 million per chip, greatly increasing the storage ability. IBM believes that this technology could potentially drop the cost of storage to one cent per gigabyte.

Hewlett-Packard has announced that it can stamp circuits directly onto a wafer from a master grid through nano-imprint lithography. The current storage capability on these chips is only 64 bits (compared with standard chips that hold 256 million bits), but they can potentially scale to hold 10 times the data that can currently be stored on a square micron. The nano chip was created through wiring a chip with trenches 40nm wide and filling the trenches with platinum. One thousand molecules were placed at each grid junction to act as switches. The molecules change orientation depending on the electrical signal sent, performing the binary functions fundamental to computing. Hewlett-Packard may become the most cost-effective solution, as it predicts one pentabyte of storage per penny.

Intel has moved forward with 90nm design rules on 300mm wafers. At these sizes the amount of processing power on a wafer is approximately tripled. [54]

Greater storage capacity at a fraction of the cost will redefine most of the hardware industry. Beyond computers, there will be lower demand for zip and other forms of portable memory disks, IT consultants, and less need for physical space (to house servers, etc.). At the same time, we will likely see huge advances in toys and gaming; electronics around the home will become much more advanced. Digital cameras will have multiples of what is available in today's memory cards. TiVo will no longer require deletion to free up memory. Access to most materials will be quick and easy.

Light-Based Electronics

Early in 2002, it was discovered that through the use of “quantum wells” it is possible to trap electrons, forcing them to jump to different energy levels and resulting in the emission of light. The quantum wells are made by placing semiconductive films a few nanometers deep between insulating material. The films trap the electrons, forcing them to move to new energy levels. One potential use of this technology is light-based electronics. [55]

Samsung is working to produce a nano-enhanced 32-inch flat-screen monitor by the holiday season of this year. [56] The nanotubes are being used to stimulate individual pixels, because they fire off electrons when an electric current is applied to them. The technology enables a cheaper and more energy efficient screen that is as thin as an LCD display.

Ntera, an Irish startup, is also working on flat-screen technology that incorporates nanotechnology. [57] The company is using nanosized electrodes placed in a thin film. The electrodes stimulate colored molecules to create pictures that are close to paper quality. In addition to traditional electronics (televisions, computer monitors, and mobile phone displays), the technology could be used for billboards, e-books, and store displays, redefining the publishing and printing industries along with advertising and retail.

Fuel Cells

Nanotubes could dramatically increase battery performance. There is a fair amount of research looking into innovative fuel cells. Researchers have found that carbon nanotubes may be able to increase battery life over current graphite capabilities by a factor of two. [58] Graphite is the form of carbon used as an electrode in today’s rechargeable lithium batteries. Scientists found nanotubes’ open ends facilitate the reactions that occur at the electrodes of batteries, enabling twice the energy storage capability of current batteries.

NEC Corporation scientists were able to create a fuel cell from a particular type of nanotube called a “nanohorn.” [59] The fuel cell has 10 times the energy storage of a traditional lithium battery. Nanotubes have greater fuel storage capability because of their shape, which results in a large surface area, and they are easily permeable to gases and liquids.

This technology has the potential to enable significantly extended use of portable items—making it possible for something such as a laptop to run for days, rather than hours. The technology will likely result in a move away from traditional combustion engines, changing the auto market.

Appendix C: Slow Down! You're Going Too Fast

While scientists and researchers are working to bring the nanotechnology revolution sooner, there is concern among some that the pace of innovation is too fast. Many people are concerned about our overall lack of molecular-level knowledge. They feel that it is critical for us to have a more comprehensive understanding of the laws that govern the quantum scale before we begin mass production of nano products. The opposition is focused on the uncertainty and fear of the potential perils resulting from molecular-sized objects that are invisible to the naked eye and that abide by a different set of physical laws. Concerns range from the "Grey Goo" phenomenon, to healthcare concerns about exposure to nanoparticles.

The Grey Goo concern is the worry that self-replicating technology will result in something similar to the bad Hollywood movie, *The Blob*. First presented by Bill Joy in a *Wire* magazine article in 2000, the Gray Goo concern built a following. [60] Individuals fear that once we are able to create the self-replicating technology that we need to mass produce at the nanoscale, the technology will replicate beyond our control and we will be overwhelmed.

While many knowledgeable people have raised concerns of varying degree surrounding the self-replicating capabilities that eventually will be inherent to nanotechnology, several points counter their arguments. First, self-replication will take place in controlled environments where solutions must be mixed, or computer programming is involved. If an external computer guides the self-replication, the possibility of uncontrolled overproduction is impossible. [61] Additionally, and the main counterpoint, self-replicating systems are all around us—self-reproduction is an inherent property of life, yet we have managed to prevent any one thing from extending beyond our control.

Other frequently voiced concerns surround the lack of understanding of the potential environmental and health risks that particles at the nanoscale could represent. For instance, carbon nanotubes closely resemble the molecular structure of asbestos. Is there the potential for nanotubes to represent a respiratory threat? [62] And, at the nanoscale, we will have trouble detecting them and cleaning them up. Pat Roy Mooney, the executive director of ETC, an activist group in Minnesota, "worries about environmental damage and diseases driven by unexpected responses of people and other living things to the accumulation in their systems of artificial particles the Earth has never seen before." [63]

In our view, however, the biggest threat of nanotechnology is that the capabilities fall into the wrong hands. The true potential harm comes from the technology being developed or controlled by radicals and extremists. While there is potential for great advances to be made for the most beneficial use, the technology also can enable people to inflict great harm. We need to encourage the development of nanotechnology by responsible groups. If we lead the innovation, we can establish rules and guidelines at the start of development. Additionally, we need to understand how this technology functions and behaves, as well as how it could be used as a weapon, in order to protect ourselves.

To ensure the safety of nanotechnology while not hindering innovation, several individuals and groups have offered proposals for regulation. Ways of preventing deliberate harmful utilization of nanotechnology include access limitation, export controls, professional ethics, and inherent safety of the various forms of nanotechnology. [64] What we cannot do is limit or hold back innovation. At some point, someone is going to develop the technology, and the safest place to be is at the forefront of that innovation.

Appendix D: The Dow 30 and Nanotechnology's Effects

It's hard to think of an industry that isn't going to be disrupted by nanotechnology.

David Bishop, Director of MEMS Research Lucent Technologies. [65]

Alcoa Inc. (AA)

Alcoa does not currently mention nanotechnology on its website.

Alcoa's aluminum and other materials businesses will likely experience a reduction in demand with the advent of nanotechnology-enhanced materials. Nanotechnology holds the promise of better materials—materials with enhanced physical properties such as increased strength, flexibility, heat resistance, electrical conductance or insulation, and lighter weight.

Altria Group (MO)

Altria does not currently mention nanotechnology on its website.

Both the food business and the tobacco business will be affected by nanotechnology. Genetically enhanced foods will likely become more common. Better ways of storing and harvesting food will likely increase efficiencies in production and reduce waste. Demand for food will rise with the growing population due to nano advances in healthcare.

Additionally, the advances in healthcare will be able to reverse the harmful effects of smoking.

American Express Co. (AXP)

American Express does not currently mention nanotechnology on its website.

Amex will benefit from the cheaper chip technology. Credit cards and traveler cheques may someday soon have nano chips embedded in them, which would provide greater security and more efficient processing.

AT&T Corp. (T)

AT&T does not currently mention nanotechnology on its website.

Cheaper, higher-quality computer chips will influence the manner of transmitting voice. Videophones will become commonplace, with the introduction of cheap, ultrathin display panels and enhanced OLED capabilities. The telecommunications industry will experience major changes.

Boeing Co. (BA)

Boeing has a nanotechnology initiative focusing on material advancements. The company is also researching nanotech developments for electronics and fuel cells.

Aircrafts will experience the benefits of nano advances in both materials and computing. Stronger materials will be available. Lighter planes will result in fuel efficiencies.

It will become cost effective to have computers monitoring all aspects of the plane and flight. Computers will be able to optimize the flight paths and schedules. Planes will be able to immediately adjust to wind currents and other weather.

Caterpillar Inc. (CAT)

Caterpillar does not currently mention nanotechnology on its website

Caterpillar, as a leading manufacturer in construction and mining equipment, diesel and natural gas engines, and industrial gas turbines, will see its markets change dramatically in the face of nanotechnological developments. Mining may be replaced by laboratory mineral and metal production. Alternative sources of fuel could replace diesel and gas to make its engines obsolete.

Citigroup Inc. (C)

Citigroup does not currently mention nanotechnology on its website.

Banking is an industry driven primarily by human capital. However, advances in computing will allow for the automation of many functions and will reduce costs through increased efficiency and reduce the number of employees needed for specific tasks. Additionally, nanotechnology will become a huge source of investment banking business and will create a lot of new wealth for the economy.

Coca-Cola Co. (KO)

Coca-Cola does not currently mention nanotechnology on its website.

Nanotechnology will not alter the classic coca-cola syrup. It will, however, still affect the experience of customers. Nanotechnology may be able to create longer-lasting carbonation and provide consistent and exact molecular make-up of the syrup. Even before those advances, it is likely that customers will receive their soda in better packaging, which will increase their “enjoyment.” Packaging developments in cans and bottle labels will provide better insulation, thereby keeping your drink colder longer. Less permeable materials will maintain carbonation levels, resulting in increased shelf life.

DuPont Co. (DD)

Nanotechnology will directly influence the future of each division of DuPont. The company has already devoted a lot of effort to its nanotechnology initiative.

The company website lists nanotechnology as a core technological capability in coatings and color technologies and electronic and communications technologies. The company’s Teflon fabric protector uses nanomaterials to coat each fiber in fabrics and textiles. There are efforts to utilize nanotubes in flat-panel displays. DuPont is partnered with MIT and Raytheon in the $50 million Institute for Soldier Nanotechnologies (ISN) effort to create nano-enhanced military uniforms. Board member Goran Lindahl provides evidence of the firm’s commitment to nanotechnology—he is co-chairman of Nanomix, Inc., a developer of products made from nanoscale materials and components.

Eastman Kodak Co. (EK)

Kodak's website does have brief mention of nanotechnology.

Eastman Kodak has used nano particles since the 1960s. Nanoscaled silver particles are used as filters to manage the flow of light between the layers of color film. Nano particles are also used to remove excess chemicals in the development process.

Ink for the company's ink-jet printers also use nanoscale particles in efforts to reduce printer clogging and increase the definition of the printed material.

Nanotechnology will have significant influence on both the photo and printing markets. As developments in computing take place, film could be replaced by digital technology. The same materials being developed to form electronic paper may eventually replace photographs. If the pixel quality on a cheap electronic screen is better and less expensive than a traditional print, replacement will certainly occur.

ExxonMobil Corp. (XOM)

ExxonMobil's website lists the use of nanotechnology in the company's molecular fingerprints and nanofactories initiatives. The company is looking to utilize nanotechnology to create better lubricants, more environmentally friendly fuel, and more efficiency in oil use (potentially 50% more gas from a barrel of oil). Exxon is also focused on creating alternative fuels, such as a hydrocarbon processor for fuel cell-powered vehicles. Nanotechnology is being used to optimize the structure of chemicals, as well as in the development of synthetic lubricants, which will increase efficiency, reduce the number of required oil changes, and reduce emissions.

General Electric Co. (GE)

GE has devoted an entire group to its nanotechnology effort, the GE Global Nano Research Group. The group has focused efforts in biomimetics (reverse engineering biology), nanotubes, and nanowires, nanocomposites, and nanostructured optoelectronics.

General Motors Corp. (GM)

General Motors has invested in the development of nanocomposites. Already the company has introduced nano-enhanced parts to its 2002 line of mid-sized vans. The vans have side steps made of GM's advanced thermoplastic olefin (TPO), which provides a stiffer, lighter, and less brittle in cold temperatures solution at the same price as a traditional step because of the lower volume required. Material advancements will affect car design dramatically, and will result in better fuel efficiency and longer-lasting vehicles (due to better lubricants and stronger components).

GM will also be influenced by fuel-cell developments. As hydrocarbon fuels are developed or better forms of solar energy storage are created entirely, new engines will be produced.

Hewlett-Packard Co. (HPQ)

Hewlett-Packard has publicly announced that over half of its long-term R&D budget is earmarked for nanotechnology initiatives. The company has founded a Quantum Science Research center with the aim of developing the technologies that will be crucial to the business in 10 or more years. The company's primary focuses are on nanoscale science and the fundamental physics of switching to develop the knowledge base needed to truly leverage the power of the nanoscale. The emphasis has been placed on molecular electronics, nanowires, and self-assembly. The company already has a patent for computers that can fit on the head of a pin. Nanowire (wires that are 2nm thick) development is for the purpose of enabling nanocomputers to connect to and to operate larger-scale devices. H-P has a patent for "chemically synthesized and assembled electronic devices," which is an inexpensive, scalable, and easy way to make numerous electronic devices, such as logic, memory, and communications and signal routing devices.

Home Depot (HD)

Home Depot does not currently mention nanotechnology on its website.

As with other retailers, nanotechnology will change Home Depot's business. More integrated computing will enable better inventory control, better price points, and greater efficiencies throughout the store. Nanotube-enhanced displays will eliminate the need to physically change signs; instead, simple computer programming will adjust any displays throughout the store.

Honeywell International Inc. (HON)

Honeywell's efforts are focused in the area of nanocomposites—using molecular design to create materials with enhanced properties. The different business lines will all experience benefits from enhanced materials.

Intel Corp. (INTC)

Intel's nanotechnology research has focused on transistors. The company has developed a transistor that is a few nanometers long and only three atoms thick. Four hundred million of these transistors could potentially fit on a single chip, increasing to 10 GHz from today's fastest speed of just over 1 GHz.

International Business Machines Corp. (IBM)

IBM has clearly been a leading thinker and developer in nanotechnology. From the development of the scanning tunneling microscope, to the manipulation of atoms to form the letters IBM, to the company's current millipede project, IBM has made significant nanotechnology efforts.

IBM is deeply invested in developing nanotechnology—the company's work has focused on everything, from creating the necessary tools to work at the nanoscale to materials and computational applications of nanoscale design. Nano project areas include cantilever sensors, chemical AFM, magnetic resonance imaging, dynamic force microscopy, bottom-up nanomachines, nanoscale integrated circuits, assembly tools for molecular structures, thermomechanical storage and AFM, STM on organic materials, and ultrathin magnetic structures.

Millipede is the company's major nanotechnology effort. It is a thermomechanical storage technique capable of achieving data density in the hundreds of Gb/in^2 range. (The expected limits of magnetic recording are in the 60-70 Gb/in^2 range.) Millipede utilizes the micromechanical components of AFM (atomic force microscopy) to melt tiny depressions (which represent bits of data) into a polymer medium. The AFM probe can read and write data. To create a high read-back rate IBM constructed arrays of probes that are fabricated onto single chips.

IBM also has research efforts focused on OLEDs (organic light emitting devices) for all sizes of flat-panel display applications. Microdisplays are the initial applications where OLEDs could replace existing technologies. Microdisplays are either compact virtual displays with magnifying optics or small direct view displays with high information content.

International Paper Co. (IP)

International Paper does not currently mention nanotechnology on its website.

The company's three main product lines—paper, packaging, and forest products—all stand to be displaced by advancements in materials and computing. OLEDs will potentially provide a cheaper, reusable form of electronic paper. Material advancements will provide lighter, more effective packaging and materials that will replace wood and other forestry products on a cost and efficiency basis. The forest products business will likely experience less (if any) disruption in the orchard and nursery and the hunting and leasing business lines.

JP Morgan Chase & Co (JPM)

JP Morgan Chase does not currently mention nanotechnology on its website.

All members of the banking industry will experience similar effects. (See Citigroup description.)

Johnson & Johnson (JNJ)

Johnson & Johnson does not currently mention nanotechnology on its website.

However, nanotechnology will play a significant role in the development of the pharmaceutical industry over the next decade. Predictions are that by 2020 half of all major pharmaceuticals will be developed through nanotechnology. While not explicitly stated on its website, the company has been involved with nanotechnology. J&J was a corporate sponsor of BioMEMs & Biomedical Nanotech WORLD 2002, and Johnson & Johnson Ventures has been involved in consortiums on nanotechnology.

McDonald's Corp. (MCD)

McDonald's does not currently mention nanotechnology on its website.

McDonald's experience with nanotechnology will include changes in packaging through material advancements and efficiencies created through integrated computer systems. Chip advances one day may track freshness of food and time-efficient preparation, For example, the griddle may be able to calculate the appropriate cook time of meat based upon surface heat, surrounding heat, and food weight.

Merck & Co. (MRK)

Merck does not currently mention nanotechnology on its website.

While not explicitly mentioned on its website, Merck is often listed as a significant investor in nanotechnology. The company's German division has a multibillion-dollar deal with Ntera, a company developing nanomaterials to manufacture electronic paper. The company has given presentations on the influence that nanotechnology will have. Merck's primary initiatives are lab-on-a-chip technology, medical diagnostic sensors, and drug delivery.

Microsoft Corp. (MSFT)

Microsoft's research center is keeping up on the developments in nanotechnology. Microsoft researchers have visions of a day when computing is immediately involved in most aspects of everyday life. The company is researching low-power, portable or wearable devices that interface with traditional computing environments. Innovations include "sensors to track and respond to user activities in order to build interfaces that require little or no attention from the wearer." Microsoft has three research groups working on quantum computing and nanotechnology. The ongoing technological revolution will require Microsoft to continue to leverage its research groups to create new innovative solutions that will move in the direction that the market is going.

Minnesota Mining & Manufacturing Co. (MMM)

3M is investing time and money into finding new solutions for coatings, dental restoratives, fuel cells, lubricants, and nano-particle filtration.

Procter & Gamble Co. (PG)

P&G's only mention of nanotechnology on its website is regarding the company's support of educational and development programs for nanotechnology. However, a director of P&G sits on the Nanotechnology Business Roadmap for Industry board. The company is aware of the disruption that nano-enhanced materials such as nanopants could have on its business, and it is staying abreast of the developments. It has published on the subject of nanoparticles as dye replacements. In 2001, the company, along with British Aerospace, provided funding for a center for innovation in microsystems and nanotechnology at Newcastle and Durham universities. P&G also has research efforts focused on dendrimers.

Nanotechnology will change the consumer goods market.

SBC Communications (SBC)

SBC does not currently mention nanotechnology on its website.

As with most technology industries, the wireline and wireless industries will undergo fundamental technological change. Nanotechnology's role in optics lies not so much in the optics themselves as in the manufacturing process. Nanotechnology will provide cheaper fabrication alternatives.

United Technologies Corp. (UTC)

United Technologies does not currently mention nanotechnology on its website.

Nanotechnology's influence on UTC will be similar to that on other industrial manufacturers. (See Honeywell description.)

Walt Disney Co. (DIS)

Disney does not currently mention nanotechnology on its website.

Disney will likely experience many of the benefits from cheaper, faster computers as well as other electronic advances including OLEDs. The film business will be able to produce more advanced graphics and more advanced animation. The electronic advances will revolutionize its marketing capabilities. The parks and resorts will be able to further enhance rides and entertainment features. Nanoelectronics and materials will also become part of the retail business. While there is no need for Disney to be among the development leaders in nanotechnology, the company will eventually want to license many of the advancements.

Wal-Mart Stores Inc. (WMT)

Wal-Mart does not currently mention nanotechnology on its website.

Wal-Mart will find the influence of nanotechnology on its business to be very similar to the enhancements nano provides to other retailers like Home Depot. (See Home Depot description.)

Endnotes

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[2] Rolf Allenspach, head of the nanoscale physics team at IBM Zurich Research Laboratory.

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[29] Dennis Normile, "Just Two Words: Carbon Nanotubes," *Business 2.0*, September 2002, 36.

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Companies Mentioned *(Price as of 05 May 03)*

Alcoa Inc. (AA, $23.18, NOT RATED)
Altria Group, Inc. (MO, $30.95, NEUTRAL, TP $32)
AT&T Corporation (T, $16.74, NEUTRAL, TP $16)
Boeing (BA, $27.62, OUTPERFORM, TP $50)
Caterpillar Inc. (CAT, $52.68, OUTPERFORM, TP $59)
Citigroup (C, $39.53, OUTPERFORM, TP $50)
Coca-Cola Company (KO, $40.53, OUTPERFORM, TP $48)
Eastman Kodak (EK, $30.75, NOT RATED)
ExxonMobil Corporation (XOM, $35.45, NEUTRAL, TP $37)
Home Depot, Inc. (HD, $28.92, NOT RATED)
Honeywell International Inc. (HON, $24.18, NEUTRAL, TP $24)
International Paper (IP, $35.9, OUTPERFORM, TP $46)
J.P. Morgan Chase & Co. (JPM, $30.36, OUTPERFORM, TP $35)
Johnson & Johnson (JNJ, $56.46, NOT RATED)
McDonald's Corp (MCD, $17.49, OUTPERFORM, TP $21)
3M (MMM, $124.81, NEUTRAL, TP $125.00)
Procter & Gamble Co. (PG, $90.14, NOT RATED)
SBC Communications, Inc. (SBC, $23.53, OUTPERFORM, TP $25)
United Technologies (UTX, $62.17, NEUTRAL, TP $65)
Walt Disney Company (DIS, $18.49, OUTPERFORM, TP $23)
Wal-Mart Stores, Inc. (WMT, $55.58, OUTPERFORM, TP $65)
Dow Chemical Company (DOW, $32.23, OUTPERFORM, TP $55)
E.I. Du Pont (DD, $42.8, UNDERPERFORM, TP $45)
General Electric (GE, $28.83, NEUTRAL, TP $28)
General Motors Corp. (GM, $35.74, RESTRICTED)
Intel Corp. (INTC, $19.02, NOT RATED)
International Business Machines (IBM, $86.52, NEUTRAL, TP $87)
Hewlett Packard (HPQ, $16.8, NEUTRAL, TP $18)
Lucent Technologies (LU, $2.04, NEUTRAL, TP $1.75)
Merck & Co. (MRK, $58.96, NEUTRAL, TP $64)
Motorola Corporation (MOT, $8.12, NEUTRAL, TP $7)
Mitsubishi (MSBHY, $11.75, NOT RATED)
Xerox Corporation (XRX, $10.16, NOT RATED)
Altair International (ALTI, $0.34, NOT RATED)
Veeco (VECO, $16.51, NOT RATED)
Flamel Technologies (FLML, $8.52, NOT RATED)
FEI Company (FEIC, $18.03, NEUTRAL, TP $19)
Pharmacopia (PCOP, $9.07, NOT RATED)
Symyx Technologies (SMMX, $15.62, NOT RATED)
Skyepharma (SKYE, $8.62, NOT RATED)
Nanophase Technologies (NANX, $3.00, NOT RATED)
Elan (ELN, $4.04, NOT RATED)
Zygo (ZIGO, $7.38, NOT RATED)
Nanometrics (NANO, $5.33, NOT RATED)
NanoPierce Technologies (NPCT, $0.15, NOT RATED)
Harris and Harris Group (TINY, $4.30, NOT RATED)
Nanogen (NGEN, $1.35, NOT RATED)
Nexia Biotechnologies (NXB.PK, $0.80, NOT RATED)
NEC (6701, ¥379.00, UNDERPERFORM, TP ¥400.00)
Hitachi (6501, ¥432.00, OUTPERFORM, TP ¥622.00)
BASF (BASF.DE, eu40.35, NEUTRAL, TP eu38)

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> **The industry average refers to the average total return of the analyst's industry coverage universe (except with respect to Asia/Pacific, Latin America and Emerging Markets, where stock ratings are relative to the relevant country index).*
>
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