Chapter 1

The Hitchhiker's Guide to Nanotechnology

In This Chapter

- Finding out what nanotechnology is and how it will change your world
- Identifying the difference between real science and science fiction
- Investing wisely in the emerging nanotech industry — and still keeping your shirt

> *. . . necessity . . . is the mother of our invention.*
>
> *from* The Republic *by Plato (c. 370 B.C.)*

Welcome to the world of nanotechnology — technology capable of fulfilling our every need (almost). It's safe to assume that you know a little bit about nanotechnology from picking up this book. However, you may have a few unanswered questions. Maybe you've heard it described as "The Next Industrial Revolution" on the news followed by some business commentary. Maybe you're a Will Smith fan and saw his 2004 movie *I, Robot,* where "nanites" save the day, dismantling the main computer from the inside. Other than a financial topic or clever plot device, what is nanotechnology (exactly)? Do I *need* nanotechnology? Will I be able to cash in on a "nanotechnology bubble" or will I lose my shirt as I did with the dot-coms? These are all fair questions; we address each of them in this chapter.

Grasping the Essence of Nanotechnology

We start off this chapter by defining nanotechnology and showing you not only the need but also the inevitability of this technology. We then go into detail explaining what you can expect from nanotechnology. (Short, sharp, and to the point — that's our motto!)

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Finding out what it is

Nano, Greek for "dwarf," means one billionth. Measurement at this level is in *nanometers* (abbreviated "nm") — billionths of a meter. To put this into perspective, a strand of human hair is roughly 75,000 nm across. On the flipside of the concept, you'd need ten hydrogen atoms lined up end-to-end to make up 1 nm. Figure 1-1 illustrates the differences in scale that range from you all the way down to one hydrogen atom.

The definition

Nanotechnology can be difficult to determine and define. For example, the realm of nanoscience is not new; chemists will tell you they've been doing nanoscience for hundreds of years. Stained-glass windows found in medieval churches contain different-size gold nanoparticles incorporated into the glass — the specific size of the particles creating orange, purple, red, or greenish colors. Einstein, as part of his doctoral dissertation, calculated the size of a sugar molecule as one nanometer. Loosely considered, both the medieval glass workers and Einstein were nanoscientists. What's new about current nanoscience is its aggressive focus on developing applied technology — and the emergence of the right tools for the job.

When faced with a squishy term that can mean different things to different people, the best thing to do is to form a committee and charge it with drawing up a working definition. In fact, a committee *was* formed (the National Nanotechnology Initiative) and the following defining features of nanotechnology were hammered out:

1. Nanotechnology involves research and technology development at the 1nm-to-100nm range.
2. Nanotechnology creates and uses structures that have novel properties because of their small size.
3. Nanotechnology builds on the ability to control or manipulate at the atomic scale.

Numbers 1 and 3 are pretty straightforward, but Number 2 uses the eyebrow-raising term "novel properties." When we go nano, the interactions and physics between atoms display exotic properties that they don't at larger scales. "How exotic?" you ask? Well, at this level atoms leave the realm of classical physical properties behind, and venture into the world of quantum mechanics. David Rotman described this best in his 1999 article, "Will the Real Nanotech Please Stand Up?" (published in the March/April edition of *Technology Review*), when he quoted Mark Reed, a nanoelectronics scientist at Yale University:

> "Physical intuition fails miserably in the nanoworld . . . you see all kinds of unusual effects." For example, even our everyday electrons act unusual at the nano level: "It's like throwing a tennis ball at a garage door and having the ball pop out the other side."

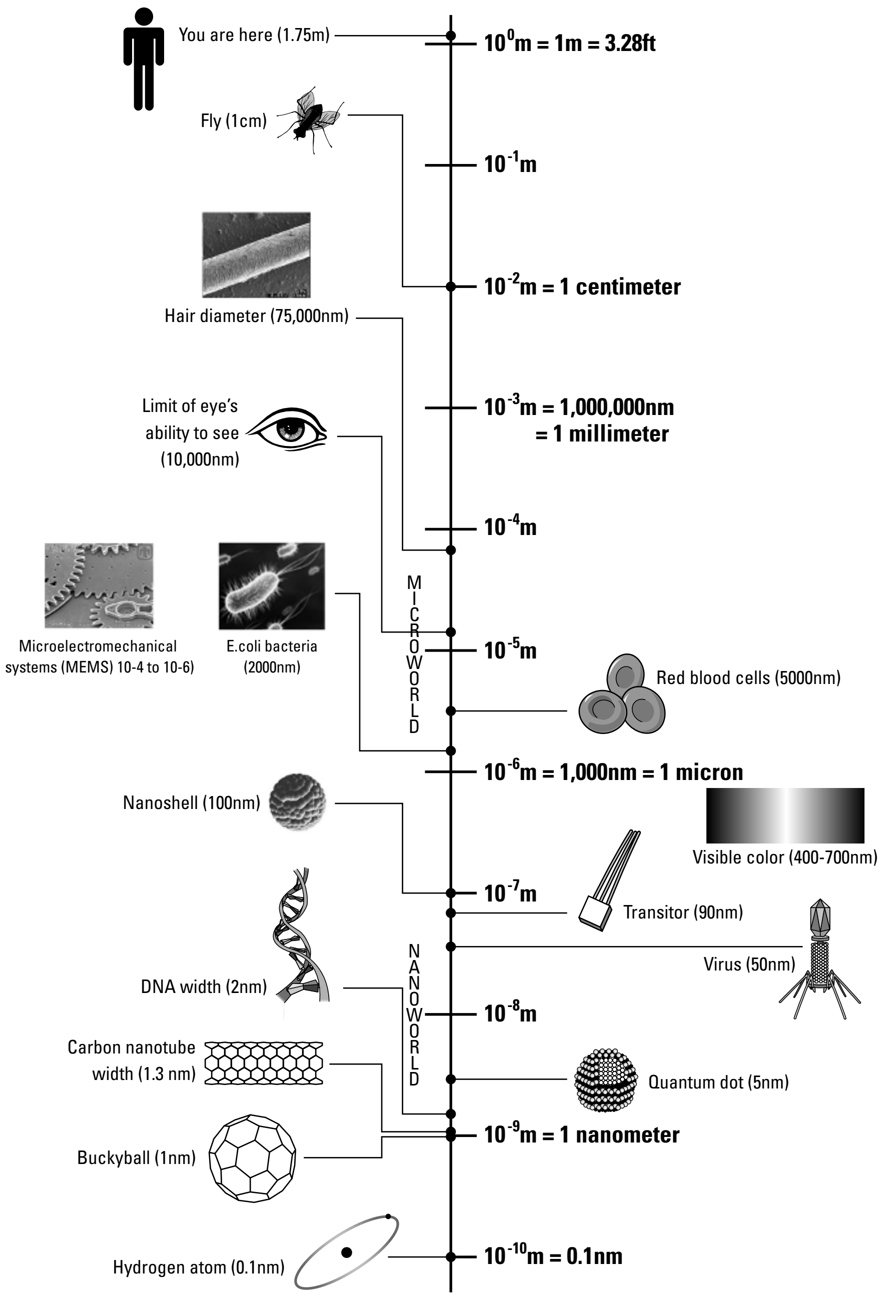

Figure 1-1: Size comparisons, from you (1.75 meters, or approximately 5 ft. 7 in.) all the way down to the hydrogen atom (0.1 nm).

Need another concrete example? Check this one out. It is demonstrably true that a gold nanoparticle has a color, melting point, and chemical property different from those you'd find in a macro-scale Fort Knox gold brick. That's because the interactions of the gold atoms in the larger gold brick average out — changing the overall properties and appearance of the object. A single gold nanoparticle, on the other hand, can be its own idiosyncratic self — a tiny object, free from the averaging effects of countless other gold atoms.

The applications

Nanotechnology is, at heart, interdisciplinary. You'll get only part of the story if you just use chemistry to get at the properties of atoms on the nano level — adding physics and quantum mechanics to the mix gives you a truer picture. Chemists, physicists, and medical doctors are working alongside engineers, biologists, and computer scientists to determine the applications, direction, and development of nanotechnology — in essence, nanotechnology is many disciplines building upon one another. Industries such as materials manufacturing, computer manufacturing, and healthcare will all contribute, meaning that all will benefit — both directly from nanotechnological advances, and indirectly from advances made by fellow players in the nano field. (Imagine, for example, quantum computers simulating the effectiveness of new nano-based medicines.)

There are two approaches to fabricating at the nano scale: top-down and bottom-up. A *top-down* approach is similar to a sculptor cutting away at a block of marble — we first work at a large scale and then cut away until we have our nano-scale product. (The computer industry uses this approach when creating their microprocessors.) The other approach is *bottom-up* manufacturing, which entails building our product one atom at a time. This can be time-consuming, so a so-called *self-assembly* process is employed — under specific conditions, the atoms and molecules spontaneously arrange themselves into the final product. (Self-assembly is described further in Chapter 8.)

Some science-fiction plots — they know who they are — revolve around this self-assembly concept, conjuring up plot lines infested with tiny self-replicating machines running amok. (For a closer look at this far-fetched notion, see the "Welcome to Nano Park" sidebar in this chapter.) For the near-term, it looks like the top-down approach will be favored because it tends to provide us with greater control (and, more importantly, it uses some time-tested techniques of the computer industry). If we were betting men — which we are not, because as men of science we know that the House always wins — we would venture that the top-down approach will be the fabrication method of choice for quite awhile.

Evolving into Nanotech

If you take a look at the world around us, you'll notice that nature herself designs at the molecular level. Nanotechnology intends to imitate nature by taking advantage of the unique properties of nano-scale matter to come up with more efficient ways of controlling and manipulating molecules. With technology, smaller is better. If you take a look at technical evolution, you'll notice that we're continually getting smaller — computers the size of a room in the 1950s now fit on your lap; cellphones the size of a brick in the 1980s now fit in your shirt pocket. Consumer convenience, the economics of resources and competition, and the advantages of faster processing, higher productivity, and better quality all play a part in motivating companies to go small.

Technology is not only getting smaller, it's also evolving faster. As new technologies develop, we build upon previous knowledge. Thanks to the Internet, this knowledge base — and rate of information exchange — is increasing rapidly. To illustrate this evolution of technology, check out the evolution of electrical components: from the vacuum tube to the solid-state transistor to the carbon nanotube field effect transistor.

- **Vacuum Tube (1897):** This was the ancestor of the transistor, essentially a light bulb with three, instead of two, terminals. It was large, hot, and prone to burning out.
- **Solid-State Transistor (1947):** Instead of using a filament, the solid-state transistor switches between On and Off using different materials — metals and semiconductors. This let us come up with transistors that were smaller in size, didn't give off as much heat, and were far more durable.
- **Carbon Nanotube Transistor (1998):** A carbon nanotube (refer to Figure 1-1) — a graphite sheet rolled into a tube — comes in two main forms, metallic and semiconducting. The carbon nanotube was discovered in 1991 and within only seven years, was used for shuttling electrons across two electrodes. Not only is it incredibly small (nano-scale), but it also uses less energy and gives off less heat by using few electrons to indicate whether it's on or off. (For more on carbon nanotubes, see Chapter 4.)

It took 50 years to get from the vacuum tube to the first solid-state transistor — and another 50 years of refinement to get solid-state transistors to be all they could be. But when we'd developed the needed tools and understanding, it only took seven years from the discovery of the carbon nanotube to turn it into what may be the ultimate transistor.

The history

The word "nanotechnology" proper was coined by Nario Taniguchi in 1974 to describe machining with tolerances of less than a micron. But this really isn't the term's true beginning. Three noteworthy events and discoveries got this ball rolling — all by Nobel laureates (and when a Nobel Prize winner says something, you listen . . . and try to understand).

- **The Vision:** In 1959, Caltech physicist Richard Feynman gives his famed talk "There's Plenty of Room at the Bottom," outlining the prospects for atomic engineering. (To read the talk in its entirety, check out `www.its.caltech.edu/~feynman/plenty.html` for a handy transcript.)

- **Seeing is Believing:** In 1981, Gerd Binnig and Heinrich Rohrer of IBM's Zurich Research Laboratory create the scanning tunneling microscope, enabling researchers to both see and manipulate atoms for the first time. (For more on the scanning tunneling microscope, see Chapter 3.)
- **Nanostructures:** In 1985, Robert F. Curl Jr., Harold W. Kroto, and Richard E. Smalley discover buckminsterfullerenes (buckyballs — refer to Figure 1-1), soccer-ball-shaped molecules made of carbon and measuring roughly 0.7nm wide. (For more on buckyballs, see Chapter 4.)

Why you want nanotechnology in your life

Nanotechnology will increase your standard of living — no ifs, ands, or buts. Done right, it will make our lives more secure, improve healthcare delivery, and optimize our use of limited resources. Pretty basic stuff, in other words. Mankind has spent millennia trying to fill these needs, because it has always known that these are the things it needs to ensure a future for itself. If nanotechnological applications pan out the way we think they will pan out, we are one step closer to ensuring that future.

Security

Security is a broad field, covering everything from the security of our borders to the security of our infrastructure to the security of our computer networks. Here's our take on how nanotechnology will revolutionize the whole security field:

- **Superior, lightweight materials:** Imagine materials ten times stronger than steel at a fraction of the weight. With such materials, nanotechnology could revolutionize tanks, airframes, spacecraft, skyscrapers, bridges, and body armor, providing unprecedented protection. Composite nanomaterials may one day lead to shape-shifting wings instead of the mechanical flaps on current designs. Kevlar, the backbone fiber of bulletproof vests, will be replaced with materials that not only provide better protection but store energy and monitor the health status of our soldiers. A taste of what's to come: MIT was awarded a $50 million Army contract in 2002 to launch the Institute for Soldier Nanotechnologies (ISN) developing artificial muscles, biowarfare sensors, and communications systems.
- **Advanced computing:** More powerful and smaller computers will encrypt our data and provide round-the-clock security. Quantum cryptography — cryptography that utilizes the unique properties of quantum mechanics — will provide unbreakable security for businesses, government, and military. These same quantum mechanics will be used to construct quantum computers capable of breaking current encryption

techniques (a needed advantage in the war against terror). Additionally, quantum computers provide better simulations to predict natural disasters and pattern recognition to make *biometrics* — identification based on personal features such as face recognition — possible.

- **Increased situational awareness:** Chemical sensors based on nanotechnology will be incredibly sensitive — capable, in fact, of pinpointing a single molecule out of billions. These sensors will be cheap and disposable, forewarning us of airport-security breaches or anthrax-laced letters. These sensors will eventually take to the air on military unmanned aerial vehicles (UAVs), not only sensing chemicals but also providing incredible photo resolutions. These photos, condensed and on an energy-efficient, high resolution, wristwatch-sized display, will find their way to the soldier, providing incredible real-time situational awareness at the place needed most: the front lines.
- **Powerful munitions:** Nanometals, nano-sized particles of metal such as nanoaluminum, are more chemically reactive because of their small size and greater surface area. Varying the size of these nanometals in munitions allows us to control the explosion, minimizing collateral damage. Incorporating nanometals into bombs and propellants increases the speed of released energy with fewer raw materials consumed — more (and better-directed) "bang" for your buck.

Healthcare

Making the world around us more secure is one thing, but how about making the world *inside* us more secure? With nanotechnology, what's beneath our skin is going to be more accessible to us than it's ever been before. Here's what we see happening:

- **Diagnostics:** Hospitals will benefit greatly from nanotechnology with faster, cheaper diagnostic equipment. The lab-on-a-chip is waiting in the wings to analyze a patient's ailments in an instant, providing point-of-care testing and drug application, thus taking out a lot of the diagnostic guesswork that has plagued healthcare up to now. New contrast agents will float through the bloodstream, lighting up problems such as tumors with incredible accuracy. Not only will nanotechnology make diagnostic tests better, but it will also make them more portable, providing time-sensitive diagnostics out in the field on ambulances. Newborn children will have their DNA quickly mapped, pointing out future potential problems, allowing us to curtail disease before it takes hold.
- **Novel drugs:** Nanotechnology will aid in the delivery of just the right amount of medicine to the exact spots of the body that need it most. Nanoshells, approximately 100nm in diameter, will float through the body, attaching only to cancer cells. When excited by a laser beam, the nanoshells will give off heat — in effect, cooking the tumor and destroying it. Nanotechnology will create biocompatible joint replacements and artery stents that will last the life of the patient instead of having to be replaced every few years.

Resources

The only thing not in short supply these days is more human beings — and we're not about to see a shortage of them any time soon. If we are going to survive at all — much less thrive — we are going to need to find ways to use the riches of this world more efficiently. Here's how nanotechnology could help:

- **Energy:** Nanotechnology is set to provide new methods to effectively utilize our current energy resources while also presenting new alternatives. Cars will have lighter and stronger engine blocks and frames and will use new additives making fuel more efficient. House lighting will use quantum dots — nanocrystals 5nm across — in order to transform electricity into light instead of wasting away into heat. Solar cells will finally become cost effective and hydrogen fuel cells will get a boost from nanomaterials and nanocomposites. Our Holy Grail will be a reusable catalyst that quickly breaks down water in the presence of sunlight, making that long-wished-for hydrogen economy realistic. That catalyst, whatever it is, will be constructed with nanotechnology.
- **Water:** Nanotechnology will provide efficient water purification techniques, allowing third-world countries access to clean water. When we satisfy our energy requirements, desalinization of water from our oceans will not only provide enough water to drink but also enough to water our crops.

You say you want a revolution?

We predict that a few revolutions will roll over us in the course of the next 50 years — revolutions that will have great impact on our lifestyles and economy, and will involve nanotechnology, energy, and robotics. We've broken down each revolution here, complete with an estimated peak year for each one's public and financial popularity. Note, however, that nobody's jumped in a time machine to check up ahead; these peak years are based on the "gut feelings" of the authors, and on our research and observations of current trends. But we aren't just spinning tales. In February 2005, Business Week Online polled its readers, asking when they thought nanotechnology would change their lives: 34 percent said by 2007; an additional 51 percent said by 2015. At this point, it's not a matter of "if" but a matter of "when" — it's nearly as certain as death and taxes.

- **Nanotechnology itself:** We're thinking **2012** is about the time that significant revolutionary products will be available, along with solid companies within the industry. A "nanotechnology bubble" will begin to develop around 2010, but this may not be as drastic as the "Internet bubble." (See the "Getting a (Small) Piece of Nanotechnology for Yourself" section, later in this chapter.) Low-power, high-density computer memory, longer-lasting batteries, and some medical applications (including cancer therapy and diagnostics) will be some of the early products (pre-2010).

Advances in computer processing will follow (2015), and new materials and composites will come online toward 2020. The order of events will likely be computers and medical first, and then materials — all overlapping but peaking at their respective years.

Energy: Our crystal ball says **2025** is going to be the Nanotechnology Energy Year. With demand for energy rising in industrializing countries such as China and India, oil will continue to be that highly-sought-after resource. Oil prices and prosperity have an inverse relationship — as oil prices go up, prosperity goes down. Goldman Sachs has recently (April 2005) suggested that we may enter into a "super-spike" period of oil demand, with prices as high as $105 a barrel — almost twice the current price. It has also been suggested (by Princeton University geologist Kenneth Deffeyes) that world oil production will peak around Thanksgiving 2005. Unfortunately, production capacity has grown more slowly than demand, which makes things even worse.

Nanotechnology will combine efficient use of our current sources while providing directions to explore for alternate sources of energy. Nanomaterials that emerge around 2020 will not only provide lighter/stronger materials for vehicles but will also improve efficiency in the collection, storage, and transmission of energy, greatly aiding our transition from gas to solar, hydrogen, or maybe even renewable bio-fuels (for example, vegetable oils and bioalcohols such as ethanol and methanol).

Robotics: Think **2045.** This may seem a little farfetched, because you expect something with the personality of C3-PO and the powers of a Jedi, but today you're getting R2-D2 — just bells and whistles. However, there are a few driving forces making robotics economically feasible: defense, space exploration, and labor. In the near term, autonomous UAVs (short for *U*nmanned *A*erial *V*ehicles) will keep continuous watch over our borders, and robots will dispose of roadside bombs in the battlefield. Space exploration will be done by robots, cutting the need for human involvement and thus allowing us to go farther than we've ever gone before.

As nanotechnology develops better sensors and processors and the energy revolution provides abundantly cheap energy, robots will be in demand as cheap manual labor, increasing our overall standard of living. Not only will we have robotic dogs and vacuum cleaners but also assembly-line industrial labor, bringing money back to Western nations. Perhaps a "robotic arms race" will emerge, not as a mighty military machine but as a productivity machine — each nation trying to make the cheapest goods as quickly as possible. All this will gradually grow over the next few decades — but once the hardware is in place (around 2030), the software and artificial intelligence will soon follow.

Some of these years may seem a long way off, but these changes will arrive faster than you may think. If you're currently in college, they'll happen in your lifetime.

Knowing what to expect (and not expect)

Futuristic excitement aside, our expectations for nanotechnology need to be realistic and we need to be patient, for not all the advances that nanotechnology is set to bring will happen overnight. Nanotechnology will not be a miracle cure. Although there will be some fantastic advances, not everything that we imagine will come to fruition. However, nanotechnology is also sure to usher in things that we never envisioned coming — products that could end up changing the world.

Nano-scale science isn't a free-for-all — there are rules. We won't be able to manufacture something that, at the molecular level, is chemically unstable. Scientists know how most things work chemically and physically, but there have been a few surprises — and we learn the rules along the way. Time to take a look at some examples of the nanotechnology we now have, what we can improve upon, what will be new, and what (we can confidently say) will never happen.

What we have

Nano applications are already showing up in areas as diverse as computing, transportation safety, and medicine. The steps may seem modest by future standards, but they get big effects from tiny things. Three examples illustrate what we can do now:

- Computer transistors have broken below the 100nm barrier — transistors are officially nano-sized. Look for the devices that house them to shrink as well, and for devices that are already small (such as cellphones) to become more powerful.
- Airbag sensors, although micro in size and bigger than nano, are used in most recent cars — some of them already saving lives. These sensors will continue to shrink, becoming more powerful and accurate.
- At least one home pregnancy test (Carter-Wallace's "First Response") uses both gold nanoparticles and micrometer-size latex particles on an external, disposable test sheet. The product takes advantage of how gold nanoparticles of different sizes reflect light differently. If a woman is pregnant, a specific hormone is present that causes the micro-sized and nano-sized particles to clump together — and those bigger particles reflect a distinctive color: a visible pink strip appears on the test sheet. If she's not pregnant, no hormone is present, which means no clumping of the nanoparticles and no pink strip.

What will be improved

Besides introducing new products and procedures, nanotech will advance those that already exist. In January 2005, the Lemelson-MIT Program identified the top 25 innovations of the past 25 years. Nanotechnology was number 21 . . .

which is good. What's even better is that the other 24 would all be positively influenced by nanotechnology. Try these examples on for size:

- Cellphones with longer battery life
- Global Positioning Systems that are smaller and more accurate
- Computers that are faster and smaller
- Memory storage that packs greater capacity into a smaller space and uses less energy
- DNA fingerprinting that is quick and accurate

Other items not on the list will be oil additives designed to get more out of our precious resource, new medical diagnostics and drug delivery . . . even an aesthetically pleasing sunscreen. (Most sunscreens are a white, thick and sticky cream. Nanophase Technologies has developed a sunscreen that is transparent — the active ingredient is a nano-scale material that, because of its small size, doesn't scatter visible light.) Nanotech will crop up everywhere in existing products, even — or especially — in places you can't see.

What will be new

Nanotechnology promises to be a cornucopia of wonders — improving our healthcare, optimizing our use of resources, increasing our standard of living. Detecting disease at the molecular level will lead to new treatments for old ills. The development of materials ten times stronger than steel — but a tenth of the weight — offers to make transportation faster and more efficient. (Imagine, for example, how air transportation would change if airframes were lighter and stronger, plane engines used less fuel, and sensors and smart material automatically deformed the wings to minimize drag.) New, nanotech-based paints and coatings will prevent dirt and water from adhering to surfaces such as kitchen counters, vinyl siding, cars, and windows. (Imagine a car you never have to wash, that rolls dirt and water right off so you don't even have to use your windshield wipers.)

Speaking of cleanliness, EnviroSystems' EcoTru disinfectant cleaner is the only EPA-registered Tox Category IV disinfectant product — it doesn't harm the skin, eyes, lungs, or body if ingested. Conventional disinfectants dissolve in a solvent, and are meant to drown the organisms with toxic chemicals — which can be about as bad for humans as for small organisms. EcoTru uses nanospheres of charged oil droplets suspended in water to carry the active ingredient that ends up penetrating the microorganisms' membranes. This stuff is so good that Doctors Without Borders used EcoTru in the operating room as an antiseptic when they ran out of their regular antiseptic. Of the 500 patients that they used EcoTru on, none got an infection. EcoTru is also already used as a disinfectant on airplanes, on cruise ships, and in healthcare facilities, and, given Doctors Without Borders's experience, may be used as an antiseptic in the future.

What will not happen

Science fiction writers describe swarms of molecule-size robots swimming through your bloodstream cleaning your arteries while shooting cancer cells. And the nanobots that aren't fixing your body are out there fixing and building the world around us, one atom at a time. These scenarios are highly improbable, if not impossible. If they do eventually prove possible, they're decades (if not centuries) away.

As marvelous as it is to envision nanobots curing our bodies and quickly assembling and disassembling inanimate objects, these methods may not even be the most efficient approach. After all, some of the best medicine involves coaxing the body to help fix itself — and building inanimate objects one atom at a time (even something as simple as a chair) is no quick task. There may be a better, more inventive way to use engineering principles at the nano scale — one that takes advantage of the opportunities that chemistry and intermolecular interactions offer. But those opportunities are far more modest and (well, yeah) small-scale than science fiction would suggest.

The dramatic creation and transformation of macro-scale objects makes for spectacular entertainment but dicey science. Here's why: Molecular chemistry is very complex and involves controlling atoms in three dimensions. At each reaction site, the atoms feel the influence of neighboring atoms. To do any mechanics at this level (which is what nanobots would have to do for this to work), you would need to control the motion of each and every atom — a very difficult juggling act.

A lot of this nano-zealous science fiction got started in 1986, when K. Eric Drexler, founder of the Foresight Institute (a nonprofit organization dedicated to educating the public about nanotechnology), penned *Engines of Creation: The Coming Era of Nanotechnology*. In it, he describes self-replicating nanoassemblers building objects one atom at a time. He also describes a doomsday scenario referred to as "gray goo" — myriads of self-replicating nanoassemblers making uncountable copies of themselves and consuming the earth. "Gray" because they're machines; "goo" because they're so small they'd look like a thick liquid. Scientists have since ridiculed this Drexlerian vision — even Drexler himself (in 2004) said "runaway replication" was unlikely.

In the December 1, 2003, edition of *Chemical & Engineering News,* Eric Drexler and Richard Smalley, Nobel Prize winner and discoverer of the buckyball, squared off, arguing for and against molecular manufacturing. The "Point-Counterpoint" article was a series of letters between the two, where Drexler continues to outline his "mechanical" molecular manufacturing, whereas Smalley argues against such a model by describing a need for "chemistry" even at the nano level. One source of contention is the "gray goo" scenario. Drexler had presented this scenario as a warning to not let nanotech get out of hand whereas Smalley sees it as unnecessarily scaring the public on a doomsday scenario that's a) highly unlikely and b) threatens public support for nanotech by harping the negative. In the end, they both disagreed on molecular manufacturing but continue to promote nanotechnology's potential.

Welcome to Nano Park

In 2003, Michael Crichton, the author of *Jurassic Park*, published his next sci-fi doomsday book, *Prey*. Crichton takes us to the top-secret research labs of Xymos Technology, where the self-replicating microscopic machines prey on the scientists. In the end, the humans prevail (sorry to ruin the ending, but hey, *somebody* had to be left alive to buy the book). This book, and others like it in the grand tradition of high-tech disaster fiction, pilfers the most visually stunning aspects of an emerging technology and then presents the worst-case scenario of what could go wrong. Without a conflict (nanobots running amok) there's no resolution (humans winning) and no story. Unfortunately, in an effort to make his story plausible, Crichton mixes a little too much science fiction with reality — even the company name Xymos suggests the name of a real nanotech company (Zyvex). Here are some of the many flaws:

- Crichton confuses two basic tools of nanotechnology, the scanning-probe microscope and an electron microscope (see Chapter 3 for an explanation of both).
- The description of a nanobot is a bit off — "one ten-billionth of an inch in length." This is the size of a single atom — certainly not of a whole robot.
- The nanobots are too big to fit inside a synapse and control human beings. Synapses, junctions interconnecting the neurons of the central nervous system, are only a few atoms wide and these nanobots are at least a hundred times bigger. This claim ties in with the previous one — nanobots "one ten-billionth of an inch in length." Although Crichton is consistent in his size reference, nanobots composed of only a few atoms wouldn't have the computational power to do anything that the book claims they can do.

These books may offer some benefit by generating interest in the subject and drawing people into science. Unfortunately, they may also instill some unnecessary fear and anxiety in our society as new technologies emerge.

Getting a (Small) Piece of Nanotechnology for Yourself

Nanotechnology is set to insinuate its way into our economy in ways that we can only imagine — more probably, in ways that we could never dream. Nanotechnology as an industry will be hard to identify and track, considering it's very pervasive — it touches upon a lot of different industries. Familiar products will be the first to take advantage of nanotech — clothing, cosmetics, and novel industrial coatings. When the processes to make these products are mastered, new and innovative products will begin to emerge. Businesses will rise, and those that don't adapt to this changing environment will fall by the wayside. Now that you're salivating at the prospects of making a quick buck, eager to enter the Lilliputian world of atoms and molecules, this section of the chapter will temper your appetite and present what we believe to be a *realistic* picture of the current industry — and how it will probably play out.

The nanotech industry

The National Science Foundation projects that nanotech will be a $1 trillion industry by 2015 — that's 10 percent of the current GDP of the United States. Small wonder (so to speak) that the National Nanotechnology Initiative has increased federal funding for nanotechnology research and development from $464 million in 2001 to $982 million in 2005 (as shown in Figure 1-2). Governments across the world poured $4 billion into nanotech research in 2004.

However, according to Lux Research Inc., only $13 billion worth of manufactured goods will incorporate nanotechnologies this year. In the grand scheme, that's not very much. Nanotechnology, because of its complexity and reach over different industries, will grow slowly over many decades. Therefore, we must be patient and not expect a huge explosion of products coming online all at once.

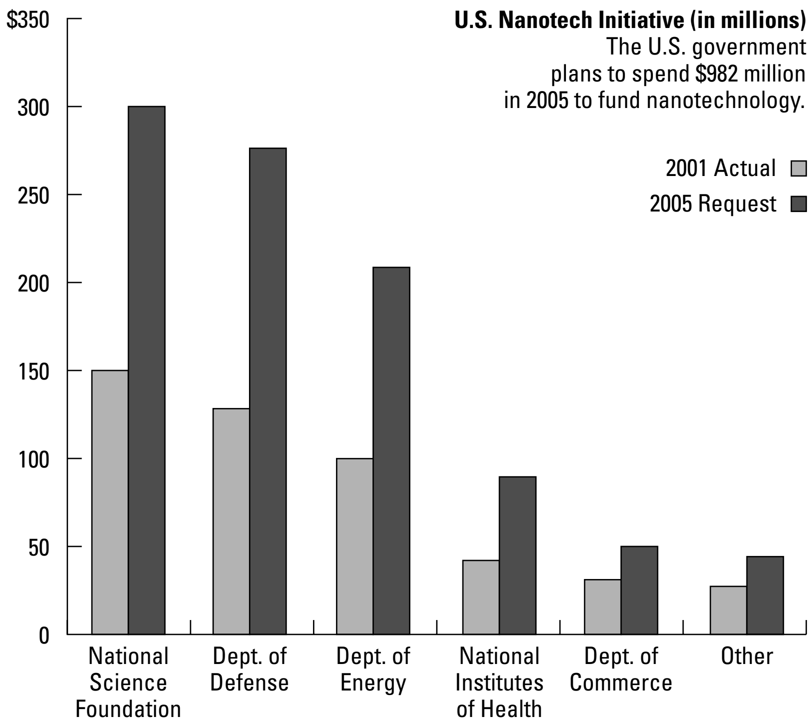

Figure 1-2: 2005 breakdown of nanotech expenditure among different government departments.

Today, nanotech companies are either developing their knowledge base through research or are producing the materials for other people's nanotech research. There are three entities from which nanotechnology will emerge: open research (universities and national labs), large corporations, and start-ups. These entities, in turn, have three options: They can produce their discoveries, license them, or sell the rights to them outright. Licensing may be an attractive option — it creates cash flow with minimal overhead.

Big companies will have some advantage here, given their resources and ability to purchase high-end measurement equipment. Some large industries, such as pharmaceuticals and microchips, will be able to successfully integrate nanotechnology because they already have the processes and facilities in place to get their product to market — something small companies may not have access to.

However, this shouldn't discourage small companies who have the flexibility to adapt. Small companies are set to develop products, processes, and intellectual property, becoming attractive takeover candidates by big companies. In the end, everyone wins — investors make money, small companies develop products rapidly and efficiently, and big companies produce and distribute the end product to the consumer.

Both large and small companies, given nanotech's reach, will have to develop partnerships and collaborations — not only between different industries but also between different companies, universities, and government labs. Not only will they exchange research but also resources. For example, Rice University has a partnership with the Texas Medical Center, the largest medical center in the world. Additionally, Rice (as well as other universities across the nation) has broken down some financial barriers by developing the Shared Equipment Authority (SEA), which will train and allow businesses to use million-dollar measurement equipment for reasonable prices. If you want (for example) to learn how to use a scanning electron microscope, it will cost you $200 to get trained and $20/hour for each subsequent use. That's incredibly cheap, considering that the equipment costs $500,000 to begin with, and more than $40,000/year just to keep it maintained.

Battle of the bubbles: Nanotech versus Internet

Every industry has an *economic bubble* — speculation in a commodity that causes the price to increase, which produces more speculation, which causes the price to increase . . . until, at some point, the price reaches an absurd level and the bubble bursts, causing a sudden — and precipitous — drop. Bubbles aren't good — they encourage people to misallocate resources in ways that don't pan out, with nonproductive results. Additionally, the crash that follows can cause great economic problems. Of course, if you don't get carried away, an economic bubble isn't all bad — it allows money to flow into a new industry to give it financial support to grow from. But too much blind enthusiasm too soon can backfire as market forces weed out ventures that don't produce actual profits in a reasonable time.

Many industries have had bubbles — the railroad industry, the automobile industry, even the tulip industry had an economic bubble. The most recent example was the Internet bubble in the late 1990s. Alan Greenspan, chairman of the Federal Reserve Board, identified this emerging bubble in 1996, calling investor speculation "irrational exuberance," which should have been enough to warn off most folks — but fools and their money are soon parted.

So, is it foolish to invest now in nanotechnology? Not necessarily. We have no doubt that there will be a "nanotechnology bubble" (within the next five years?), but we hope it will prove to be more "exuberant" and less "irrational." One thing to keep in mind is that, with the dot-com bubble, companies were started for $5,000 by lawyers and marketing agents who were pushing an idea — and not necessarily a product. Nobody was quite sure what to do with the idea yet. The essentials of the scientific knowledge base could be pretty well absorbed by your average information-technology technician after only a few months of training. Nanotechnology and nanoscience research, on the other hand, are a much more complex kettle of fish. They require in-depth scientific knowledge and a Ph.D.-level background. This knowledge base will be indispensable to any nanotech start-up company, ensuring that the field will not be inundated by every Tom, Dick, and Harry.

This requirement of high-level technical know-how is slowing nanotechnology's growth. There is a shortage of talent — a limited supply of scientists coming up against increasing demand. Additionally, product-cycle times — the time from research to market — is long. On the flipside, nanotech has fewer barriers to market adoption than the Internet had. In order for online stores to be successful, customers had to own a computer, establish an Internet connection, and gain confidence in online transactions. Nanotechnology will already be integrated into existing products — no massive new-product-adoption process will be required.

Nanotechnology's biggest advantage over the Internet as The Next Big (Little?) Thing will be its patentable intellectual property. Web-based innovations were difficult to patent, allowing competitors to quickly adapt and clone a product within months. Nanotechnology's intellectual property creates a major barrier to entry by being incredibly difficult to replicate. The time cost to replicate is measured in years, encouraging the competitor to either take a different approach or license the patent. This barrier to entry is fantastic for small companies; they have more time to develop without getting immediately crushed by the big dogs.

What's in a name?

Nanosoft . . . Nanosonic . . . Nano Inside. These are just a few words and phrases that folks have tried to trademark with the United States Patent and Trademark Office. Whether they'll be successful, we don't know yet. "Nano" has recently become the generic word for "high tech" — its cachet is similar to what "virtual" and "holo" had in the past few decades.

A few companies that already have "nano" in their names do loosely develop some "nano" products. U.S. Global Aerospace, for example, which uses nanofiber technology in its cockpit doors, recently changed its name to U.S. Global *Nano*space — that's a drop of 14 orders of magnitude! Nanogen makes *micro* arrays for genetic research. Its NanoChip array has test sites 80 microns in size, spaced 200 microns apart — not quite nano but headed in the right direction.

These quasi-legit nano-namings may have a hidden bonus — they tend to make investors leery, prompting them to scrutinize the claims and dig deeper into a company's nano-legitimacy. After all, we shouldn't be able to "just add nano" to sell a stock or company. But don't be surprised if some folks try that anyway.

Caveat Emptor — Buyer Beware

If recent history is any indication, our coming nanotech bubble may be overhyped and fueled with stock speculation. In this section, we hope to quell some of this speculation early on and paint a realistic picture for you. Currently, very few nanotech companies are public (that is, offering stock for public purchase) — and the ones that are have a stock chart that reads more like a cardiogram than a steady line of growth. That hasn't deterred some early players; on the Dow Jones Industrial Index, 19 of the 30 companies have launched nano initiatives. This section takes a look at two particular companies and throws in some indexes you can follow as well.

Nanosys

In April 2004, Nanosys filed for a $115 million initial public offering (IPO) with the Securities and Exchange Commission (SEC). They are a company rich in patents — over 200 — but alas, no profits yet (sigh). This is not to say they won't ever make money — they are one of the companies that our research shows has some great potential — and it's a pretty sure bet they'll license their research.

For now, they're cautious. In the Nanosys SEC filing, the company stated: "To date, we have not successfully developed any commercially available products. . . . We do not anticipate that our first products will be commercially available for at least several years, if at all." (*If at all?* Not the rosiest picture.) Nanosys even withdrew its filing in August 2004, stating "volatility of capital markets." But Nanosys has clout as one of the poster-child nanotech companies — and we give them credit for not starting a wild nanotech bubble before the industry has had time to mature.

Altair Nanotechnologies, Inc.

On February 10, 2005, Altair Nanotechnologies, Inc. [NASDAQ: ALTI], announced a breakthrough in their lithium-ion battery-electrode material. This novel nanomaterial — composed of nano-size lithium-titanium-oxide particles — does the following for their rechargeable batteries:

- **Delivers more power:** You get three times the power of existing lithium-ion batteries, to be exact.
- **Allows faster recharge:** Recharge takes a few minutes instead of hours.
- **Ensures longer life:** The material improves the number of recharge and discharge cycles from a few hundred to many thousand cycles.

On this news, the stock spiked. Here's what the results looked like:

- **Day before:** Closed at 2.08 with volume of 500k.
- **Day of:** Closed at 4.77 (129.3% increase) with volume of 56.6 million.
- **Day after:** Peaked at 6.52 (another 36.6% increase) with volume of 101.6 million.

Not bad for two days' worth of work. As of mid-April, 2005, ALTI had a 50-day moving average of 3.8 with an average volume close to 10 million. On April 19, 2005, they announced the initial shipment of their electrode nanomaterial for testing at a partner company, Advanced Battery Technologies, Inc. This nanomaterial will be incorporated into Advanced Battery's Polymer-Lithium-Ion (PLI) batteries tested in electric vehicles.

Investment tools and strategies

Whether or not Altair Nanotechnologies or Nanosys are going to be the next eBay is certainly up in the air. Given the volatility of owning individual stocks in nanotechnology, it's wise to go with something a little more diverse, such as an exchange-traded fund (ETF) or mutual fund. Unfortunately, there are no nanotech ETFs or mutual funds at this time. Harris & Harris [NASDAQ: TINY] is as close as you're going to get for now; it's a publicly traded venture-capital firm specializing in nanotech companies.

Merrill Lynch established a "Nanotech Index" [Amex: NNZ] in 2004 — on April Fools Day, of all days (those guys are such kidders). The index consists of 22 small companies whose future business strategy is based on nanotechnology. Lux Research, Inc., is a research and advisory firm focusing on the economic impact of nanotech businesses. Their index, Lux Nanotech Index [Amex: LUXNI], follows 26 publicly traded nanotech companies. Merrill Lynch's Nanotech Index is open for trading, but Lux Nanotech Index is not.

The world according to nano

Nanotechnology, given its scientific complexity, is going to require a large amount of upfront capital — and substantial government assistance. In 2003, 52 percent of the $5.5 billion invested in nanotechnology came from national governments. The following table shows the Venture Analytics breakdown of nanotechnology investment.

Nano Investment

Country	2003 Nanotech Funding in Millions of Dollars	Percent from National Government
Japan	1,610	50
U.S.	1,524	51
China	480	58
South Korea	280	71
Germany	218	54
Australia	193	48
U.K.	160	56
World Total	5,544	52

This chart can be misleading — a wide gap in financing does not necessarily result in a wide gap in manpower. Although the United States and Japan outspent China, engineers and scientists in China make between one-sixth and one-tenth of what Americans earn. The United States spends five times as much as China but has less than half as many researchers (1.3 million Chinese versus 734,000 American). Additionally, China's universities and vocational schools produced 325,000 engineers this year — five times as many as the United States.

As you conquer your greed and quell your fears (both wise moves), here are a few generic tips to keep in mind. For further financial understanding, there's a copy of *Investing For Dummies* (authored by the inestimable Eric Tyson and published by Wiley) with your name on it.

- **Follow the money:** There will undoubtedly be huge investments into nanotech. Be mindful of large volume shifts, indicating large institution investment.
- **Follow the trend:** 75 percent of all stocks follow the Dow Jones Industrial Average — this will include nanotech stocks. If stocks are going up, buy; if going down, sell. Buy low, sell high.

- **Don't listen to tipsters:** Tipsters will, more than likely, be wrong about a lot of nanotech. We still need those scientists to help business analysts make sense of what's plausible and realistic. Do your own research; don't let a news sound bite influence your decision and control your money.
- **Set a stop loss:** Set a sell-point with your brokerage firm; make it roughly 7 percent below your purchase price — and as the price goes up, increase this stop-loss point. Doing so prevents what happened to many when they rode the 1990s Internet crash into the ground.