COVER STORY

The Business Of Nanotech

There's still plenty of hype, but nanotechnology is finally moving from the lab to the marketplace. Get ready for cars, chips, and golf balls made with new materials engineered down to the level of individual atoms

Pity the poor alchemists. They spent the Middle Ages in candle-lit laboratories, laboring to brew universal elixirs and to turn base metals into gold or silver. They failed utterly. By the dawn of the Scientific Revolution, researchers equipped with microscopes founded modern chemistry -- and dismissed alchemy as hocus-pocus.

But it turns out alchemists were just a few centuries ahead of schedule. Today, in sparkling labs equipped with powerful microscopes, scientists on three continents are promising dramatic new materials and medicines that would make alchemists proud. This work takes place in the realm of nanotechnology, industry's tiniest stage. The standard unit of measurement, a nanometer, is a billionth of a meter -- barely the size of 10 hydrogen atoms in a row. In this universe entire dramas can unfold on the tip of a pin, and a sneeze packs the

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Why so small? Researchers have discovered that matter at this tiny scale often behaves very differently. While some of the science behind this phenomenon is still shrouded in mystery, the commercial potential of the infinitesimal is coming sharply into focus. Familiar materials -- from gold to carbon soot -- display startling and useful new properties. Some transmit light or electricity. Others become harder than diamonds or turn into potent chemical catalysts. What's more, researchers find that a tiny dose of nanoparticles can transform the chemistry and nature of far bigger things, creating everything from fortified fenders to superefficient fuel cells. Engineers working at the nano scale have a brand-new tool kit that's full of wonder and brimming with potential riches.

Now it's time to start cashing in. Throughout 2005, companies large and small will be rushing more nano-based products from labs to the marketplace. Consumers will encounter nanotechnology in the form of nick-proof trims on Hummers, Wilson tennis racquets with extra pop, even golf balls designed to fly straight. Investors, meanwhile, will be faced with a slew of bold announcements. On Feb. 1, for example, computer giant Hewlett-Packard Co. (**HPQ**) disclosed a breakthrough in nanotechnology that, within a decade, could carry computing beyond today's silicon and transistors. "We are reinventing the computer at the molecular scale," says Stan Williams, an HP senior fellow and co-author of the report.

For now, nano is starting out modestly. The biggest markets for nanoparticles remain in familiar products, from the black rubber filler in tires, a $4 billion industry, to the silver used in traditional photography. Lux Research Inc., a New York nanotech market researcher, estimates that only $13 billion worth of manufactured goods will incorporate nanotechnologies this year. That's little more than a rounding error in the global economy.

Feverish Activity

Yet new nano-based products that could have a far bigger impact are only a step or two away. Within the next two years, diagnostic machines with components built at the nano scale should allow doctors and nurses to carry pint-size laboratories in their briefcases, perhaps to test for HIV or count white blood cells on the spot. Nano sensors will scour airports and post offices for anthrax and sarin. Toward the end of the decade, scientists say, new computer memories composed of nanoparticles could conceivably pack the digital contents of the Library of Congress into a machine the size of a yo-yo. By that point, Lux predicts, nanotechnologies will have worked their way into a universe of products worth $292 billion (see table, "**Nothing "Nano" about It**").

How does nanotechnology conjure up such surprises? Nature provides examples of this molecular magic. Think of coal compressing, over millennia, into diamonds. The gems are made of the same carbon atoms. But they've been rejiggered over time into orderly crystal patterns linked by superstrong chemical bonds. Soft becomes hard, sooty blackness becomes glittering clarity.

These days scientists can pull off such transformations between coffee breaks. With atomic probes they manipulate molecules, one-upping Mother Nature. Delving into the nano realm gives them startling surprises right in the old periodic table of elements -- and they're filing a flurry of patents to lay claim to these miraculous materials. "It's a land grab," says Douglas Sharrott, a patent lawyer at Fitzpatrick, Cella, Harper & Scinto in New York.

The questions around nano are no longer whether it's coming or if it's real but just how big it will be. Some see nano simply as a new material revolution, akin to the dawn of plastics. Others herald a transition as dramatic as mankind's advance from stone to metal tools. But those hazy predictions aside, the questions that are echoing from laboratories in Tokyo to the hectic offices of short-sellers on Wall Street are about money. Which nanotechnologies will

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Activity on the ground is feverish. Some 1,200 nano startups have emerged around the world, half of them in the U.S. Companies that long labored in dull-as-dishwater materials businesses are finding that they can create a stir by trumpeting their mastery over age-old particles, from specks of ceramic to soot. Brokerages such as Merrill Lynch & Co. (**MER**) and Punk, Ziegle & Co. are scouring the markets for nano-focused companies and plunking them into nano indexes. Meanwhile, investors, torn between an alluring new market and the fear of a dot-com-like bubble, are struggling to get a grip on exactly what nano means for them.

Their confusion is understandable. Nano is not a single industry but a scale of engineering involving matter between 1 and 100 nanometers. Instead of one new phenomenon, like the Internet, nano offers new possibilities for thousands of materials that already exist. This means much of the early activity will likely take place at industrial giants. Already, 19 of the 30 companies in the Dow Jones industrial index have launched nano initiatives. Says Margaret Blohm, manager of General Electric's (**GE**) nanotechnology research and development program: "I lose sleep at night because expectations are so high."

How do these tiny molecules create big new products? Sometimes size alone is the key. Consider DuPont's (**DD**) new Voltron, a super-durable wire coating used in heavy-duty electric motors. If you looked at previous generations of such coatings through a powerful microscope, the chemical components would look loosely packed, with irregular spaces between the molecules. This structure leads the material to break down more easily. Voltron's nanoscale particles fill in many of the voids, making a stronger insulator that lasts longer. In DuPont's tests on electric motors, a coating of Voltron extended the time between failures by a factor of 10, to more than 1,000 hours. And since such motors consume an estimated 65% of U.S. electric power, lengthening their life and efficiency promises big energy savings. "This chemical combination can only be done with nanomaterials," says Krish Doraiswany, a senior planning manager for DuPont's nanotech research effort.

Most of the early advances in nano will improve what we already have. Examples: lightweight army fatigues that resist chemical weapons and food packaging designed to keep last month's lettuce green and crunchy. Later this year, duffers will be able to buy golf balls manufactured by NanoDynamics Inc. in Buffalo, N.Y., that are designed to prevent a shift in weight as they spin. This should create balls that fly straight down the fairway and even hold a steadier line on the putting green. "If demand for the balls takes off, this could become a major business for us," says NanoDynamics CEO Keith Blakely, who plans to sell the balls for a pricey $5 apiece.

Beyond straight putts and fresh produce, can nano live up to its potential to create entirely new industries and corporate titans? The answer depends on how the players, from regulators to entrepreneurs, handle a host of thorny challenges. Governments must devise smart regulations to control new materials and therapies. Companies face logistical conundrums, such as carrying out quality control on shipments of minuscule carbon nanotubes and silicon crystals -- the I-beams and sheet glass of this industrial revolution -- that are virtually invisible.

The nascent industry also must hammer out standards and enforcement practices that are sorely lacking. A 2004 study by Lux Research found that many of the 200 global suppliers of basic nanomaterials failed to deliver what they promised. "As a group they have a frighteningly poor track record," says Lux Vice-President Matthew Nordon. The upshot? Until the industry puts a qualified supply chain in place, only innovators working with world-class labs can count on reliable material. This limits access to nanotechnology and hurts its growth.

An even greater challenge for nano industries is to ensure that their new materials are safe in the human body and in the environment. Setbacks could sink nano companies and even lead to a global backlash among the same activists who are raging against genetically modified food. "I'm worried about an overreaction to both the hype and the fear," says Kristen Kulinowski, an executive director at Rice University's Center for Biological & Environmental Nanotechnology.

Such concerns rattle the equity markets. As recently as last summer, about a dozen nanotech companies were positioning themselves for initial public offerings. But last year's most widely anticipated IPO in the sector -- a $115 million offering for Nanosys Inc. in August -- was withdrawn at the last minute as investors cooled to a company rich in patents but still years from making a profit. Now the IPO market appears stalled, even for stars such as Nanofilm, a profitable Valley View (Ohio) manufacturer of optical films, and Konarka Technologies Inc., a Lowell (Mass.) leader in plastic solar panels.

Premature Marketing?

Doubts and confusion plague the market, where even the definition of nano is open to debate. When Merrill Lynch analysts released their Nano Index last April featuring 25 companies, critics howled that they were fueling hype -- and that a few of the pharmaceutical outfits on the list were included simply because they engaged in the common practice of making molecules. Merrill retooled the list, limiting it to companies that publicly stress a commitment to nano. Still, Manuel P. Asensio, president of Asensio & Co., a short-seller that is still betting against the stock of one nano index company -- NVE Corp. (**NVEC**), a maker of electronic sensor instruments -- continues to grumble. "There is no market yet," he says. "Isn't Merrill attempting to create a retail fervor?" Merrill's Steven Milunovich, who directs its nanotech research, responds that the firm covers only three of the stocks on the index and compiles the list not to recommend investment vehicles but as a way to track the young industry. "It's a 30-year trend, and we're only at the beginning," he says.

In today's cautious climate, investors are focusing less on dazzling visions and more on companies with real products, customers, and profits. The leading performer in Merrill's index in 2004 was MTS Systems Corp. (**MTSC**), a 39-year-old testing-equipment company whose tools are widely used in nano labs. Its stock rose 80%. Harris & Harris Group Inc. (**TINY**), a venture-capital firm with heavy investments in nano, saw its stock rise 75% -- a sign that investors hold high hopes for the segment. But most businesses selling true nano products, from materials company Altair Nanotechnologies Inc. (**ALTI**) to France's Flamel Technologies (**FLML**), a medical supplier, suffered market declines through 2004. And the Merrill index fell another 12% in January, 2005.

No doubt nano is in for its share of bumps, with flops sure to outnumber successes by a wide margin. Yet the technology of the tiny is on track to disrupt nearly everything in its path, including companies, industries, and universities. Why? At the atomic level the boundaries among biology, chemistry, physics, and electronics lose much of their meaning. The sciences start to merge. Many of the winners in nano will be those that can reach across old boundaries and create novel hybrids. Israeli biologists and electrical engineers, for example, have teamed up to attach dna to carbon nanotubes to create microscopic transistors. These assemble themselves in the lab following a biological blueprint. The result is an inanimate transistor -- but one that grows, like a tadpole or a toenail.

Funding Magnet

Companies that can bring such innovations to market stand to restructure entire industries. Korea's Samsung Group plans to produce TV displays featuring the most prominent building blocks of the Nano Age -- carbon nanotubes -- by 2006. If successful, these screens could be lighter, cheaper, brighter, and more energy-efficient than today's models. The technology would spread quickly from

TVs to computer screens, even electronic billboards. GE is adding a new nano-focused wing to its R&D center in Niskayuna, N.Y. The company won't disclose the size of its investment but says a 50-member team of researchers is looking to seed nano into everything from medical technology to lighting to high-performance turbines.

For entrepreneurs, nano spells funding. Venture capitalists have invested $1 billion in nano companies, nearly half of it in the past two years. Meanwhile, government funding is holding steady at $4.7 billion annually, nearly equally divided among Asia, Europe, and North America. The cash is pouring into university labs and new nano corridors from Albany to Shanghai and Fukuoka prefecture in Japan. "Any professor with his head screwed on has moved research programs into nano," says Greg Blonder, a partner at Morgenthaler Ventures.

Many of the early prospectors are focusing on health-care testing tools, which are far less regulated than medicines and therapies. LabNow Inc., an Austin (Tex.) startup, has its sights set on addressing the AIDS epidemic. Using minute channels and sensors, the company has devised a blood laboratory on a chip the size of a business card. The patient places a single drop of blood on the chip, which is then inserted into a small electronic reader. Within minutes, HIV/AIDS patients can get a count of their white blood cells -- a crucial metric for treatment. Currently that test takes weeks or months in poor regions of the world, where blood samples are trundled back and forth in slow trucks. Patients can die waiting for the results. LabNow's technology has the potential to speed AIDS treatment in much of the world -- and let LabNow cash in on the $5 billion global market for point-of-care testing. In October, LabNow got $14 million in equity funding from a consortium led by George Soros. The company hopes to roll out its systems in South Africa by the end of 2005.

Red Flag

More dramatic breakthroughs are expected within two or three years as companies developing novel medical procedures begin to emerge from the regulatory maze. Already, nano-ized versions of existing drugs are causing a stir. Last month, American Pharmaceutical Partners Inc. shares surged 50% on news that the Food and Drug Administration had approved the marketing of Abraxane, a nanoscale protein-based drug for the treatment of metastatic breast cancer. The nano version is able to squeeze into places in the body that its existing macro counterpart cannot without intolerable side effects. Further out, researchers are working on customized treatments, such as nanoparticles built to match the unique genetic profile of a patient's cancer cells -- and programmed to seek out and destroy them. Hundreds of these therapies are in the works. Most will fail. But if even a handful succeed, they could change medicine.

To achieve such triumphs, nano companies must squelch fears about the effects of the particles in the body. Worries grew last spring when researchers at Southern Methodist University reported brain damage in a large-mouth bass that had been swimming in an aquarium stoked with common carbon-based nanoparticles known as buckyballs. Although far from conclusive, such findings raise red flags worldwide -- and they extend far beyond the networked legions of activists. Last year, giant reinsurer Swiss Reinsurance Co. warned against a rush into nano, citing "the unforeseeable nature of the risks it entails and the recurrent and cumulative losses it could lead to."

One industry that should be able to tap nano's potential without those risks is semiconductors. As the circuits and pathways on the chips grow tinier, manufacturers are running into problems. Electrons tunnel through flimsy walls that are only several atoms thick. The electricity coursing through the intricate maze generates searing heat, which is increasingly costly and hard to control. As the industry struggles to maintain Moore's Law, which predicts the doubling of computing power every 18 months, costs are exploding. The price of a new semiconductor fabricating plant is projected to reach $10 billion by the end of the

decade.

Nano innovators aren't likely to replace the silicon chip anytime soon, but they could help ease the squeeze over the next decade. This process has already started with memory chips, the least complicated kind. Within two or three years, developers hope to make viable memory chips from spaghetti-shaped carbon nanotubes, each one only 1 nm wide. Further out, engineers are learning how to replace minuscule metal circuits and gateways on today's chips with new nano-engineered materials. IBM researchers have built transistors with carbon nanotubes that promise "a huge leap in performance while cutting heat loss," says Phaedon Avouris, a researcher at Big Blue's Nanometer Scale Science & Technology Labs.

Despite this progress, it's a long hike to nanocomputing, not a sprint. HP researchers don't expect their platinum circuits to debut until 2011 at the earliest. And it won't be until much later in the next decade, say scientists, that nanotechnology may be able to provide a new architecture for faster computing in the post-Silicon era.

The future of nanotechnology? It may seem strange now, but within a decade or so the term is likely to vanish from syllabuses and portfolios and remain part of company names only as a vestige of the past. After all, nano denotes only size. Once work on that scale becomes routine, that buzzword will fade. But the physical world -- medicines, metals, and even the roles the elements play -- will be utterly changed by this revolution, all brought about by bits far too small for the eye to see.

By Stephen Baker and Adam Aston