



Nanoparticles
in sunscreen

Nanoparticles in
energy drinks

Nanoparticles
in microfibers

TINY TROUBLES

How Nanoparticles Are Changing Everything From Our Sunscreen to Our Supplements

By Carole Bass

It's a beautiful summer day. You pull on your stain-resistant cargo shorts and odor-resistant hiking socks, gulp down an energy-boosting supplement, slather yourself with sunscreen and head out for a ramble in the woods. Are you poisoning yourself? When you get home, you jump in the shower and toss your clothes in the wash. Are you poisoning the environment? Maybe.

Your sunscreen, energy drink and high-tech clothing may be among the 800-plus consumer products made with nanomaterials: those manufactured at the scale of atoms and molecules. Sunscreen that turns clear on the skin contains titanium dioxide, an ordinary UV-blocker in extraordinarily small particles. Odor-eating socks are made with atoms of germ-killing silver. Supplement makers boast of amazing health effects from swallowing nanosolutions that are completely untested for effectiveness or safety. And that stain-repellant clothing? The manufacturer won't even tell you what nanomaterials are in it.

The problem is not just that you, the consumer, don't know what's in the products you use. The much bigger problem is that at the nanoscale, common substances behave in uncommon ways. And nobody—not even the world's leading nanoscientists—knows what nanoparticles do inside the body or in the environment.

Nanotechnology, a fast-growing global industry, is essentially unregulated. Advocates and independent scientists agree that we need to get ahead of the risks before it's too late. Some call for a moratorium on the riskiest nanoproducts. Some say we just need more research, and more protection for workers in the meantime. All are worried about unleashing a powerful new technology that could have vast unintended consequences. Nanomaterials are in food, cosmetics, clothing, toys and scores of other everyday products. Yet when it comes to trying to get a handle on them, we can't answer the most basic

questions. What companies are using nanomaterials, and where? What kinds, and in what amounts? How much of the potentially hazardous stuff is escaping into the air, water and soil? Into our food and drinks? Nobody knows.

At a February workshop on what research is needed to better understand nanorisks, speaker after speaker presented questions without answers. Rutgers University environmental scientist Paul Lioy, assigned to talk about human exposures to nanomaterials, was especially blunt.

"This is basically virgin territory," he said. "The fact that it's virgin territory is not good for the field, and it should be fixed really quick."

Big Benefits, Big Risks?

Nanomaterials are not new. Some exist naturally, and others result from combustion—like the ultra-fine particles in diesel exhaust that have been linked to respiratory and heart diseases.

What's new is nanotechnology, the ability to manufacture and manipulate minuscule materials into forms such as quantum dots, spherical buckyballs, and cylindrical carbon nanotubes. These engineered nanomaterials take on unusual properties: changing color, for example, or becoming electrically conductive, or penetrating cell walls. And they have many uses. Carbon nanotubes, or CNTs—made by rolling up sheets of graphite just one atom thick—are extremely light and strong; they show up in high-end tennis rackets and bicycle frames. Nanosilver is used as an antimicrobial agent in everything from paint to toothpaste to teddy bears. Nanometal oxides are blended into ceramics and coatings, making them more durable.

While there's no universal definition, the "nano" moniker generally covers materials between one and 100 nanometers. A nanometer is one billionth of a meter, or between 50,000 and 100,000 times thinner than a human hair.

Nanotech offers enormous potential benefits.▶

NOBODY—NOT EVEN THE WORLD'S LEADING NANOSCIENTISTS—KNOWS WHAT NANOPARTICLES DO INSIDE THE BODY OR IN THE ENVIRONMENT.



Medical researchers are investigating ways to use nanomaterials to target tumors and then deliver tiny amounts of drugs directly inside the cancer cells, sparing the healthy cells. Possible green tech applications include cheaper, more efficient solar panels and water-filtration systems, energy-saving batteries and lighter vehicles that use less fuel.

That's the upside. But exciting new wonder materials often reveal a dark side, too. Asbestos—now synonymous with bankruptcy-inducing lawsuits and slow, painful death—was once seen as a miraculous fireproofing agent that would save millions of lives. Much of its damage could have been avoided if industry and government had heeded the ample danger signs. Now, early research on the potential hazards of nanotech is producing danger signs of its own. Workers handling nanomaterials face the biggest risks. But there are concerns for consumers, too, especially with products—like cosmetics, food and sup-

plements—that go directly on or in the body. And with potentially toxic nanomaterials washing down the drain and into the water and soil, there's reason to worry about environmental damage as well.

Yet studies on nanotech's downside are a mere nanospeck compared to the research that's being done on how this technology can benefit humanity—and corporate profits. Of \$1.5 billion in federal nano spending each year, only between 1% and 2.5% goes toward studying environmental, health and safety risks. Worse, there's no national strategy for deciding what questions need to be answered, or what to do with those answers as they arrive.

Occupational Hazards

Since the 17th century, when Italian physician Bernardino Ramazzini pioneered the field of occupational medicine, researchers have looked to the workplace

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REGULATING NANOTECH: Barely at the Starting Gate

The European Union (EU) is leading the way on regulation of nanotechnology with two recent initiatives, while the U.S.—which is putting nano ingredients in an increasing number of products—has done very little. Even the European regulations will take some time to go into effect, but they're a significant start.

The EU will require increased safety testing for nano-containing cosmetics, and require labeling of nanoparticles on the ingredient lists for such products. These products go directly on the body and can be absorbed by the skin—and sunscreens are a particular worry.

Nanomaterials in food are not yet regulated, though rules are pending in the EU's Novel Foods Directive that would keep them out of foods until subjected to non-animal standardized safety test-

ing. Earlier this year, Canada became one of the first countries to require companies to disclose information about nano ingredients in products.

According to the Project on Emerging Nanotechnologies (PEN), there are more than 800 manufacturer-identified consumer products on the market with nano ingredients. Nick Berning, a spokesperson for Friends of the Earth (FOE), which has been leading the campaign to regulate nanomaterials internationally, says, "There's scant regulation if any in the U.S.; Europe—which has generally been more cautious about adopting new technologies and more open to regulation—is leading the way. In the U.S., we've had two decades of ideological push to limit regulations and safety precautions for consumers. Although nanotech is widely used in

clothes, household appliances, sunscreens—all sorts of products—we don't regulate it."

FOE has called for a moratorium on the commercial release of new nano food products until a legislative framework to regulate them is developed. FOE has identified more than 100 food and agricultural products that contain untested and potentially dangerous nanomaterials or were made with nanomanufacturing. But it thinks the actual number of such products is much higher.

In a doctoral thesis for the Technical University of Denmark, Steffen Foss Hansen points out that nanomaterials could be covered by existing EU regulations, but "it is often unclear if current regulation is actually applicable when it comes to specific nanomaterials and their diverse applications." He says, for

Nano Now: Charting Our Own Destruction?

COMPANY	PRODUCT	THEIR REASON FOR NANO
McDonald's	Adhesive for burger containers	Nano-scale starch adhesives allow for longer shelf life
Skin Rx Solutions	Advanced Protection SPF 30 Oil with Clear Z-Cote Zinc	Nano Z-Cote technology allows a clear, rather than white, product
Kara Vita	Clearly It Acne Treatment Lotion	Nanoparticle-containing moisturizers and antioxidants nourish and repair skin
Remington	CleanXchange™ Foil Shaver	Nanosilver-coated foils credited with reducing redness and irritation
Pure Plushy	Benny the Bear toy	Silver nanoparticles fight against harmful bacteria, molds and mites
Behr	Behr Premium Plus Exterior Paint	Nanoparticles lend the paint improved adhesion and anti-mildew properties
BMC Cycling	BMC Racing Fourstroke F501 bicycle	Adds material value by the admixture of microscopically small carbon tubes
AMD	AMD® Athlon™ 64 X2 Dual-Core Processor	Shrinking lithography (to etch 50 nanometer transistor gates) reduces surface area and power use
Andis	Andis Elevate 3/8" Nanosilver Gold Infused Curling Iron	Nanosilver infusion of "real silver" used to kill bacteria
Sharper Image	Antibacterial Silver Athletic and Lounging Socks Contour-Foam Silver Crescent Travel and Nap Pillow	Millions of silver nanoparticles offer antibacterial and antifungal properties Nanosilver particles are infused throughout Sharper Image's exclusive space-age Contour-Foam Silver products for germ-killing properties
Honeywell	Hite Brewery beer bottles	Multilayer polyethylene terephthalate (PET) bottles made with Aegis OX barrier nylon resin demonstrate near-zero oxygen transmission rates for extended periods of time
Dog Gone Smart	Dog Gone Smart pet beds and clothing	Nanotechnology reduces the spread of bacteria, is dirt-resistant and lends durability

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example, that safety testing is triggered by specific production weight thresholds—in tons—that are hardly likely to be met by products on the nanoscale. Some governments have adopted voluntary environmental programs (VEPs) for nanotech, Hansen says, but these have not had much effect. Further regulation is needed, he says, because "we do not know enough to say that nanomaterials

tor of the National Nanotechnology Coordination Office, downplays it. "Until we have information that there are truly inadequacies in existing regulations, any additional regulations beyond what we already have would be burdensome to industry and the advancement of the field," he says.

It's not clear what "existing regulations" Teague is talking about. According

action on climate in the face of eight years of federal inaction, California may be ready to regulate nanotech on its own. Assembly member Mike Feuer said in March that he intends to introduce nanotech regulations into the state legislature this year. According to Feuer, the legislation could include a notification provision and standards for worker exposure and environmental releases.

NO U.S. LAW IS SPECIFICALLY DESIGNED TO REGULATE NANOTECHNOLOGY.

are safe, but there is evidence that some nanomaterials are hazardous depending on their particle characteristics, how they are applied and how humans and the environment are exposed to them."

In the U.S., which earmarked \$1.5 billion for nanotech research in 2009 (with only \$256 million going to risk-assessment work), federal officials have been slow to recognize the need for regulation—though that could change under President Obama. Clayton Teague, direc-

tor to Ian Illuminato, FOE's ranking nanotech expert, in the U.S. "nano product manufacturers are still not required to identify nanoparticle ingredients on product labels or conduct nano-specific safety tests on these ingredients, or submit their products for approval prior to commercialization. No U.S. law or regulation is specifically designed or has been amended to regulate nanotechnology and nanomaterials."

In what might be a parallel to state

It could be that California is already empowered to take action on nanotech. A state law signed last year gives the California Department of Toxic Substance Control broad authority to regulate "chemicals of concern" in consumer products. Regulations will be in place by 2011.

CONTACT: Friends of the Earth, www.foe.org/europe-leading-way-nanotechnology-regulation; National Nanotechnology Initiative, www.nano.gov.

—Jim Motavalli

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OF THE \$1.5 BILLION IN FEDERAL NANO SPENDING EACH YEAR, ONLY 1% TO 2.5% GOES TOWARD STUDYING ENVIRONMENTAL, HEALTH AND SAFETY RISKS.



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for advance warning of new illnesses. From janitors blinded by ammonia fumes to chimney sweeps who absorbed cancer-causing soot through their skin, workers get sick first and most acutely because of their intense, daily toxic exposures. That's why much of the still-sparse nano health and safety research has focused on the possible hazards of working with nanomaterials. Scientists can't expose workers to potential toxins

defenses. In a University of Rochester study of the accidental nanoparticles known as ultrafine pollution, they bypassed the protective blood-brain barrier and slipped directly into the brain's olfactory bulb. Other research demonstrates that nanomaterials can penetrate the deepest part of the lungs. From there, they cross into the bloodstream and various organs.

Based on evidence like this, the European Union's occupational health and safety agency issued an expert report in March, citing nanoparticles as the number-one emerging risk to workers. In the U.S., NIOSH has issued a guidance document urging employers to avoid exposing workers to nanomaterials—for example, by enclosing equipment and using ventilation to reduce dust and fumes. But NIOSH has no regulatory power; it can only suggest.



The Pig-Pen Effect

"You're producing a personal cloud of exposure," Paul Lioy warned. "Every time you breathe. Every time you move. If the materials you're wearing have [nano]materials that can be released, they will be released. It's basically the Pig-Pen effect."

Lioy, the Rutgers environmental scientist, was speaking theoretically. His audience was fellow scientists, gathered in Bethesda, Maryland, for a workshop sponsored by the federal government. The workshop's title: "Human & Environmental Exposure Assessment of Nanomaterials." Lioy's assignment: Talk about the need for research to "characterize exposure to the general population from industrial processes and industrial and consumer products containing nanomaterials." His message: There *is* no research on whether and how the general population is exposed to nanomaterials. Searching the scholarly literature, Lioy's associates "spent hours looking for data ... and found nothing," he said.

While workers are on the front lines of nanoexposure, Lioy cautioned against ignoring consumer exposures. "We are all in contact with it—300 million of us, if we use products that have nanoparticles," he declared. And while nanomaterials that are embedded in a hard surface like a computer keyboard are probably not a big worry, clothing and cosmetics might be a different story, he said. That's where his comparison to Pig-Pen, the *Peanuts* character forever surrounded by a cloud of dirt, comes in: the idea that every time we move, nanoparticles might come loose from our

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and watch to see if they keel over. But if employers cooperate, researchers *can* find out what materials workers are using, in what amounts and forms, and under what conditions. Then they can simulate those exposures with lab animals.

Some studies find little or no risk. Others are alarming. Last year, British researchers reported that when long, straight carbon nanotubes—shaped like asbestos fibers—were injected into mice, they caused the same kind of damage as asbestos. Of course, workers wouldn't ordinarily stick themselves with a needleful of CNTs. But a follow-up study this year, by the National Institute for Occupational Safety and Health (NIOSH), found that when mice inhaled CNTs, the tiny tubes migrated from their lungs to the surrounding tissue—the very spot where asbestos causes the rare cancer known as mesothelioma.

One reason nanomaterials can cause trouble is that they are small enough to evade the body's

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NANOBOTS

Tiny Machines Could Be Hugely Efficient—Or Turn Us All Into “Grey Goo”

Here come the...nanobots. Although it sounds like something out of the *Terminator* films, scientists are taking seriously the concept that we could engineer tiny machines to, well, serve man. And hopefully not in the same sense as the 1960s *Twilight Zone* episode—where the alien volume *To Serve Man* turned out not to be an exercise in altruism but a cookbook.

As early as 1959, noted genius and scientific authority Dr. Richard Feynman imagined the possibilities of tiny machines accomplishing useful work. In surveying the huge, room-filling computers of the day, he asked in a speech at CalTech, “Why can’t we make them very small, make them of little wires, little elements—and by little, I mean *little*. For instance, the wires should be 10 or 100 atoms in diameter, and the circuits should be a few thousand angstroms across....”

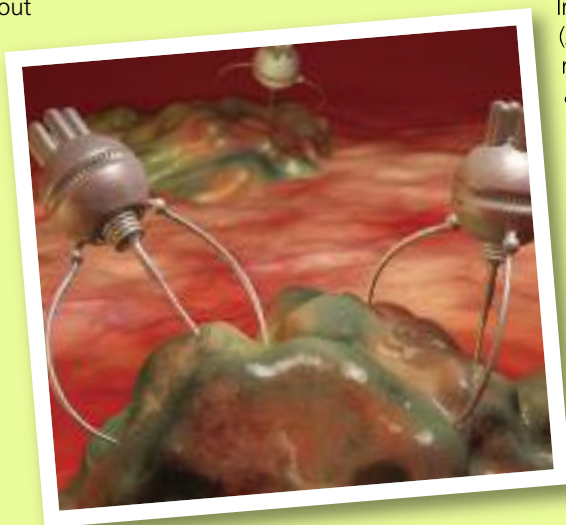
“When we get to the very, very small world—say, circuits of seven atoms—we have a lot of new things that would happen...Atoms on a small scale behave like *nothing* on a large scale, for they satisfy the laws of quantum mechanics.”

The latter-day scientist Dr. K. Eric Drexler, who first wrote of the possibilities of nanosystems in a 1981 paper for the National Academy of Sciences, talks of Feynman’s work as leading the way to a new form of manufacturing. He envisions not self-replicating machines (a potentially scary concept), but tiny factories that make tiny parts “that can be snapped together to make more nanofactories.”

Drexler imagines incredibly efficient “micron-scale computer CPUs” running on 100 nanowatts that would make possible air-cooled desktops with a billion individual processors. Surgical tools guided by sub-cellular programmable computers will operate on the molecular level, enabling “the precise destruction of cancer cells and AIDS viruses.” Nanobots might conceivably build mate-

rials that are 100 times stronger than diamonds or high-quality graphite, Drexler says.

The technology is not as far off as it seems. The very real possibility of nanotechnology manufacturing was explored in a 2006 National Research Council report entitled *A Matter of*



Size. Sensors for medical diagnostics, such as Drexler imagines, “are built every day with the aid of processes that exemplify molecular self-assembly,” the report says. “More complex structures can be generated by more sophisticated self-assembly processes.”

Today’s microelectronics factories use photolithographic processes to optically project patterns onto silicon wafers. Using this process, electronic circuits can be built with wires as narrow as 90 nanometers. Semiconductor manufacturers are working on the 65-nanometer level, and 45- and 32-nanometer manufacturing processes are underway. The report concludes, “There is no fundamental physical barrier to practicing lithography at atomic levels.”

The use of nano in biotechnology is also well advanced, and the re-engineering of cells for new purposes is firmly established. Biological processes can and likely will form the basis of many manufacturing processes.

In conclusion, the report’s authors see “an amazing future” for nanotechnolo-


gy, including a distant time in which virtually any stable chemical structure can be built up atom by atom or molecule by molecule. The big challenge: The need to operate at very high speeds, with very low error rates and almost perfect thermodynamic efficiency.

But there are potential problems, too. In his 1986 book *Engines of Creation* (Anchor), Dr. Drexler imagined self-replicating nanomachines running amok, and breaking down biological material, eventually turning everything into “grey goo.” Author Bill McKibben popularized this frightful idea in his book *Enough: Staying Human in an Engineered World* (Times Books).

But Drexler himself has backed away from grey goo, though he still considers it “well within the realm of physical law.” Today, he says, “I thought it was important to outline a worst-case scenario.” But he doesn’t think self-replicating machines of the type that could turn us all into mush will ever be in widespread use. “I also underestimated the popularity of depictions of swarms of tiny nanobugs in science fiction and popular culture,” Drexler says.

Another worry is nanoweapons. The futurists Michael Vassar and Robert A. Freitas, Jr., imagine self-replicating attack systems called “ecophages” making copies of themselves (à la *The Terminator*) and eating the enemy or his resources as they self-replicate. They propose a nanoshield defense.

The authoritative *Jane’s Defence Weekly* suggests that the design of new chemical agents “that attack specific body organs such as the central nervous system would enable far smaller amounts of the chemical to be made without detection and would require only small, low-level facilities.” Non-lethal chemical weapons might also emerge to subdue belligerents for riot control and police work, *Jane’s* says.

CONTACT: Dr. Drexler, <http://e-drexler.com>; National Research Council’s “A Matter of Size,” www.nap.edu/catalog.php?record_id=11752; Smalley Institute, <http://cnst.rice.edu>. —*Jim Motavalli* 

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moisturizer or our stain-resistant togs.

Noting that “a lot of nanoparticle uses are terrific,” Lioy said he doesn’t want society to do without. As scientists do the necessary studies, “I think a lot of issues will go away,” he said. “I just don’t want unintended consequences.”



Down the Drain

Cyndee Gruden is getting the poop on nanopollution—literally.

One of the main environmental concerns about nanomaterials is what happens when they wash out of clothing, hair or skin and go down the drain. Do they harm aquatic life? Do they interfere with wastewater treatment?

Gruden, a civil engineering professor at the University of Toledo in Ohio, is tackling part of that last question by looking at the



ONE REASON NANOMATERIALS CAN CAUSE TROUBLE IS THAT THEY ARE SMALL ENOUGH TO EVADE THE BODY’S DEFENSES.

effects of two nanometals—titanium dioxide and zinc oxide, used in sunscreens, paint and other products—on bacteria.

Metals “can be toxic to microorganisms,” she notes. “In fact, that’s specifically what they’re for” in consumer products: to inhibit mold, mildew and other nastiness. But when nanometals make their way to a sewage treatment plant, Gruden worries that they might harm the beneficial bacteria that break down what’s delicately known in the business as “biosolids.”

Her preliminary findings, which she presented at a meeting of the American Chemical Society (an academic group, not an industry organization) in March, are mixed. Nano-titanium dioxide damaged bacteria, causing cell walls to break at “relatively low concentrations,” similar to what you might see at a sewage treatment plant, Gruden says in an interview. But “in terms of function, what does that mean? Are the bugs able to do what they’re supposed to do?”

To answer that question, she added some biosolids to her test tubes and measured how much methane the bacteria produced as they digested for five days. The titanium dioxide didn’t seem to slow the bugs down; in fact, methane production actually increased. But when Gruden added nano-zinc oxide, gas pro-

duction slowed down. She’s running more experiments this summer to see what happens when the bacteria are exposed to the bugs for a full 30 days.

“The take-home message for me is, the behavior of these particles is very complex,” Gruden says. “When you take a nanoparticle and put it into the environment, you have to know how it’s going to behave. And we don’t.”

One metal Gruden didn’t look at is nanosilver, widely used as a microbe-killer. The Project on Emerging Nanotechnologies, a nonprofit research and advocacy organization funded by the Pew Charitable Trusts in Washington, D.C., maintains an inventory of more than 800 consumer products advertised as using nanotechnology. Silver is by far the most frequently identified material.

In an experiment publicized last year, Arizona State University graduate student Troy Benn bought nanosilver-containing socks off the Internet and simulated washing them in jars of water. He found that, for several brands, most or all of the silver disappeared in just a few washings. Silver has been used to kill bacteria since ancient times, when the Greeks found that wine stayed fresh longer in vessels lined with the precious metal. It’s potent enough that the U.S. Environmental Protection Agency (EPA) regulates silver as a pesticide. Which raises the question: What does nanosilver do to the “good bugs” downstream, at the sewage treatment plant and elsewhere?

In 2006, a trade organization of wastewater treatment operators was concerned enough about a new silver-ion-emitting Samsung washing machine to pressure the EPA to include such equipment under its pesticide rules. The EPA responded by cracking down, not only on the washer but also on manufacturers of products advertised to contain nanosilver, including a line of supposedly sanitary computer peripherals. Separately, a coalition of consumer, health, and environmental groups filed a petition last year asking the EPA to impose a moratorium on nanosilver products until more safety research is done. In addition, the EPA has awarded a grant to Arizona State researchers to investigate interactions between various kinds of nanomaterials and wastewater biosolids.

Oversight or Overlooked?

In the U.S., the EPA has emerged as the lead agency on nano oversight. But that’s not saying much. It is wrestling with the possible risks of nanomaterials, but so far has taken almost no action to regulate them.

In a voluntary Nanoscale Materials Stewardship Program, the EPA asked companies to

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CONVERSATIONS:

Pat Roy Mooney, Canadian Nanotech Campaigner

A native of the Canadian prairies, Pat Roy Mooney is executive director of the Ottawa-based ETC Group (ETC stands for erosion, technology and concentration) and a 30-year campaigner on agriculture and biodiversity issues. He is a winner of the Right Livelihood Award (the "Alternative Nobel Prize"), Canada's Pearson Peace Prize and the Giraffe Award, given to people "who stick their necks out."

A longtime campaigner to protect seed diversity, Mooney has led ETC to call for a moratorium on all research involving molecular self-assembly and self-replication. "There is a critical need to evaluate the social implications of all nanotechnologies," the group says. Soon after concluding our interview Mooney boarded a flight to Berlin, where he was to speak at a nanotechnology conference. "I'm in a lot more demand in Europe at the moment," he said.

E Magazine: Canada would appear to be a leader in regulating nanotech in that it at least requires some disclosure of nanotech ingredients.

Pat Roy Mooney: Well, the U.S. government does require some information, but Canada is pushing harder from a very slow start. A report last year from the Science Council of Canada did galvanize the government to do more. There is no pending legislation that I'm aware of in Canada, though there have been intense conversations about it. Bureaucrats have been meeting about it in the federal health and agriculture departments, but it's all very slow moving. I met with some interdepartmental committees, and they were shocked to discover that there are nanotech ingredients already in food.

E: The Europeans appear to be taking a tougher stance on nanotech.

PRM: The European Parliament [of the EU] is certainly concerned, but its executive branch, the European Commission, is less so. And it will take a long time for those rules they've adopted on cosmetics to go into effect. Nanotech in cosmetics is a serious issue, but we're also eating the stuff. Some analyses say that it could take



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until 2017 for us to have the basics in place to fully regulate nanotech. That's a pessimistic view, but it could take that long—and by then it might be a \$2 trillion market and very hard to regulate at all. The Europeans want a global approach to regulation, and there are international dialogues occurring aimed at coordinating the regulations. North America is dragging its feet, and the Europeans are saying they don't want to wait.

E: California could regulate nanotech on its own (See "Regulating Nanotech," page 22). Wouldn't that create a lot of confusion when states and the federal government have different regulations on how products are labeled?

PRM: It does create a mess, but when a state is the size of California, it tends to have a lot of influence. California was the tail that wagged the General Motors dog in regulating tailpipe emissions. State regulation is not ideal, but in the absence of any alternative it's a good thing. In the province of Ontario, we've just announced a ban on the use of pesticides and herbicides in backyard gardens. It's just one province doing it, but the impact is large enough to put pressure on the industry.

E: How many food products contain nanotech ingredients?

PRM: It's in 80 or so food products on the world market. Some of those ingre-

dients are in food packaging, but nanoparticles from the packaging can get into food. These 80 are just what's being disclosed by the companies on their own. It's mostly North American products. We can't be sure of what is happening in China. There's a massive investment there; nanotech is huge in China. But there's no obligation for Chinese exporters to report what's in the food they ship out. And we've had some pretty bad experiences with Chinese food products. It could all be perfectly safe, but we have no idea.

E: I know that you also work on biotech issues.

PRM: There are some similarities to biotech. There was an uproar in Europe when it was discovered that American companies had sold genetically modified and unlabeled corn products there. Labeling is mandatory in Europe. It was an error—some of the products sold for human consumption had in fact been modified only for livestock feed. Together, U.S.-based Monsanto and Dupont, plus the Swiss company Syngenta, sell 50% of all commercial seeds and have no less than 90% of the biotech seed market. And it does leave you breathless, the idea that these companies can monitor their own biotech safety standards. You'd think we'd learn from our mistakes. The big companies have investment in nanotech, too. Globally, more than 260 food, beverage and agriculture companies have investments in nanotechnology.

E: Will we eventually have international nanotech regulations?

PRM: It's hard to know. I think we will have regulations in the end because the reports from peer-reviewed testing are so discouraging—none have given green lights. It's all red or yellow lights. That can't keep on happening without people saying, "Hey, this is not such a great idea."



CONTACT: ETC Group, www.etcgroup.org. —J.M. **E**

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submit information about what nanomaterials they're using. Very few did, and even the companies that participated withheld large amounts of data as business secrets. This March, the EPA began requiring manufacturers of carbon nanotubes to file pre-manufacturing notices under the Toxic Substances Control Act. California is requiring carbon nanotube makers to share their environmental, health and safety test data with the state, and is considering imposing the same mandate on makers of nanometal oxides, like the ones Gruden is testing.

But the EPA is not the only federal agency with responsibility for nanomaterials. Cosmetics, sunscreen, and food and beverages—which fall under the jurisdiction of the Food and Drug Administration (FDA)—make up roughly 30% of

PEN's consumer products inventory. Yet the FDA is poorly equipped to ensure the safety of nano-containing dietary supplements, according to a 2008 report by two former agency officials. (Friends of the Earth has urged mandatory labeling of nanofoods and a moratorium on nano-containing cosmetics until they're shown to be safe.) The Occupational Safety and Health Administration, which is responsible for protecting workers, has not even begun to work on nano rules.

A former EPA official, J. Clarence Davies, proposes merging all these agencies and more into a new Department of Environmental and Consumer Protection. A "scientific agency with a strong oversight component," it would cover products, pollution, workplace health and safety, climate change and health effects of nanotechnology as well as other

© CHUCK WADEY ADVENTURES IN SYNTHETIC BIOLOGY



UNLEASHED: Unpredictable Synthetic Organisms

Synthetic biology envisions that we can redesign natural biological systems and make them more efficient, and build living machines from common chemical ingredients. And it's probably an understatement to say, as *The New Atlantis* journal does, that such Brave New World reordering offers both promise and peril.

Living machines could have many practical applications. Scientists are dreaming of tiny bioengineered organisms that can produce medicines (combating malaria is an early application), attack cancer cells and pollutants, and even produce hydrogen for the vehicles of tomorrow.

The field is still evolving. The first international synthetic biology conference was held at MIT in 2004; the fourth and most recent took place in Hong Kong last October. Much research is university-based in the U.S., Japan, Israel and Europe, but there are also several private companies,

including Codon Devices, Synthetic Genomics and Amyris Biotechnologies.

The genetics pioneer J. Craig Venter (who famously sequenced the human genome) has brought both venture capital and government money into companies that can—and do—patent synthetic biological forms. "We've been digitizing biology," he said at the Technology, Entertainment, Design (TED) conference last year. "And now we're trying to go from that digital code to a new phase of biology with designing and synthesizing life."

The discipline known as synthetic genomics aims to artificially recreate specific genes or genomes from synthetic, chemically produced DNA. For instance, scientists believe they will soon be able to recreate nearly any virus by replicating its complete DNA sequence. The price for synthetic DNA is dropping rapidly and could soon reach just 10 cents per base pair (from \$10 as recently as 2000), mak-

ing commercial uses more practical.

Obstacles remain, however, including the fact that bioengineered systems tend to be somewhat unpredictable. But that hasn't stopped the march toward applying the science. According to the ETC Group's *Extreme Genetic Engineering: An Introduction to Synthetic Biology*, "In five to 10 years...it will become no big deal to cobble together a designer genome, insert it into an empty bacterial cell and—voilà—give birth to a living, self-replicating organism." The peril is that we could be giving birth to organisms that, if released into the environment, will behave in ways far beyond those intended.

Consequences of unleashed and uncontrolled genetically engineered microorganisms (GEMs) could range from habitat damage to extinction of wild species through competition or infection. So far synthetic biology experiments have taken place under carefully controlled conditions,

technologies, Davies writes in his April 2009 report, "Oversight of Next Generation Nanotechnology?"

Outside the U. S., regulators are taking a somewhat more precautionary approach. Still, governments have adopted very few nano-specific rules to protect people or the environment. But there are bright spots. At Rice University in Houston, Texas, for example, Vicki Colvin and her colleagues are trying to engineer nanomaterials that are safe from the get-go, rather than looking for ways to minimize harm from nanotoxins.

But fears abound that the teeny genie is escaping from its bottle. The asbestos parallel causes particular concern—prompting the Australian Council of Trade Unions, for example, to call for that country to adopt nano regulations by year's end. At the Bethesda workshop in February, Har-

vard industrial hygienist Robert Herrick advocated an all-out effort to gather information about nano exposures and possible related illnesses. The asbestos industry could have undertaken a similar effort in the 1930s, he noted. Instead, industry execs decided to keep the subject quiet. If they had gone the other way, Herrick wondered, "how different would history be?"

CONTACTS: Friends of the Earth nanotech information: www.foe.org/healthy-people; Human & Environmental Exposure Assessment of Nanomaterials Workshop: www.nano.gov/html/meetings/exposure/index.html; Project on Emerging Nanotechnologies: www.nanotechproject.org. **E**

CAROLE BASS, a journalist, writes about the environment, workplace health, legal affairs and other subjects.



in the Wild

but commercial applications—such as toxic cleanups—envision their wide dispersal.

In a special 2005 issue, the science journal *Nature* concluded that "our ability to quickly and reliably engineer biological systems that behave as expected remains quite limited." The magazine uncharacteristically created a comic book, *Adventures in Synthetic Biology*, that went with the special issue and imagined a junior scientist reprogramming some bacteria to see what happens, only to have it grow to enormous size and then explode.

"Hmm," the young scientist says, "I better learn more about what I'm doing before I try anything else!"

Perhaps to head off such concerns, experts from the J. Craig Venter Institute (JCVI), the Center for Strategic and International Studies and MIT, with funding from the Alfred P. Sloan Foundation, released a report, "Synthetic Genomics: Options for Governance," in 2007. Firms

that supply synthetic DNA could, for example, be required to use special software to screen out malicious orders. Owners of DNA synthesizers could be required to register their machines. And university courses could address risks.

"Designing ways to impede malicious uses of the technology while at the same time not impeding, or even promoting beneficial ones, poses a number of policy challenges for all who wish to use or benefit from synthetic genomics," says Michele Garfinkel, policy analyst at JCVI and lead author of the report.

The proposed fixes seem inadequate to the challenge posed by synthetic biology. And it's not only commercial applications that pose concerns. Synthetic biology presents a significant terrorist threat. "If ever there were a science guaranteed to cause public alarm and outrage, this is it," says Phillip Ball, a consulting editor at *Nature*.

"Compared with conventional biotechnology and genetic engineering, the risks involved in synthetic biology are far scarier."

We could take comfort from the fact

that the 1972 Biological and Toxic Weapons Convention bans the production of "microbial or other biological agents, or toxins...that have no justification for prophylactic, protective or other peaceful purposes." But terrorists don't abide international treaties. Because it is possible to recreate viruses, rogue scientists could synthesize deadly killers such as Ebola, though their effective dispersal over wide population areas is not as simple as it appears on television shows like *24*.

The rush to develop artificial life has developed into a free-for-all, with regulation lagging considerably behind the advancing science. If we are to give more than lip service to the precautionary principle, they'll need to be brought in line.

CONTACT: *Nature* comic book, www.nature.com/nature/comics/syntheticbiologycomic/index.html; *The New Atlantis* "Promise and Peril" article, www.thenewatlantis.com/publications/the-promise-and-perils-of-synthetic-biology; Synthetic Biology FAQ, <http://syntheticbiology.org/FAQ.html>. —*Jim Motavalli* **E**