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The Smaller the Better

The limitless promise of nanotechnology -- and the growing peril of a moratorium.

Ronald Bailey | December 2003 Print Edition

"The best way I can describe it is if you close your eyes and dream. You could never be hungry, never be sick, have all the energy you need, all the water, all the food and no diseases. There is no aspect in the world economy or your personal life that is not assumed to be transformed by this new technology."

The amazing development that is supposed to usher in this utopia is nanotechnology, the manipulation of matter at the molecular and atomic level. But the man who made these wild-eyed, pie-in-the-sky claims was not nanotech prophet Eric Drexler, author of *The Engines of Creation*, the 1986 book that popularized the concept, and founder of the Foresight Institute, dedicated to working out its implications. Nor was it Neal Stephenson, the visionary science fiction writer who imagined a future transformed by nanotechnology in his 1995 novel *The Diamond Age.* And it wasn't Richard Smalley, winner of the 1996 Nobel Prize in chemistry, director of the Rice University Center for Nanoscale Science and Technology, and co-discoverer of the novel carbon molecules called nanotubes and fullerenes, whose strength and electronic properties are at the heart of future nanotech applications.

No, the speaker expounding on the wonders of nanotechnology was Roy Pat Mooney, a longtime anti-globalization activist who directs the Action Group on Erosion, Technology, and Concentration (ETC Group). His nanotech vision was part of a talk he gave at a November 2002 conference in the Philippines. The funny thing is that Mooney and his allies want to impose an immediate, comprehensive global moratorium on the development of nanotechnology. That's right: Mooney wants, at a minimum, to delay the arrival of technologies he himself believes could banish hunger, disease, and material want forever.

The ETC Group, which issued its call for a moratorium in a January 2003 report, wants to stop nanotech until "civil society" has a chance to catch up. "In the future," its report declares, "molecular manufacturing poses enormous environmental and social risks and must not proceed -- even in the laboratory -- in the absence of broad societal understanding and assessment." The ETC Group "proposes that governments declare an immediate moratorium on commercial production of new nanomaterials and launch a transparent global process for evaluating the socioeconomic, health and environmental implications of technology." Since "emerging technologies require scientific, socioeconomic, and societal evaluation in order for governments to make informed decisions about their risks/benefits and ultimate value," the group advocates an International Convention for the Evaluation of New Technologies. ETC is not alone in demanding a nanotech moratorium. In an editorial in the September 2003 issue of *smalltimes* magazine, Greenpeace UK's chief scientist Douglas Parr writes: "Greenpeace has not called for a ban on nanoparticles, but a moratorium until the hazards are characterized and understood."

Mooney and his fellow activists cannot be lightly dismissed. They have been leaders in the largely successful global campaign against plant biotechnology. And Mooney already has the support of major organizations such as the Rockefeller Foundation and Ford Foundation. The prestigious Dag Hammarskjöld Foundation helped organize and pay for a conference on nanotech last year at its headquarters in Uppsala, Sweden. The ETC Group and like-minded activists are backed by a coalition of foundations known as the Funders Working Group on the New Technologies, based in San Francisco. "They have more money to organize against nanotech than we have to promote it," complains Mark Modzelewski, executive director of the NanoBusiness Alliance, an industry group.

The advocates of a nanotech moratorium are apt to find a sympathetic audience among the "nanoethicists" who are emerging as a result of the National Nanotechnology Initiative. The NNI, launched in 2000, has grown to be a $774 million federal program, of which about $28 million has been allocated to study the social implications of nanotechnology. Writing in the February 2003 issue of the journal *Nanotechnology*, bioethicists from the Joint Center for Bioethics at the University of Toronto note that as nanotech expenditures have increased, so have calls for regulation. "These two trends seem to be on a collision course towards a showdown of the type that we saw with GM [genetically modified] crops," they write. "As the science of NT [nanotechnology] leaps ahead, the ethics lags behind....The ethical issues fall into the areas of equity, privacy, security, environment and metaphysical questions concerning human-machine interactions."

The article concludes: "The call by ETC for a moratorium on deployment of nanomaterials should be a wake up call for NT. The only way to avoid such a moratorium is to immediately close the gap between the science and ethics of NT. The lessons of genomics and biotechnology make this feasible. Either the ethics of NT will catch up, or the science will slow down."

Nanotechnology excites both extravagant hopes and deep fears, sometimes in the same people. While there are grounds for caution, the tremendous promise of nanotechnology will never be realized if we allow fear to rule us and give in to those who insist upon zero risk as a condition of progress. The manageable hazards associated with nanotechnology are small compared to the danger posed by the burgeoning movement to stop its development until all objections have been satisfied.

Nanotech Wow!

In congressional testimony on May 12, 1999, the Nobel Prize-winning chemist Richard Smalley argued that "the impact of nanotechnology on health, wealth, and the standard of living for people will be at least the equivalent of the combined influences of microelectronics, medical imaging, computer-aided engineering, and man-made polymers in this century." And nanotechnology is coming on fast. "For the first time in history, a technical revolution will approach the abruptness of a political event," writes technology analyst William Atkinson in his 2003 book *Nanocosm: Nanotechnology and the Big Changes Coming From the Inconceivably Small*. "No one in any age has heard, seen, or felt anything like it. But you will." He adds, "A.D. 2003 will seem antediluvian not in fifty years but in fifteen."

At a recent nanotechnology conference in Washington, D.C., Commerce Undersecretary Philip Bond predicted: "Nanotech will produce materials 100 times stronger than steel with a fraction of the weight. The Library of Congress can be stored in a memory module the size of a sugar cube. Nanotechnology will enable clean, pollution-free manufacturing; do something about global warming; provide a sensurround education; [make] information technology...a utility accessible everywhere; [produce] more-efficient renewable energy; and [offer] bioengineered tissues to replace damaged ones. These predictions are not just pie in the sky....Almost every frustration we deal with in this Vale of Tears will be touched by this technology."

As these predictions suggest, nanotech is not one thing; it is more a conceptual breakthrough than a specific technology. Nanotechnology arises from the insight that it is possible to manufacture objects by placing individual atoms and molecules in precise locations.

A nanometer is one-billionth of a meter. Ten hydrogen atoms lined up would fit within a nanometer. Our DNA molecules are 2.5 nanometers wide. A typical bacterium, say *E. coli*, is a thousand times bigger, measuring between 1,000 and 2,000 nanometers, while a virus like the ones that cause the common cold measures around 20 nanometers. The width of the dot above this letter *i* is approximately 1 million nanometers. From the point of view of the nanocosm, the tiny etchings on our densest microchips are vast highways.

Nanotechnology cuts across every business and industry, from information processing, telecommunications, and computers to industrial materials and pharmaceuticals. Every industry can benefit from smaller, more efficient products. At an April conference sponsored by the National Nanotechnology Initiative, Mihail Roco, the nanotech guru at the National Science Foundation, noted, "Developments in nanotechnology are going much faster than expected; in fact, development time is less than half that we expected." Roco also flatly declared, "If a company does not enter nanotechnology now -- in five years it will be too late -- it will be out of business."

The NanoBusiness Alliance's Modzelewski estimates there are already 1,200 nanotechnology startups in the United States alone, and he predicts that number will double in the next 18 months. Roco, who chairs the National Science and Technology Council's Subcommittee on Nanoscale Science, Engineering, and Technology, points out that 75 percent of the 7,000 or so nanotechnology patents are held by Americans. The budget for the National Nanotechnology Initiative has grown from $270 million in 2000 to $774 million in 2003 and is expected to rise to $850 million next year. According to Roco, private nanotech R&D funding is at least three times the government's spending.

The National Science Foundation projects that global markets for nanotech products will exceed $1 trillion annually sometime between 2010 and 2015. This will include markets for novel nanoscale materials ($340 billion), new nanotech-enabled pharmaceuticals ($180 billion), and new electronics ($300 billion).

Getting Small

Nanotechnology is not just a gleam in some inventor's eye; nanotech products already exist. Right now most commercial nanotech applications involve nanocoatings and catalysts. Window manufacturers Pilkington and PPG Industries, for example, offer self-cleaning windows coated with nanoparticles that catalyze dirt and cause rainwater to sheet down and wash away the grime rather than bead up. The same technique is being developed for self-sanitizing tiles in restaurants and hospitals.

Lee Jeans and Eddie Bauer offer spill-resistant pants using "nanowhisker" fabric technology developed by NanoTex. NanoTex fabrics feature billions of 10-nanometer-long nanowhiskers that repel moisture and stains. Popular sunscreens use nanoparticles of zinc oxide to block damaging ultraviolet rays. Pharmaceutical companies are devising nanosized systems that deliver precise doses of drugs to specific tissues. Such systems will greatly reduce side effects while boosting therapeutic benefits.

Nanotech also will have a profound effect on electronics. Kodak and DuPont are producing organic light emitting diodes (OLEDs), made of carbon-based polymers rather than semiconductors. Display screens made of OLEDs, unlike LCDs, emit their own light; they're brighter, thinner, lighter, faster, and more energy efficient than LCDs, and they can be viewed from any angle without losing their brightness or contrast. Kodak offers an OLED screen in one of its high-end digital cameras. Such displays are ideal for computers, PDAs, and cell phones, or whatever combination of these comes to dominate the market for personal electronics. DisplaySearch, a market research firm that focuses on flat panel displays, projects that the market for OLED displays will rise from $85 million in 2002 to more than $3 billion in 2007. Similar technology is being used to create highly energy-efficient lighting that could cut U.S. energy consumption by 10 percent and save $100 billion annually.

Within a decade, analysts foresee various nanotechnologies enabling things like complete medical diagnostic laboratories on one-inch computer chips; ubiquitous computers, some built into clothing; powerful, long-lasting batteries; efficient solar cells; new drugs and drug delivery systems; cheap visual displays; medical monitoring systems embedded in people's bodies ready to sound an alert when a disease organism strikes or a cancer cell develops; and cheaper space travel. And such products will be created using less energy and producing less waste than conventional manufacturing.

Further in the future, visionaries like Eric Drexler foresee the advent of molecular manufacturing based on self-replicating nanoassemblers capable of making any item you might desire. The main ingredients would be dirt and air. Shovel in some dirt, and out would pop a computer, a car, a pair of khakis, or a cabbage, depending on the recipe you specified.

Nanomedical applications would include nanobots smaller than seven-nanometer-wide red blood cells that would cruise people's bodies on search and destroy missions, looking for pathogens and cancer cells. The National Science Foundation's Roco predicts that nanotechnological developments could someday extend human life spans by 20 to 30 years. Nanobiomedical visionary Robert Freitas has proposed a scheme for replacing the entire circulatory system with sapphire "vasculoids" that use nanomachines to ferry oxygen, nutrients, and anti-pathogenic elements around the body. He expects such a system to be available in less than 50 years. Nanotechnology would so boost computing capacities that it might be possible to upload your personality into an almost indestructible inorganic substrate, thereby achieving a kind of immortality.

"We will make progress equivalent to that of the whole 20th century in the next 15 years," declared information technology entrepreneur Ray Kurzweil, author of *The Age of Spiritual Machines*, at a 2002 Foresight Institute conference. "Progress in the 21st century will be equivalent to 20,000 years of progress at today's rate."

Of course, humanity will achieve that sort of progress only if we're allowed to.

Nanotech Yuck!

If the dazzling visions of nanotechnology's benefits are the "wow" phase, the gathering backlash against nanotechnology might be described as the beginning of a "yuck" phase.

That reaction is based on an exaggeration of the risks posed by nanotechnology, coupled with a fundamental misunderstanding of how innovation leads to progress.

The ETC Group sees three nanotechnological risks that require regulation. First, it believes nanomaterials could threaten human health and the natural environment. Second, it worries about the danger of uncontrollable self-replication by nanotech automatons. Finally, it fears the consequences of dramatic socioeconomic change.

The ETC Group commissioned a review of the scientific literature on the toxicology of "ultrafine" particles from British toxicologist Vyvyan Howard. (One can be forgiven for suspecting that it selected Howard because he is a vigorous campaigner against crop biotechnology.) After surveying 27 scientific studies that looked at the health effects of ultrafine particles, many of which focused on particulate air pollution, Howard concluded that various relatively harmless substances may become toxic when transformed into nanoparticles because of "the increased reactivity associated with very small size." After all, one of the qualities that researchers prize in nanoparticles is their increased reactivity. Based on this conclusion, the ETC Group wants to shut down all research on nanomaterials, at least until laboratories design "best practices" for handling them. It also wants a five-year moratorium on the commercialization of any nanomaterial products.

The effects of loose nanoparticles do need to be (and are being) studied. But contrary to the ETC Group's implication, heedless scientists and greedy corporations are not about to flood our bodies and the world with dangerously toxic nanoparticles. It's important to recognize that people already breathe in lots of nanoparticles. Humanity began manufacturing them as soon as we tamed fire. And as Ken Lyon, director of business development at Altair Nanomaterials, notes, "Nature made nanomaterials a long time before mankind started making them on purpose. There are lots of natural sources of nanomaterials -- salt particles from ocean storms, for example. They are all around us. Enzymes and viruses are all in the nanosphere."

Gunter Oberdorster, a professor of environmental medicine at Cornell University, has noted that "ultrafine particles [smaller than 20 nanometers] have the highest number concentration but the lowest mass concentration, a major anthropogenic ETC source being emissions of internal combustion engines," especially diesel engines. Matter Engineering, a Swiss firm specializing in the measurement of ambient nanoparticles, notes that each cubic centimeter of urban air already contains about 10,000 nanoparticles. Natural sources of nanoparticles include volcanic activity, forest fires, and sea spray. Of course, breathing particulates is not good for your lungs; studies show that air pollution increases the risk of lung and cardiovascular diseases. But there's little reason to believe that manufactured nanoparticles raise special concerns in this connection.

Keep in mind that most manufactured nanoparticles are not going to be running around loose. Altair's Ken Lyon notes, "Nanomaterials are usually incorporated into something else -- ceramic coatings, glass, plastics. By the time it's in a coating, it no longer exists as a nanomaterial." Altair makes titanium dioxide nanoparticles that are incorporated into products such as self-cleaning glass and UV-blocking sunscreens. Titanium dioxide is considered to be so nontoxic that it is approved for use in food, generally up to 1 percent of the product's final weight. A 1998 Environmental Protection Agency risk assessment concluded, "Based on its low toxicity, there is reasonable certainty that no harm will result from aggregate exposure to the U.S. population, including infants and children, to residues of titanium dioxide." Lyon notes, "We know what happens to people who ingest titanium dioxide: Their poop turns white."

Pat Collins of Hyperion Catalysis International, which makes multiwall carbon nanotubes for use in products such as automobile plastic composites, points out: "We compound our carbon nanotubes into plastics. You can sand, grind, slice, and dice, and the nanotubes won't get liberated. We've looked for free nanotubes and have never found them. The plastic particles in which the nanotubes are incorporated are much bigger than the nanotubes themselves."

Asked about the ETC Group's proposed moratorium, Collins says: "I don't want to get into a public pissing match, but I don't think it's a valid concern. What they're talking about is all very hypothetical risks. There's no risk using nanotubes in plastics." Lyon also rejects the call for a moratorium but agrees that "the industry has an obligation to be cautious as we develop new products." He says "adequate steps are being taken to make sure that people exposed to the stuff are safe."

We don't have to just take the nanotech industry's word for it. The National Science Foundation established a Center for Biological and Environmental Nanotechnology (CBEN) at Rice University; its mission is to evaluate the health and environmental effects of new nanomaterials. Kevin Ausman, CBEN's executive director, says the ETC Group's concerns are "based largely on speculation and hypotheses." About the proposed moratorium, Ausman says: "I don't think a ban is reasonable. It's such a broad class of materials; if we have to wait until everything is proved absolutely safe, we're never going to develop nanomaterials. What you need is a parallel development of the application of nanomaterials and impact assessment at the same time." In other words, proceed with caution.

Paul Burrows, manager of the Nanoscience Initiative at the federal government's Pacific Northwest National Laboratory, says of nanomaterials: "I wouldn't eat them. We should treat nanoparticles like we would any other chemical." Burrows notes that our current technologies contain a lot of materials that would be hazardous if they didn't stay put. "Your cell phones contain chips with gallium arsenide in them," he says. "Arsenic isn't good for you."

Ausman notes that most particulate inhalation problems, such as black lung or silicosis, "result from exposures over a long time and at high levels; occasional exposures for short periods would not be dangerous." He expects the same would be true for nanomaterials such as carbon nanotubes. Ausman also thinks the laboratory "best practices" regime envisioned by the ETC Group is unnecessary. "The standard precautions in labs and manufacturing are sufficient to protect people in labs and factories," he says. "They are part of a research community used to handling hazardous materials."

The ETC Group is fond of quoting CBEN Director Vicki Colvin's estimate that only $500,000 has been spent so far on evaluating the health and environmental risks of nanotechnology. An irritated Mihail Roco dismisses Colvin's claim as the grandstanding of "a younger researcher who is trying to raise money for her center." Colvin's center is spending $500,000 on environmental research, Roco says, but the National Nanotechnology Initiative is spending about $50 million researching the environmental and social issues raised by nanotechnology. In any case, he says, "It would be unwise to spend 50 percent of nanotech research money thinking about the societal and environmental issues of products that will not ultimately be developed." Or as Ausman puts it, "I am not worried that in the near term nanomaterials are going to cause any serious problems," and "there's a lot of lead time before there's a lot of stuff out there."

Gray Goo

The second nanotechnology risk that worries ETC Group activists is runaway self-replication. Mooney points to a scenario suggested by Eric Drexler himself in *The Engines of Creation*: Self-replicating nanobots get out of control and spread exponentially across the landscape, destroying everything in their path by converting it into copies of themselves. In this scenario, the biosphere is transformed by rampaging nanobots into "gray goo."

But according to Nobelist Richard Smalley, "Self-replicating nanorobots like those envisioned by Eric Drexler are simply impossible to make." Mihail Roco likewise dismisses such nanobots as "sci fi," insisting there is "common agreement among scientists that they cannot exist."

Drexler replies, reasonably enough, that we know nanoassembly is possible because that's what living things do. Cells, using little machines such as ribosomes, mitochondria, and enzymes, precisely position molecules, store and access assembly instructions, and produce energy. Some have quipped that biology is nanotechnology that works.

As that analogy suggests, there is a close affinity between nanotechnology and biotechnology. "The separation between nanotechnology and biotechnology is almost nonexistent," said Minoo Dastoor, a senior adviser in the National Aeronautics and Space Administration's Office of Aerospace Technology, at the National Nanotechnology Initiative's conference in April. For future missions, NASA needs machines that are resilient, evolvable, self-sufficient, ultra-efficient, and autonomous. "Biology seems to be able to do all these things very elegantly and efficiently," noted Dastoor. "The wet world of biology and the dry world of nanotechnology will have to live side by side and merge."

The fact is that no one has yet definitively shown that Drexler's vision of molecular manufacturing using nanoassemblers is impossible. So let's suppose Smalley and Roco are wrong, and such nanobots are possible. How dangerous would self-replicating nanobots be? One of the ironies of the debate over regulation of nanotechnology is that it was nanotech boosters like Drexler who first worried about such risks. To address potential dangers such as the uncontrolled self-replication envisioned in his gray goo scenario, Drexler and others founded the Foresight Institute in 1989. Over the years, Foresight devised a set of guidelines aimed at preventing mishaps like a gray goo breakout.

Among other things, the Foresight guidelines propose that nanotech replicators "must not be capable of replication in a natural, uncontrolled environment." This could be accomplished, the guidelines suggest, by designing devices so that they have an "absolute dependence on a single artificial fuel source or artificial 'vitamins' that don't exist in any natural environment." So if some replicators should get away, they would simply run down when they ran out of fuel. Another proposal is that self-replicating nanotech devices be "dependent on broadcast transmissions for replication or in some cases operation." That would put human operators in complete control of the circumstances under which nanotech devices could replicate. One other sensible proposal is that devices be programmed with termination dates. Like senescent cells in the human body, such devices would stop working and self-destruct when their time was up.

"The moratorium is not a new proposal," says Foresight Institute President Christine Peterson. "Eric Drexler considered that idea a long time ago in *The Engines of Creation*
and dismissed it as not a safe option. With a moratorium, we, the good guys, are going to be sitting on our hands. It's very risky to let the bad guys be the ones developing the technology. To do arms control on nanotechnology, you'd better have better nanotechnology than the bad guys."

Software entrepreneur Ray Kurzweil is confident that nanotech defenses against uncontrolled replication will be stronger than the abilities to replicate. Citing our current ability to reduce computer viruses to nuisances, Kurzweil argues that we will be even more vigilant against a technology that could kill if uncontrolled.

Smalley suggests we can learn how to control nanotech by looking at biology. The natural world is filled with self-replicating systems. In a sense, living things are "green goo." We already successfully defend ourselves against all kinds of self-replicating organisms that try to kill us, such as cholera, malaria, and typhoid. "What do we do about biological systems right now?" says Smalley. "I don't see that it's any different from biotechnology. We can make bacteria and viruses that have never existed before, and we'll handle [nanobots] the same way."

Nanotech theorist Robert Freitas has written a study, "Some Limits to Global Ecophagy by Biovorous Nano-replicators With Public Policy Recommendations," which concludes that all "scenarios examined appear to permit early detection by vigilant monitoring, thus enabling rapid deployment of effective defensive instrumentalities." Frei-tas persuasively argues that dangerous self-replicating nanobots could not emerge from laboratory accidents but would have to be made on purpose using very sophisticated technologies that would take years to develop.

Magic Monopolies

Nanofactories would be magic boxes that could produce whatever a person desired. A world of nanotech abundance would be highly disruptive: If material needs could be satisfied at the touch of a button, who would have to work? Who would own the nanofactories? How would people pay for items produced by nanotechnology? If nanotech works, big changes are in store.

Not surprisingly, the ETC Group's worries in this connection are chiefly egalitarian, specifically that nanotechnology will increase the power of corporations and governments while further immiserating the poor. Yet the new technologies that have been developed during the last two centuries -- antibiotics, electricity, telephony -- have greatly benefited billions, and the main economic problem in the world is that billions are still too poor to gain access to them. Furthermore, new technologies tend to be safer than the ones they replace.

Let's consider a couple of dystopic nanotech visions outlined by University of Saskatchewan sociologist Michael Mehta, an ETC Group sympathizer: "nanopanopticism" and "nanomercantilism."

The philosopher Jeremy Bentham imagined an architecture for a prison he called the Panopticon. In Bentham's prison all the cells are open to surveillance by a single guard hidden in a tower at the center. The idea is that prisoners would behave themselves because they could never be sure they were not being watched. It doesn't take much imagination to see how nanotechnology could shrink video cameras and microphones while vastly expanding the ability to record and store information. In fact, this trend seems unavoidable in the long run. Such technology solely in the hands of governments and corporations would be oppressive.

Mehta, of course, recommends the creation of new regulatory agencies to control nanotechnology and the enactment of new privacy laws to protect against the advent of nanopanopticism. In his 1998 book *The Transparent Society: Will Technology Force Us to Choose Between Privacy and Freedom?*, science fiction writer and futurist David Brin suggests another way to handle intrusive surveillance: make sure the watchers are watched. Brin persuasively argues that if spies know they are likely to be observed, they will be more restrained. Along with invisible spy devices, nanotechnology will give us tiny sensors that tell people when they're under surveillance. Such spy countermeasures also might inhibit or destroy surveillance devices that approach too closely. There is an added benefit for those who worry that someone might abuse nanotechnology. In a truly transparent society, would-be terrorists who try to build dangerous replicators would always know someone could be monitoring them. In other words, nanopanopticism would deter misbehavior rather than encourage it.

Mehta's other concern is nanomercantilism. He suggests that once a country developed the capability for molecular manufacturing using nanoassemblers, it would lose its incentive to trade. There would be no need to trade raw materials because the feedstocks for nanofactories would be derived from ubiquitous substances such as dirt and air.

In another scenario, Mehta suggests that a nation with nanofactories would become so powerful that it could reduce the rest of the world to the status of colonies. Perhaps the countries or companies that develop assembler technology would build assemblers in other countries and sell licenses to manufacture various objects. Such a world would be a true information economy, with trade consisting chiefly of blueprints for products. Or countries might not want to give assemblers to other countries, in which case assembler products might be modeled on software that works only when a license fee is paid. If the licenses were not renewed, the products would stop working or fall apart.

Like the ETC Group, Mehta evidently believes the creators of assembler technology will want to manufacture artificial scarcities to keep or expand their power or to maintain certain social institutions. Perhaps so. But once it is known that building assemblers is possible, other countries and companies no doubt will embark on crash programs to create their own nanofactories. Assuming that nanofactories really can provide people with anything they need and want, why would anyone care to block access to them by others? To the extent that competition and status seeking are inherent in human nature, those drives in a world of nanotech abundance will have to be satisfied in new ways.

Dangerous Caution

To address the social and economic effects of nanotechnology, the ETC Group is proposing a sweeping international effort to regulate and control its development. "Extreme care should be taken that, unlike with biotech, society does not lose control of this technology," warns Mooney. For the ETC Group, raising health and environmental concerns about nanomaterials and nanobots is mainly a delaying tactic. "The biggest concern really is that with a technology as powerful as this one, society has a role in deciding how it can and will be used," says Mooney. "This is going to have a profound effect on people's lives. Let people know that their jobs are going to be taken away."

In an April report on nanotechnology, the ETC Group declares: "The international community must begin work on a legally binding mechanism to govern atomtechnology, based on the Precautionary Principle, one that will look beyond laboratory research to consider the wider health, socioeconomic and environmental implications of nanoscale technologies....This protocol should be embedded in one or more of the relevant United Nations agencies....Ultimately, ETC Group believes that the international regulations for atomtechnology should be incorporated under a new International Convention for the Evaluation of New Technologies (ICENT)."

The framework for ICENT's evaluation of new technologies would be the Precautionary Principle. As the ETC Group explains, "The Precautionary Principle says that governments have a responsibility to take preventive action to avoid harm to human health or the environment, even before scientific certainty of the harm has been established. Under the Precautionary Principle it is the proponent of a new technology, rather than the public, that bears the burden of proof." Greenpeace's Douglas Parr also advocates using the Precautionary Principle to regulate the development of nanotechnology.

The Precautionary Principle can be summarized as "never do anything for the first time." (See "Precautionary Tale," April 1999.) The chief problem with the Precautionary Principle is that it encourages the natural conservatism of our species. People far more easily imagine the harms new developments might bring than the benefits. But history clearly demonstrates that the benefits of modern technology have far outweighed the harms. "Basically, people who support the strong Precautionary Principle say, 'We don't care if we throw the baby out with the bathwater,'" says the Foresight Institute's Peterson. "They don't want any risks, so they are willing to forgo the benefits."

The ETC Group also wants nanotechnology regulation to be "transparent, democratic and involve those who are potentially adversely affected by new technologies." That last proviso might have given whale oil entrepreneurs the power to veto electric lighting or allowed mimeograph machine manufacturers to nix photocopiers. When asked about how Michael Faraday, the inventor of the electric motor, might have fared under an ICENT evaluation, Mooney doesn't blink. It would "have been great if we had had a societal discussion about the impact of electricity," he says. "Someone might have said, 'This is going to be hell on horses.'"

An effective ICENT would have an effect opposite from the one the ETC Group imagines. By forbidding the spread of a technology that could end hunger, homelessness, and pollution, ICENT would in effect force poor people to remain in their traditional menial jobs while preserving corporate profits.

Mehta agrees with the ETC Group. He points to the automobile as a transformative and disruptive technology. "In the late 1800s, 85 to 90 percent of vehicles were electric," he says. "If we had had a regulatory authority that could have made the decision to go with electric instead of internal combustion engines and the power to enforce it, we would be in a different world and would have avoided a lot of later problems like urban sprawl....In 1900 people didn't have a sensitivity to social issues or a well-developed social science. We can't risk the same thing with nanotechnology, which could accelerate social injustice."

It's not clear on what basis such an authority would have opted for electric cars over internal combustion engines. Electric cars were and are more expensive than cars fueled by gasoline. If only electric cars had been permitted, we might be living in a world where people were much poorer, more crowded, and suffering from heavy metal poisoning from lead/acid batteries. Ironically, it may well be nanotechnology that finally ushers in the age of affordable electric automobiles by making possible more-efficient batteries or better fuel cells.

ICENT Assent

The ETC Group's ICENT proposal is starting to be taken seriously. Committees of both the European Parliament and the United Nations' Food and Agriculture Organization have called for the adoption of an ICENT. "ICENT would have the power to conduct analyses of the economic impacts, the effects on labor, on restructuring society," says Mooney. "ICENT would examine all scientific, economic and social issues of any new technology." Mooney argues that ICENT would improve our ability to forecast the effects of new technologies.

The track record for social, economic, and technological forecasting by experts is not very encouraging. Consider the notorious 1972 Club of Rome study *The Limits to Growth* and President Carter's *Global 2000* report, both of which predicted that humanity would run out of a wide variety of natural resources by now. Or take Stanford University biologist Paul Ehrlich's prediction that hundreds of millions of people would starve to death in massive famines in the 1970s. Such forecasts are not harmless. The predictions in the 1970s that the world would soon run out of oil, for instance, resulted in the creation of the expensive and polluting Synfuels program.

Corporations aren't any better at forecasting than government agencies. In 1876 a Western Union internal memo concluded, "This 'telephone' has too many shortcomings to be seriously considered as a means of communication. The device is inherently of no value to us." In 1943 IBM CEO Thomas Watson famously predicted there would be a global demand for perhaps five computers.

Over the short term, nanotechnology will seem less odd than the telephone or the computer did. It will simply be incorporated into products that we already know how to use: computers, cameras, clothing, cars. It will make them function better and more cheaply. By contrast, a full-fledged nanotechnology, especially if molecular assemblers can be built, will disrupt all kinds of social and economic processes. Yet there is no reason to believe that humanity will be unable to cope with what is coming.

As for unintended consequences, someday something will go wrong with nanotechnology, as it has with electricity, cars, and computers. But we shouldn't deny ourselves the benefits of a new technology just because we cannot foresee every consequence. We should proceed by trial and error and ameliorate problems as they arise. That's how the dramatic progress humanity has seen during the last two centuries was accomplished. If an ICENT had existed in the 19th century, we probably would still be riding horses, using candles for lighting, cooking on wood stoves, and gulping whiskey for anesthesia.

Mooney comes close to celebrating the emancipating possibilities offered by the new technologies he fears. Yet he seems almost wistful for a time when he and many others believed ecological and economic collapse was imminent. "We have lived so long by the assumptions of *The Limits to Growth,*
it is hard to contemplate alternative possibilities," he writes. "If nanotech does work, we might console ourselves with the knowledge that we were not really wrong all this time, it is just that *The Limits to Growth* have been postponed a few billion years....If nanotechnology is commercialized successfully, Armageddon may have to be put on the back burner."

Armageddon may indeed be postponed indefinitely, but only if, with due caution, we leave human genius free to harvest the fruits of technological progress.

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