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.   THE REVOLUTION, PT. 1   .
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THE REVOLUTION, PT. 1

A revolution is occurring in science and technology -- a revolution so profound that it is difficult to comprehend. There has been hardly any discussion of these events in the mass media, so this revolution is occurring entirely without public discussion or debate.

The revolution does not stem from computers or biotechnology or cognitive science or nanotechnology. It stems from the convergence of these four technologies into something that the National Science Foundation is calling NBIC (nano-bio-info-cogno) science,[1] which critics are calling The Little BANG (bits, atoms, neurons, and genes)[2].

In this series, we will explore the meaning of this profound revolution from the viewpoint of the environment, human health, and the future of democratic societies. We begin by describing the least well-known of these four technologies -- nanotechnology, or nanotech for short.

Nanotech is the science and engineering of materials and machines so small that they are invisible to the naked eye. Their tiny size is their advantage. When President Clinton announced the National Nanotechnology Initiative (NNI) in 2000 he spoke of a computer no bigger than a sugar cube holding the contents of the Library of Congress, sensors so small they could motor through your arteries to detect cancers at an early stage, and exotic new materials 10 times as strong as steel but a fraction of the weight.

The National Nanotech Initiative (NNI) is located inside the National Science Foundation (NSF), the nation's most prestigious scientific organization, and the Clinton budget earmarked a hefty $497 million for the NNI in 2000, which President Bush raised to $604 million in 2002 and $710 million in 2003.[3]

Nanotech is now the third largest federal research project, just below the war on cancer and the star wars missile defense shield. (See the NNI web site at www.nano.gov.) The largest federal research subsidy for nanotech ($221 million) goes to the NSF itself and the second-largest ($201 million) to the Department of Defense.[3]

Nanotech is named for the nanometer, a unit of measure, a billionth of a meter, one one-thousandth of a micrometer. The Oxford English Dictionary defines nanotechnology as "the branch of technology that deals with dimensions and tolerances of less than 100 nanometres, esp. the manipulation of individual atoms and molecules." Nanotech deals with goings on in the world where a typical grain of sand is huge (a million nanometers in diameter). A human hair is 200,000 nanometers thick. A red blood cell spans 10,000 nanometers. A virus measures 100 nanometers across, and the smallest atom (hydrogen) spans 0.1 nanometers.

At the nano scale, familiar materials act in unexpected and unpredictable ways. At the nano scale, there may be changes in a substance's elasticity, strength, and color, its tolerance of temperature and pressure and its ability to conduct electricity. So nano scientists and engineers are discovering new laws of behavior along with new commercial possibilities. [4, pg. 48]

For example, reduced to nano particles, some metals become translucent, like zinc oxide which is normally white but becomes invisible when nano-ized. [5, pg. 35] Nano zinc oxide is already available commercially in new sunscreen ointments, which are needed now more than ever because CFCs, the chemicals that gave us air conditioning, damaged the Earth's ozone shield, increasing the dangers of sunburn and skin cancer, especially for white people.

At the nano scale, tiny cantilevers can detect the presence of minuscule amounts of pollution in water. Instead of measuring pollution in parts per million or parts per billion, nano cantilevers can measure parts per quadrillion (yes, 10 raised to the power of negative 15), an astonishing sensitivity. The NNI is now developing nano-sensors, hoping they can help us clean up the billions of tons of toxic wastes created by the 20th century's ongoing experiment with better living through chemistry.

Of course chemists have been manipulating atoms and molecules for more than a century, but PRECISE manipulation at the nanoscale is really very new. Modern nanotech was made possible by the 1981 invention of the scanning tunnelling microscope (STM) which allows scientists to "click and drag" individual atoms and thus build new things in new ways. For their work on the STM, Gerd Binnig and Heinrich Rohrer at the IBM Research Laboratory in Zurich received the Nobel prize for physics in 1986. [6, pg. 44]

In 1990, two scientists at IBM's Almaden Research Laboratory in San Jose, Cal. demonstrated nano manipulation with an STM when they lined up 35 individual xenon atoms to spell out "IBM." This seemingly-trivial exercise demonstrated the first steps toward "bottom-up construction," the intentional arrangement of individual atoms into useful substances and machines. In May of this year, Japanese scientists demonstrated another breakthrough -- they moved single atoms precisely, using strictly mechanical (non-electric) techniques.[7]

Typical construction today -- even construction of the tiniest computer circuit -- relies on "top-down" techniques, machining or etching products out of blocks of raw material. For example, a common technique for making a transistor begins with a chunk of silicon, which is etched to remove unwanted material, leaving behind a sculpted circuit. This "top-down" method of construction gives the desired product plus waste residues. Using bottom-up construction, atoms are arranged -- or in ideal cases they self-assemble -- into the desired configuration with nothing left over, no waste. Thus bottom-up construction offers the possibility of waste-free manufacturing.

Bottom-up construction techniques are now being used to manufacture the surfaces of some computer disks, and to make "quantum dots" for labeling and identifying particular genes or other molecules, improving on traditional dyes. In principle, bottom-up construction could assemble more complicated structures, including perhaps nano scale robots, or nanobots.

Nanobots lie in the future (or strictly in science fiction, depending on who you believe), but nano-scale particles of carbon such as nanotubes or buckyballs, named after Buckminster Fuller, have already found their way into commercial products.

According to the Etc Group, which follows nanotech developments carefully, an estimated 140 companies are now producing nanoparticles in powders, sprays, and coatings that are being used in a variety of products, including sunscreens, automobile parts, tennis rackets, scratch-proof eye glasses, stain-repellent fabrics, self-cleaning windows, and more.[8, pg. 2] Mitsubishi Chemical in Japan has reportedly begun construction of a plant to manufacture nanotubes at the rate of 120 tons per year, with plans to increase output to 1500 tons per year by 2007.[9]

The manufacture and use of nanoparticles is entirely unregulated in the U.S. and elsewhere. Furthermore, industry has developed no standard protocols for handling nanoparticles safely during manufacture, use, or disposal. The environmental and human health effects of nanoparticles are untested and unknown.

The April 11, 2003 edition of Science magazine reported the first nanoparticle experiments. When mice were exposed to nanotubes (which have a diameter of about 10 nanometers), the nanotubes lodged in the alveoli, the deepest portions of the mice's lungs and triggered the formation of granulomas, "a significant sign of toxicity," according to the researcher who conducted the experiment, Chiu-Wing Lam at NASA's Johnson Space Flight Center in Houston.[10]

Carbon nanotubes were not the only nanomaterials to raise red flags. Toxicologist Gunter Oberdorster at the University of Rochester School of Medicine exposed rats to 20-nanometer particles of polytetrafluoroethylene, or PTFE, and all the rats died within 4 hours, according to Science. Rats exposed to 130-nanometer particles of PTFE showed no effects. Oberdorster noted that rats' macrophage cells, which normally clear junk out of the lungs, had trouble clearing the 20-nanometer particles.[10] We will explore this subject in more detail later in this series.

Nanotechnologists have no doubt that nanomachines lie in our future. Only their true nature remains in question. At least one experimental nanomachine has already been built. Powered by the energy of adenosine triphosphate (the energy source in human cells) and standing only 11 nanometers tall, this nano motor can rotate a metallic rod (750 nanometers long, 150 nanometers thick) at 8 rpm. [6, pg. 47] With the recent addition of a chemical switch, the nano-motor can be turned on and off at will.[11] Such a machine serves no useful purpose today, except to demonstrate possibilities and fuel dreams.

A major controversy over the future of nanomachines has been simmering since 1990 when K. Eric Drexler published Engines of Creation, in which he envisioned a household appliance something like a microwave oven using bottom-up construction to make anything you might want -- a computer chip, a Rolex watch, or a carrot. The key to Drexler's futuristic dream is what he calls an "assembler" operating under software control -- a nanobot programmed to assemble atoms into anything you can imagine, including copies of itself. [12, pg. 75]

Today, more than a decade after starting the nanobot debate, Drexler brushes aside scornful critiques by Nobel laureates and maintains his faith in the future of nanobot assemblers. Writing in Scientific American in September 2001, he said,

"Inspired by molecular biology, studies of advanced nanotechnologies have focused on bottom-up construction, in which molecular machines assemble molecular building blocks to form products, including new molecular machines. Biology shows us that molecular machine systems and their products can be made cheaply and in vast quantities. [12, pg. 74]

Eventually, Drexler says, these cheap, plentiful machines will improve and extend life for everyone:

"Medical nanobots are envisioned that could destroy viruses and cancer cells, repair damaged structures, remove accumulated wastes from the brain and bring the body back to a state of youthful health." [12, p. 74]

Furthermore, Drexler says, programmable nanobots would save the natural environment as well:

"[W]hen a production process maintains control of each atom, there is no reason to dump toxic leftovers into the air or water. Improved manufacturing could also drive down the cost of solar cells and energy storage systems, cutting demand for coal and petroleum, further reducing pollution. Such advances raise hopes that those in the developing world will be able to reach First World living standards without causing environmental disaster." [12, pg. 74]

The National Science Foundation shares most of Drexler's utopian vision. Dr. Mihail Roco -- chief architect of the NNI -- says nanotech will bring us a "new renaissance in our understanding of nature, means for improving human performance, and a new industrial revolution in coming decades."

NSF believes the nano revolution is not far off. Roco predicts that "Nanotechnology will fundamentally transform science, technology, and society. In 10 to 20 years, a significant proportion of industrial production, healthcare practice, and environmental management will be changed by the new technology." [13, p. 19]

Roco says nanotech will give us "highly efficient manufacturing of all human made objects," leading to "long term sustainable development." In medicine, he says, nanotech will "revolutionize diagnostics and therapeutics." Indeed, Roco envisions a global society entirely transformed by nanotech: "The effect of nanotechnologies on the health, wealth, and standard of living for people in this century could be at least as significant as the combined influences of microelectronics, medical imaging, computer-aided engineering, and man-made polymers [plastics] developed in the last century."[13, pg. 2]

Where the NSF and Drexler part company is at nanotech's dark side. Where the NSF sees nanotech creating a few problems that are relatively minor and entirely manageable, Drexler sees the possibility of global disaster.

Drexler warned in 1990 that the dark side of nanomachines might include a self-replicating assembler that goes haywire (by accident or by malevolent design) and starts replicating itself incessantly, filling up the planet with "grey goo," a scenario that has come to symbolize the dangers of nanotech.

The National Science Foundation does not categorically deny the possibility of self-replicating assemblers, saying only that "A number of very serious technical challenges would have to be overcome before it would be possible to create nanoscale machines that could reproduce themselves in the natural environment. Some of these challenges appear to be insurmountable with respect to chemistry and physics principles, and it may be technically impossible to create self-reproducing mechanical nanoscale robots of the sort that some visionaries have imagined." [13, pg. 11]

Despite his grey goo nightmare, Drexler remains an avid and optimistic proponent of nanotech. He argues that the grey goo problem can be avoided by thoughtful humans. His Foresight Institute has even published a set of "safety rules" to minimize abuses of nanotech (www.foresight.org). Still, Drexler wrote in Scientific American in 2001, "[T]he challenge of preventing abuse -- the exploitation of this technology by aggressive governments, terrorist groups or even individuals for their own purposes -- still looms large." [12, p. 75]

[To be continued.]

[1] Mihail C. Roco and William Sims Bainbridge, editors, Converging Technologies for Improving Human Performance (Washington, D.C.: National Science Foundation, June, 2002. http://rachel.org/library/getfile.cfm?ID=208

[2] "The Little BANG Theory," ETC Group Communique #78 (March/April 2003). Available on the web at http://www.etcgroup.org/documents/comBANG2003.pdf . And see The Etc Group, The Big Down (Winnipeg, Manitoba, Canada, January 2003). Available at http://rachel.org/library/getfile.cfm?ID=210 . The Etc Group is the primary source of information about nanotechnology for non-governmental organizations. See http://www.etcgroup.org and make sure to read their publication called Communique at http://www.etcgroup.org/search.asp?type=communique . To get a sense of the "gold rush" mentality that grips the nanotech industry today, check in daily at http://nanotech-now.com/ .

[3] Alexander Huw Arnall, Future Technologies, Today's Choices (London, England: Greenpeace Environmental Trust, July 2003). Available on the web at http://rachel.org/library/getfile.cfm?ID=207 .

[4] Michael Roukes, "Plenty of Room Indeed," Scientific American Vol. 285, No. 3 (September 2001), pgs. 48-57.

[5] Gary Stix, "Little Big Science," Scientific American Vol. 285, No. 3 (September 2001), pgs. 32-37.

[6] George M. Whitesides and J. Christopher Love, "The Art of Building Small," Scientific American Vol. 285, No. 3 (September 2001), pgs. 39-47.

[7] Lea Winerman, "How to Grab an Atom," Physical Review Focus May 2, 2003, available at http://focus.aps.org/story/v11/st19 , reporting on Noriaki Oyabu, Oscar Custance, Insook Yi, Yasuhiro Sugawara, and Seizo Morita, "Mechanical vertical manipulation of selected single atoms by soft nanoindentation using a near contact atomic force microscope," Physical Review Letters Vol. 90, No. 176102 (May 2, 2003), an abstract of which is available

at
http://ojps.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=PRLTAO000090000017176102000001&idtype=cvips&gifs=Yes .

[8] "Green Goo: Nanobiotechnology Comes Alive!" Etc Group Communique #77 (Jan./Feb. 2003), pg. 2. Available at http://www.etcgroup.org/documents/comm_greengoo77.pdf .

[9] Jayne Fried, "Japan Sees Nanotech as Key to rebuilding Its Economy," Small Times Jan. 7, 2002, pgs. unknown. Available at http://rachel.org/library/getfile.cfm?ID=217 .

[10] Robert F. Service, "Nanomaterials Show Signs of Toxicity" Science Vol. 300 (April 11, 2003), pg. 243. Available at http://rachel.org/library/getfile.cfm?ID=224 .

[11] Philip Ball, "Molecular Wheel Gets a Brake," Nature News Service Oct. 30, 2002, reporting on Haiqing Liu and others, "Control of a biomolecular motor-powered nanodevice with an engineered chemical switch," Nature Materials Vol. 1 (2002), pgs. 173-177.

[12] K. Eric Drexler, "Machine-Phase Nanotechnology," Scientific American Vol. 285, No. 3 (September 2001), pgs. 74-75.

[13] Mihail C. Roco and William Sims Bainbridge, Societal Implications of Nanoscience and Nanotechnology (Washington, D.C.: National Science Foundation, March 2001). Available at http://rachel.org/library/getfile.cfm?ID=217 .

=======================Electronic Edition========================
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THE REVOLUTION, PT. 2

In this series we are describing an on-rushing revolution in science and engineering, created by the convergence of four technologies: biotechnology, information science, cognitive science, and nanotechnology (nanotech). The National Science Foundation (NSF) refers to all this as nano-bio-info-cogno science, or NBIC for short.[1,2] See Rachel's #772.

Here we continue describing the newest of these four technologies, nanotech, which is the science and engineering of materials measuring less than 100 nanometers (100 billionths of a meter) in size, far smaller than the eye can see.

The U.S. government created a National Nanotech Initiative just 3 years ago, which now funds nanotech research to the tune of $700 million per year, about a third of that going to the Pentagon. NSF predicts that nanotechnology will be a trillion-dollar industry in the U.S. by 2015, just 12 years from now.[3] This revolution is upon us, though most of us haven't a clue it is happening, or even what it is.

In newspapers, the "big debate" about nanotech revolves around a theory known as "gray goo," proposed a few years ago by nanotech enthusiast K. Eric Drexler.[4] Drexler suggested that the future of nanotech lies with nano-sized robots, which, under software control, will manufacture useful things, including copies of themselves. Drexler named these nanobots "assemblers," and he suggested that vast armies of assemblers under software control would provide the basis for a household appliance that could manufacture anything it was instructed to manufacture -- a Rolex watch or a filet mignon, essentially fulfilling all of humanity's needs and wants, dirt cheap.

Drexler also calculated that, if one assembler took 1000 seconds to make a copy of itself, then self-replicating assemblers, gone haywire, could cover planet earth with a gray goo of assemblers within 72 hours, quickly ending life as we know it. There is even a fancy scientific name for the gray goo hypothesis, "global ecophagy." Ecophagy means "earth-eating."

Drexler's self-replicating assembler seems far-fetched at best. Several Nobel prize winners have gone out of their way to debunk Drexler's dream machine, saying it can't work because it violates known laws of chemistry and physics.[5] However, no one claims that all the laws of physics or chemistry are fully understood, so there's always wiggle room for speculation.

Despite critiques of the gray goo scenario from prestigious quarters, the federally-funded nanotech research community has been unable to dispel the specter of a world badly damaged, if not destroyed, by nanotech. No one seems to doubt that nanotech science and engineering hold great promise for churning the economy through industrial innovation and -- not incidentally -- for the accumulation of vast wealth by successful entrepreneurs. But nagging doubts about the dark side persist, partly fueled by the factual history of earlier government-subsidized technologies.

** Nuclear-powered electric plants were promised to produce "electricity too cheap to meter,"[6] but in fact they produced expensive electricity, the ever-present threat of catastrophic accidents, continuous low-level exposure of workers and neighbors to low levels of radioactivity at every point in the nuclear fuel cycle, an extremely long-lived (and so-far-unsolved) problem of radioactive wastes, and the most intractable problem of all -- the threat of use of nuclear bombs by terrorists, rogue states, or by any industrialized state that finds itself facing too many enemies and with too few soldiers to spare.[7] No one has ever proposed a realistic solution to the spread of nuclear weapons into the hands of Iranians, Pakistanis, North Koreans, and who knows who else? Behind all these potential bombs lies the technical training to make nuclear power plants, training now available at most large universities. If governments had refused to subsidize nuclear power starting in 1950, our modern problems might seem far more manageable than they do today.

** Petroleum, which gave us plastics, pesticides, and the private automobile, is now warming the planet, producing costly and destructive changes in Earth's climate including extreme droughts, floods, tornadoes, monsoons, and hurricanes.[8] Climate change, in turn, is expanding the geographic range of human diseases such as cholera, malaria, yellow fever and dengue fever. [See Rachel's #466.] Leaded gasoline alone created a phenomenally-large, intergenerational public health problem, reducing the IQs of three generations of urban dwellers, promoting attention deficits, school dropout, and violent behavior, and increasing heart disease and cancer.[9] Furthermore, petroleum-based chemistry produced its own set of nasty surprises, including large numbers of childhood cancers, immune system disorders, central nervous system diseases, attention deficits, birth defects, and injuries to the reproductive systems of men, women, and children.[10] Every week new studies elucidate the enormous public-health costs of petro-chemical technologies.[11] In this instance, huge government subsidies made possible the rapid introduction of ill-considered innovations (such as many products of chlorine chemistry),[12] and shielded the corporate sector from liability for reckless decisions.

** Agricultural antibiotics gave us plump chickens, fat cattle, and oversized pigs, but they also helped create antibiotic-resistant forms of typhoid fever, cholera, meningitis, pneumonia, gonorrhea, syphilis, salmonella, streptococcal infections ("strep throat," impetigo, scarlet fever, and rheumatic fever), staphylococcus ("staph") infections (serious blood infections common in hospitals); shigella, dysentery, and even tuberculosis. In 1992, antibiotic-resistant bacteria killed at least 13,300 people in the U.S., according to the federal Centers for Disease Control, and cost the economy an estimated $30 billion (not including pain and suffering).[13] Federal eagerness to subsidize the corporate use of antibiotics on factory farms contributed heedlessly and needlessly to these problems.

** Agricultural biotechnology was supposed to develop under precise laboratory control, reduce the use of harmful pesticides, and "feed the world." In reality, even though the commercial use of biotech food is less than a decade old, biotech crops have already increased, not decreased, the need for dangerous pesticides.[Rachel's #686] Furthermore, novel genes, held under the strictest possible governmental controls, have on several occasions escaped into plants and foods where the public had been told they would never be found.[14] Modern controls on biotechnology have proven to be a dramatic failure. Meanwhile world hunger marches on (principally because of poor distribution networks, and poverty which prevents people from purchasing available food.)

For those who care to look, there seems to be a five-step pattern in this recent history of government-subsidized technologies.

(1) It begins with a corporate decision to commandeer taxpayer funds to support the development of a new technology, after which government provides a long stream of subsidies, some in plain sight and many others hidden.[15]

(2) Next, we hear government (and corporate) hype about the limitless possibilities for increasing productivity, vastly improving the quality of life for everyone, ending poverty, curing cancer and so on.[1]

(3) Government then refuses to apply (or enforce) even the most common-sense regulations.

(4) Government (in concert with the corporate sector) suppresses unwelcome information and ignores (or discredits) dissenting voices warning of trouble ahead.

(5) Finally, government donates publicly-created knowledge and investment to corporate elites who then make profits galore for a decade or two until damage reports accumulate, the public catches on, and controversy engulfs the technology. The role of

government throughout this phase is to act like a sponge and absorb blows from an angry public, suppress unwelcome information, discredit detractors, deflect demands for strict regulation, continue to hype the technology, simultaneously spending additional tens of billions of taxpayer dollars on elaborate (and contradictory) programs of blame, denial, cleanup, restitution, and defense against lawsuits.

Nanotech has already entered stages 1 through 4 and is rapidly approaching stage 5.

As with powerful technologies before it, the dark side of nanotech is hard to separate from its bright side. Even if nanobot assemblers never materialize, self-assembly, self-repair, and self-replication remain important goals of nanotechnologists.

Even NSF's Dr. Mihail ("Mike") Roco -- never one to dwell on the dark side of nanotech or NBIC -- identifies the development of "replication and eventually self-replication methods at nanoscale" as one of the key challenges facing nanotechnologists.[16] Nanotech won't ever amount to much if it doesn't achieve self-replication.

Ray Kurzweil, inventor of the first reading machine for the blind, author of The Age of Spiritual Machines, and hardly an anti-technology Luddite, points out that, "Without self-replication, nanotechnology is neither practical nor economically feasible. And therein lies the rub. What happens if a little software problem (inadvertent or otherwise) fails to halt the self-replication?... Nuclear weapons, for all their destructive potential, are at least relatively local in their effects. The self-replicating nature of nanotechnology makes it a far greater danger."[17]

In a now-famous essay in Wired magazine (April 2000), Bill Joy, co-founder and Chief Scientist at Sun Microsystems, drew an even darker picture of a future dominated by genetic manipulation, nanotech, and robotics (GNR):

"The 21st-century technologies -- genetics, nanotechnology, and robotics (GNR) -- are so powerful that they can spawn whole new classes of accidents and abuses. Most dangerously, for the first time, these accidents and abuses are widely within the reach of individuals or small groups. They will not require large facilities or rare raw materials. Knowledge alone will enable the use of them."[18]

"I think it is no exaggeration to say we are on the cusp of the further perfection of extreme evil, an evil whose possibility spreads well beyond that which weapons of mass destruction bequeathed to the nation-states, on to a surprising and terrible empowerment of extreme individuals."

"In truth, we have had in hand for years clear warnings of the dangers inherent in widespread knowledge of GNR [genetics, nanotech, and robotics] technologies - of the possibility of knowledge alone enabling mass destruction. But these warnings haven't been widely publicized; the public discussions have been clearly inadequate. There is no profit in publicizing the dangers," Joy wrote.

The directors of the National Nanotechnology Initiative (NNI) in Washington, say they want to explore the dark side of nanotech, partly to avoid the troubles that presently engulf the emerging field of genetically engineered (aka biotech) food. Biotech -- the practice of stuffing genes from one species into an unrelated species (for example, blasting the genes from a trout into a tomato, to help the tomato survive cold weather) -- was promoted by a handful of chemical corporations aided by pliant federal regulators, some of whom came to their federal jobs fresh from the executive suites of the chemical corporations they were hired to regulate. [Rachel's #381, #382]

Between 1994 and 2001, genetically engineered products were rapidly introduced first into the U.S. milk supply, then into corn and soybeans with a noticeable absence of public debate until after the fact. Indeed, the U.S. Food and Drug Administration (FDA) declared it illegal for grocers or anyone else to label a product "not genetically engineered," for the purpose of preventing citizens from making informed choices at the grocery check-out.[19] Government's enthusiasm for biotech food has been exceeded only by its desire to suppress public debate about the technology.

It was a small group of independent researchers in western Canada -- the Etc Group (www.etcgroup.org) -- in cahoots with other non-governmental organizations, who first revealed the dark side of biotech. Once the facts began to be known, public reaction was swift and strong. Many governments in Europe banned the import of U.S. biotech foods. Scientists within the U.S. Food and Drug Administration (FDA) complained publicly that their doubts about the safety of biotech foods had been ignored and suppressed.[Rachel's #685] Canadian government officials claimed they had been offered bribes by chemical firms to approve biotech milk.[Rachel's #593, #621, #639]

The biotech story is by no means over. Eventually the chemical-biotech corporations, with the U.S. government running interference on their behalf, may overcome worldwide resistance to "frankenfoods" as they are now popularly known. Nevertheless, by almost any standard the introduction of biotech has been a public relations debacle, a scientific scandal, and a disaster for U.S. international relations. Nanotech enthusiasts in Washington are eager to avoid a biotech replay, to put it mildly.

To show its willingness to consider the dark side of nanotech, the National Science Foundation (NSF) held a conference in September 2000 on "Societal Implications of Nanoscience and Nanotechnology." Subsequently, NSF published a 272-page report of the meeting edited by Mihail Roco and an NSF colleague.[20]

In its report, the NSF acknowledges the following sorts of problems stemming from nanotech:

** nanotech may increase "the inequality of wealth," creating a kind of "nano divide" because "those who participate in the 'nano revolution' stand to become very wealthy" while "those who don't may find it increasingly difficult to afford the technological wonders that it engenders."[20, pg. 11]

** nanotech-based medical treatments may "initially" be expensive, "hence accessible only to the very rich." (18, pg. 11)

The NSF proposes to solve these problems by hiring social scientists, philosophers of ethics and other "professionally trained representatives of the public interest" who are "capable of functioning as communicators between nanotechnologists and the public or government officials."[20, pg. 12] In other words, opinion experts will be hired to tell nano experts what the non-experts think about all this, to help the nano experts make decisions about how to deploy this new technology.

As envisioned by the NSF, the general public, whose society is about to be "revolutionized" by nanotech in the next 10 to 20 years, will not have any significant say in the roll-out of nanotech, except of course to pay for it.

Environmentalists argue that the commercialization of nanotech offers an opportunity to try a more thoughtful approach to industrial innovation, adopting the "better safe than sorry" precautionary principle, instead of the more traditional "damn the torpedoes, full speed ahead."[21] No one disputes that the old way created substantial benefits, but the costs to human health and the environment have been enormous, and unpleasant new surprises are being discovered weekly if not daily. Indeed, it is no exaggeration to say that there is a consensus among many biologists that the biosphere is being shredded by previous technical innovations.[22, 23] Maybe this time around we could have the benefits of the new technology but minimize the unpleasant surprises.

The National Academy of Sciences, which manages the National Nanotech Initiative, seems to agree that nanotech should be studied, but wants it done as the technology is being introduced, not before. The difference is crucial. History reveals vividly that after a new technology has achieved commercial success, it is nearly impossible to slow it down, much less bring it to a halt. Even when major public health problems become apparent, as with asbestos, leaded gasoline, chlorofluorocarbons, and fossil fuels it can take 30 to 100 years to change course and introduce saner alternatives. The only practical time to apply restraint to nanotech would be now.

The mechanism for applying restraint would be the democratic involvement of a broad spectrum of the general public, genuinely seeking their guidance, not merely trying to manipulate them like so many robots. Numerous advanced techniques are available now for engaging the public in informed debate,[24] but the National Science Foundation has, so far, shown no inclination to give any of them a try.

[To be continued]

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[1] Mihail C. Roco and William Sims Bainbridge, editors, Converging Technologies for Improving Human Performance (Washington, D.C.: National Science Foundation, June, 2002. http://rachel.org/library/getfile.cfm?ID=208

[2] "The Little BANG Theory," ETC Group Communique #78 (March/April 2003). Available on the web at http://www.etcgroup.org/documents/comBANG2003.pdf .

[3] Anonymous, "Small Times Magazine Names Top 10 Small tech Hot Spots," Small Times March 12, 2003. Available at http://www.smalltimes.com/document_display.cfm?document_id=5641

[4] Barnaby J. Feder, "Oppositiopn to Nanotechnology," New York Times August 19, 2002, pg. C5.

[5] Richard E. Smalley, "Of Chemistry, Love and Nanobots," Scientific American Vol. 285, No. 3 (September 2001), pgs. 76-77. And: George M. Whitesides, "The Once and Future Nanomachine," Scientific American Vol. 285, No. 3 (September 2001), pgs. 78-83.

[6] Arjun Makhijani and Scott Saleska, The Nuclear Power Deception; U.S. Nuclear Mythology from Electricity "Too Cheap to Meter" to "Inherently Safe" Reactors (New York: The Apex Press, 1999). ISBN 0-945257-75-9.

[7] William J. Broad, "Chain reaction; Facing a Second Nuclear Age," New York Times Week in Review August 3, 2003, pg. 1. And see J. R. Pegg, "Bush Administration Keen on New Nuclear Weapons," Environment News Service, May 7, 2003, available at http://www.rachel.org/library/getfile.cfm?ID=228 .

[8] William Cosgrove, "Number of Killer Storms and Droughts Increasing Worldwide," World Water Council (Marseille, France) Feb. 27, 2003. Available at http://www.rachel.org/library/getfile.cfm?ID=229 .

[9] See, for example, Rachel's #529, #689. On lead and cancer and heart disease, see M. Lustberg and E. Silbergeld, "Blood lead levels and mortality," Archives of Internal Medicine Vol. 162 (2002), pgs. 2443-2449.

[10] For extensive documentation of these claims, see numerous past issues of Rachel's, available at http://www.rachel.org .

[11] Up-to-date reports about the latest studies can be found on the web sites described in Rachel's #769.

[12] Joe Thornton, Pandora's Poison; Chlorine, Health, and a New Environmental Strategy (Cambridge, Mass.: MIT Press, 2000). ISBN 0262201240.

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[14] See Rachel's #760 and the materials cited there. In addition to the scandals described in Rachel's #760, illegal biotech Starlink corn in hundreds of consumer products; illegal biotech canola in Canadian canola fields; illegal biotech cotton in India; and perhaps illegal biotech corn in the heartland of Mexico have all been reported within the past two years; see Justin Gillis, "Little Oversight of Altered Crops," Washington Post April 25, 2003, pg. E4. And see Marc Kaufman, "The Biotech Corn Debate Grows Hot in Mexico," Washington Post March 25, 2002, pg. A9.

[15] Some hidden subsidies have been described in Shannon Collier and others, Green Scissors (Washington, D.C.: Friends of the Earth and others, May 8, 2003). Available at http://www.rachel.org/library/getfile.cfm?ID=231 .

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[17] Kurzweil quoted in Sean Howard, "Nanotechnology and Mass Destruction: The Need for an Inner Space Treaty," Disarmament Diplomacy No. 65 (July-August, 2002), pgs. unknown. Available at http://www.rachel.org/library/getfile.cfm?ID=233 .

[18] Bill Joy, "Why the Future Doesn't Need Us," Wired (April, 2000), pg. unknown. Available at http://www.rachel.org/library/getfile.cfm?ID=209 .

[19] See Rachel's #382. Monsanto, the chemical giant that holds the patent rights for rBGH, a synthetic hormone that causes cows to increase their milk output, in July, 2003, sued dairy farmers in Maine to stop them from labeling their milk free of rBGH. See David Barboza, "Monsanto Sues Dairy in Maine Over Label's Remarks on Hormones," New York Times July 12, 2003, pg. unknown.

[20] Mihail C. Roco and William Sims Bainbridge, Societal Implications of Nanoscience and Nanotechnology (Washington, D.C.: National Science Foundation, March 2001). Available at http://rachel.org/library/getfile.cfm?ID=217 .

[21] On the precautionary principle, see, for example,
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http://www.rachel.org/library/getfile.cfm?ID=188 and
http://www.rachel.org/library/getfile.cfm?ID=189 and
http://www.rachel.org/library/getfile.cfm?ID=227 and
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.   THE REVOLUTION, PT. 3: ULTRAFINES   .
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THE REVOLUTION, PT. 3: ULTRAFINES

A revolution is sweeping through science and technology, blending cognitive science (how the brain works), biotechnology (manipulation of genes), information technology, and nanotechnology, or nanotech for short. The engineers who are masterminding this revolution explain that it is "essential to the future of humanity"[1, pg. 22] because it holds the promise of "world peace, universal prosperity, and evolution to a higher level of compassion and accomplishment."[1, pg. 6] They say it may be "a watershed in history to rank with the invention of agriculture and the Industrial Revolution."[1, pg. 20] The ultimate aim of the revolution is not so new: the "conquest of nature." [1, pg. 80]

The revolution is driven by the convergence of four technologies (nano, bio, info, cogno), but here we focus again on only one of the four -- nanotech -- because it is becoming the foundation stone of bio and info sciences,[1, pg. 71] because it has been largely ignored by the media, and because it is galloping forward at breakneck speed. It is no exaggeration to say that the field of nanotech is gripped by a "gold rush" mentality. Any day of the week, take a look at http://nanotech-now.com/ to catch a glimpse of the gold rush in action.

Nanotech is named for the nanometer, a unit of measure, a billionth of a meter, one one-thousandth of a micrometer. The Oxford English Dictionary defines nanotechnology as "the branch of technology that deals with dimensions and tolerances of less than 100 nanometres, esp. the manipulation of individual atoms and molecules."

In 2000, President Clinton created the National Nanotech Initiative, which is now funded at the level of $700 million per year -- the third largest public research program in the U.S., after the war on cancer and the star wars missile defense program. (See Rachel's #772 and #773.) In every state in the U.S., nanotech proponents are commandeering tax dollars to subsidize "the next big thing." Many states are hoping to establish their own "Nano Valley" as an entrepreneurial wild west modeled on Silicon Valley before the bubble burst.

In March of this year, Small Times magazine said the states with the greatest nanotech potential are California, Massachusetts, New Mexico, Arizona, Texas, Maryland, New York, Illinois, Michigan and Pennsylvania, with Colorado, New Jersey, North Carolina, Ohio, Virginia, and Washington state close behind.[2] The National Science Foundation predicts that nanotech will be a trillion-dollar industry by 2015, just 12 years from now.[2] Nanotech is advancing upon us at warp speed.

This week we will focus on only one aspect of nanotech: the environmental and human health effects of nano particles, which are particles 100 nanometers (0.1 micrometers) or less in diameter. As we saw in Rachel's #772, the intentional manufacture of nano particles is already under way, and this new industry is gearing up worldwide. Nano particles go by different names, such as nanodots, nanotubes, buckyballs, and buckminsterfullerenes, among others.

According to the Etc Group, which follows nanotech developments carefully, an estimated 140 companies are now producing nano particles in powders, sprays, and coatings that are being used in a variety of products, including sunscreens, automobile parts, tennis rackets, scratch-proof eye glasses, stain-repellent fabrics, self-cleaning windows, and more.[3, pg. 2] Mitsubishi Chemical in Japan has reportedly begun construction of a plant to manufacture nanotubes at the rate of 120 tons per year, with plans to increase output to 1500 tons per year by 2007.[4] The U.S. government's space agency, NASA, plans to spend the next five years scaling up the production of nanotubes. [1, pg. 50]

One of the most important characteristics of nano particles is their huge surface-to-volume ratio. The smaller something is, the larger its surface area is, in comparison to its volume. Because nano particles are so small, they have an enormous surface area, relative to their volume. Drug companies are planning to take advantage of those large surfaces -- for example, covering nano particles with drugs for targeted delivery into the interiors of our cells. The smaller the size of the particle, the larger the load of drugs it can carry (larger, relative to the particle's volume).

Unfortunately, the large surface area of tiny particles also makes them dangerous for at least two reasons: first, the large surfaces alone promote the reaction of oxygen with human (or animal) tissue, creating free radicals.

"Free radicals are atoms or groups of atoms with an odd (unpaired) number of electrons and can be formed when oxygen interacts with certain molecules. Once formed these highly reactive radicals can start a chain reaction, like dominoes. Their chief danger comes from the damage they can do when they react with important cellular components such as DNA, or the cell membrane [the cell's outer casing]. Cells may function poorly or die if this occurs," explains Dr. Mark Jenkins at Rice University.[5]

In sum, the large surface of nano particles offers an ideal place which oxygen reactions can occur in the airways and lungs, resulting in the formation of free radicals with subsequent cell damage or cell death, followed by inflammation.

The second danger from nano particles arises when they float freely in the air, where their large surface area provides a sticky place where metals and hydrocarbons attach themselves. The smaller the size of the particle, the larger the load of metals and hydrocarbons it can carry (larger, relative to the particle's volume).

What do we know about health effects of nano particles?

It turns out that we already have a fair amount of data on the dangers of airborne nano particles -- but researchers don't call them nano particles. They call them ultrafines. Nano particles and ultrafines are the same thing -- particles with an average diameter of 100 nanometers (0.1 micrometers) or less.

Scientists have known for more than a decade that fine and ultrafine particles in the air create haze and kill large numbers of humans. Fines and ultrafines are produced by fossil-fuel power plants, incinerators, cement kilns, and diesel engines, among other sources. As early as 1991, Dr. Joel Schwartz of U.S. Environmental Protection Agency (now at Harvard) estimated that fine particles were killing 60,000 people each year in the U.S. That shocking estimate has since been confirmed and reconfirmed and is now widely accepted.[6] Fine particles are defined as those with a diameter of 10,000 nanometers (10 micrometers) or less. Ultrafines are 100 times smaller than fines.[6]

Today, researchers are examining the properties of ultrafines and there seems to be little doubt that they are the major killers in haze. Studies in Los Angeles, California reveal that ultrafines are 10 to 50 times as damaging to lung tissue, compared to larger fine particles.[7]

Since 1991, scientists have been wondering whether fine and ultrafine particles cause harm because of their size alone, or because they carry metals and hydrocarbons deep into the lung. Researchers today believe that, in the case of ultrafines, the answer is both.

U.S. Environmental Protection Agency refers to fines as PM 10 (short for "particulate matter 10 micrometers or less in diameter"). By 1996, EPA became convinced that PM 2.5 (particles with diameters of 2.5 micrometers [2500 nanometers] or less) were far more dangerous than PM 10, and the agency proposed rules to control PM 2.5 air pollution. Corporations immediately sued in court to "get government off our backs" and to fulfill their fiduciary duty to shareholders by every legal means, even though that duty in this instance entails killing tens of thousands of anonymous citizens each year. In 2001, after a 5-year court battle, EPA won in the U.S. Supreme Court, but the agency, chastened by corporate encounters, has shelved its plan for controlling PM 2.5 air pollution.[8]

Meanwhile, new studies are piling up showing that nano particles (ultrafines, which in EPA terminology would be PM 0.1) are by far the most dangerous of all.

EPA does not collect data on nano particles in any systematic way, and has announced no plans to control them. Meanwhile the nano particle corporations and NASA are ramping up industrial operations to manufacture ultrafines in ton quantities. It appears that the stage is being set for major new trouble and an escalation of the killing.

The picture continues to develop, but current research shows that nano particles in the lung cause the formation of free radicals, which in turn, cause lung disease, and cardiovascular disease. Furthermore, nano particles carry metals and carcinogenic hydrocarbons deep into the lung, where they exacerbate asthma and other serious breathing problems. In addition, nano particles combined with metals can pass directly into the brain where they promote the formation of waxy amyloid plaques, which are the signature feature of Alzheimer's disease.

In Fresno, Calif., Kent E. Pinkerton at Univ. of Calif. Davis found from autopsies that "outwardly robust people routinely harbor damage in their lungs' small airways, setting the stage for respiratory and cardiovascular disease." The bronchioles were scarred with fibrosis and an abnormal thickening, apparently caused by "the ravages of free radicals." [6,9]

Subsequent exposure of rats to ultrafine particles at levels found in Fresno on a bad day revealed many dead cells in the rats' lungs, large numbers of inflammatory cells (neutrophils), and destruction of macrophages -- which are cells that promote health by actively removing foreign material from the lungs.[10] In other words, ultrafines kill off the lung's natural defenses, then create their own unique form of damage, promoting free radicals, cell death, inflammation and eventually cardiovascular disease.

Pinkerton's findings were confirmed by a study of the lungs of non-smoking women in Mexico City and in Vancouver, British Columbia, which revealed extensive lung damage from exposure to dirty Mexico City air, but not clean Vancouver air. [4] The small airways of the Mexican women "were very abnormal," with fibrosis and thickening.

Researcher Ken Donaldson at the University of Edinborough in Scotland has studied particles of pure titanium dioxide and pure carbon. At 10 micrometers diameter, they cause no damage to rat lungs. But when they are crushed into ultrafines "they become highly inflammogenic to the lungs," he told Science News.[6, 12, 13] In other words, carbon nano particles, without any pollutants attached (no metals, no hydrocarbons), cause lung damage by themselves. Their size alone is harmful.

Donaldson conducted similar experiments on ultrafine particles of pure styrene, with similar results, showing that nano size alone is a danger. This clearly indicates that the manufacture of nano particles will be a threat to workers, and any particles released into outside air will be a public health menace. It is worth pointing out the obvious: The smaller particles become, the harder they are to control and contain.

Nano particles floating in the air will not remain pure for long. Metals and hydrocarbons (from combustion sources like incinerators, cement kilns, fossil-fuel power plants, and diesel engines) will quickly coat their large surfaces.

It is now known that the deadly effects of fine and ultrafine particles aren't restricted to the lung, but occur in the cardiovascular system and brain. Renaud Vincent and colleagues at Health Canada (the Canadian equivalent of the U.S. National Institutes of Health) clarified the mechanism of cardiovascular damage by exposing healthy volunteers to high levels of fine particles -- the levels you might find in a city with dirty air.[14, 15, 6]

Vincent found that exposure to ultrafine particles doubles the concentration of a small protein (called endothelin) in the blood stream. Endothelin increases blood pressure. The spike in endothelin levels can be tolerated by a healthy subject, but may kill a person who is already suffering from atherosclerosis (hardening of the arteries).[6]

Importantly, the spike in endothelin concentration only occurs when subjects are exposed to fine and ultrafine particles that have metals or hydrocarbons attached to them. If the particles are purified before the humans are exposed to them, they have no effect on endothelin levels. Thus it seems to be the combination of ultrafine particles and metals and/or hydrocarbons that increases endothelin.

Other researchers have also been examining the effects of fine and ultrafine particles on cardiovascular health. Scientists at the Harvard School of Public Health exposed dogs to fine and ultrafine particles, then simulated heart attacks in the dogs by using a surgically-implanted balloon to temporarily shut off a coronary artery. Dogs that had been breathing ultrafines could not compensate for the blocked artery -- which may help explain why humans who have heart attacks on a bad-air day are more likely to die than people having heart attacks where the air is cleaner.[16]

Cardiovascular disease and heart attacks are not the only concern arising from exposure to fine and ultrafine particles in the air. A University of North Carolina research team working with dogs living in Mexico City has shown that exposure to ultrafine air pollution causes brain damage. Lilian Calderon-Garcideunas found that ultrafine particles carry metals such as vanadium and nickel into the dogs' brains through their noses. The fine particles break down the barriers that normally prevent contaminants passing into the brain.[6, 17]

Dogs are often used as models for the study of cognitive impairments that accompany old age in humans. Some dogs aged 10 and over develop the waxy plaques that are characteristic of Alzheimer's disease. Calderon-Garcideunas's study of 200 dogs in Mexico City reveals that the animals breathing ultrafine particles develop waxy beta-amyloid plaques in the brain before they are a year old.[6, 17]

Calderon-Garcideunas told science writer Janet Raloff that her findings are "definitely worrisome" because she has examined the noses of humans in Mexico City and found evidence of a breakdown of nasal tissue, similar to that found in dogs.[6]

U.S. EPA researchers and colleagues in Germany have found that metals attached to fine and ultrafine particles greatly exacerbate asthma. First they examined children in a German city where the air is contaminated with fine and ultrafine particles mixed with metals. Compared to children living in a rural German town where the air is relatively clean, the urban children showed strongly allergic reactions. The researchers then exposed mice to the two kinds of air that the children were breathing. They reported that mice exposed to metal-contaminated ultrafine particles developed strong allergic and asthmatic reactions in their airways.[18]

Using isolated lung cells, researchers found that ultrafine particles from Los Angeles air (a) carry far more toxic combustion byproducts per unit weight than do larger particles (no surprise because of surface-to-volume ratio); and (b) enter cells and settle in the mitochondria, which are the cells' source of power. Ultrafine particles turn the mitochondria into "functionless bags," researcher Andre Nel told Science News, killing the cells they were powering.[7, 6]

In sum the nanotech industry and the U.S. government are rapidly ramping up a new industrial capacity to manufacture ton quantities of ultrafine particles, very similar to particles already known to be killing tens of thousands of people in the U.S. each year. The complete catalog of harm from these particles remains to be written, but we already know that they cause or aggravate asthma and cardiovascular disease, damage the small airways of animals, adults, and children, carry metals and cancer-causing combustion byproducts deep into the lungs and even into the brain where they promote the growth of amyloid plaques associated with Alzheimer's disease.

We also know that the current regulatory system has proven to be incapable of bringing particulate pollution under control because of relentless opposition from corporations. As a matter of law, corporations are required to put profits before public health, so we can never expect them to do any better than they are doing today, until we change the law.[19]

Clearly, in the case of nano particles, we have reasonable suspicion of harm, and we have some remaining scientific uncertainty. Therefore we have an ethical duty to take preventive (precautionary) action. If there ever was a proper time to invoke the precautionary principle, this is it.[20]

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[5] Mark Jenkins, "Antioxidants and Free Radicals," 1996, available at http://www.rice.edu/--jenky/sports/antiox.html and at http://rachel.org/library/getfile.cfm?ID=299 .

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[20] On the precautionary principle, see http://www.rachel.org/library/getfile.cfm?ID=187 and http://www.rachel.org/library/getfile.cfm?ID=188 and http://www.rachel.org/library/getfile.cfm?ID=189 and http://www.rachel.org/library/getfile.cfm?ID=227 .