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 through chemistry.

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 with an STM when they lined up 35 individual xenon atoms.

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] 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 mouse'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.]


