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Communiqué

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Nanotech Un-gooed!

Is the Grey/Green Goo Brouhaha the Industry's Second Blunder?

Issue: **When Prince Charles raised concerns about the emerging revolution in nanotechnology at the end of April, tabloid headlines of Grey Goo were catapulted onto front pages of English-speaking press and elsewhere, raising the spectre of the great GM debate all over again. But nanotechnology – despite being one of the best funded new technologies in the world – is still little known outside scientific and business circles and is not regulated by governments. Scientists and industry proponents have attacked the Prince for having the audacity to raise concerns about the future impacts of atom-scale manipulations. The threat of Grey Goo (nanoscale mechanical robots reproducing uncontrollably) has become the itsty-bitsy boogey man, handily dismissed by industry and Nobel laureates as a technical impossibility. But in their zeal to pooh-pooh the Prince, they are ignoring the very real and present dangers that nanotechnologies pose, including the potential toxicity of nanoparticles and the farther-reaching implications of nanobiotechnology.**

Context: **Even while the Grey Goo theory is being pressed into service as straw man, measurable scientific advances are being made that will make some form of molecular manufacture a reality sooner than anyone thought possible.**

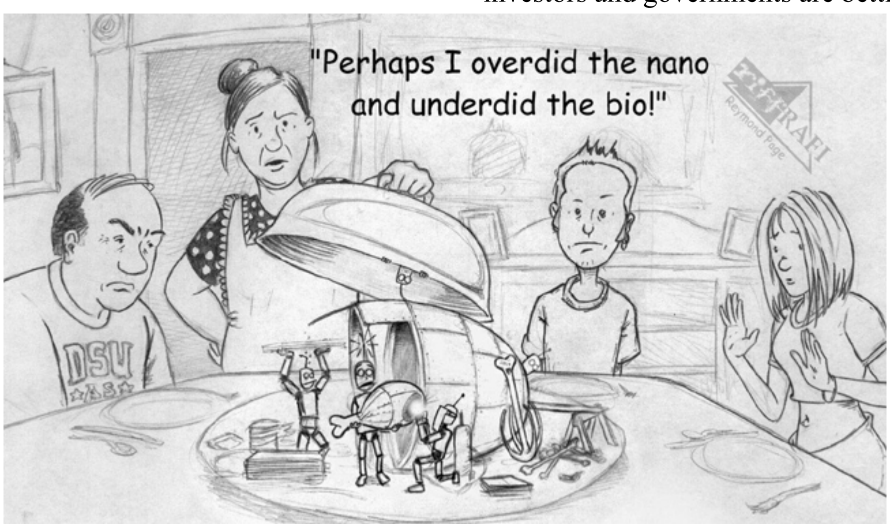
Implications: **We are not ready for this latest and greatest industrial revolution. Public debate about the societal implications of nanotechnology for the environment, the economy, labour, and democracy is paramount. We must establish laboratory protocols to protect workers from possibly hazardous materials, perform the necessary toxicology studies to find out where the specific problems are, and regulate nanotechnology research and commercialization to prevent an asbestos-like public health crisis or a Green Goo (nanobio) catastrophe.**

Policy: **Prince Charles has reportedly called for the Royal Society to convene and discuss the implications of nanoscale manipulations. On June 11, 2003, a seminar at the European Parliament on nanotechnology intended for civil society, policy makers and the media will be held at the European Parliament in Brussels (For more information, see http://www.etcgroup.org/article.asp?newsid=390). Ultimately, governments must negotiate a legally-binding International Convention for the Evaluation of New Technologies (ICENT).**

"The question now is not whether it is possible to produce hybrid living/nonliving devices but what is the best strategy for accelerating its development." — Carlo D. Montemagno[1]

Suddenly the nanotech industry and its friends are scrambling to pretend nanotech problems that have raised royal concerns exist far in the future or only in the pages of science fiction. Everything is under control, they tell us, and there is no need to fear. The truth is that one mistake has already been committed – the mishandling of regulation and safety consideration of nanoparticles. Now, in the emerging field of nanobiotech, there may be more problems brewing. A second mistake may prove unforgivable. Grey Goo (the result of self-replicating nanomachines run amok) may sound like science fiction, but when biotech muscles in on the nano-act, Green Goo consequences are real cause for concern. This ETC Group *Communiqué* is a short overview of the Grey Goo / Green Goo debate and a warning that if techno-politicians overeagerly dismiss the Goo brouhaha, they do so at all our peril.

WHAT IS NANOTECH? The simplest definition of nanotechnology is the manipulation of material at the scale of the nanometer (one billionth of a meter), which is the scale of atoms and molecules. Nanotechnology is nothing new, scientists like to point out, and it is true that manipulations on the nanoscale have been possible for at least a century. Most laboratory chemistry operates on the nanoscale. It was only in the last two decades of the twentieth century, however, that *precise* manipulations of nanoscale materials became possible. And it was only in the final years of the century that those precise manipulations began to be collected under the same taxonomic umbrella (i.e., "nanotechnology") and identified as an emerging "industry." Those scientists whose work involves nanotechnology – chemists, physicists, biologists, cognitive scientists, electrical engineers, material scientists – have only just begun to talk to each other to find out what the other knows about nanoscale phenomena. Though its name suggests small (*nanos* is Greek and means "dwarf"), today's nanotech industry has a huge future. Already hundreds of tons of nanoscale particles are showing up in consumer products as diverse as sunscreens, car parts, tennis balls, eyeglasses, and paint. The list grows longer every day. But this is just the beginning. Nanotechnology is not limited to the development of new materials with new characteristics. Scientists are also hoping to someday master new forms of molecular scale manufacture that could transform how everything in the world is made, including the raw materials we start with. According to the US National Science Foundation, the global market for nanotech products will exceed $1 trillion by 2015. Both investors and governments are betting on nanotech as "the next big thing," but insiders insist that nanotech will get even bigger and do it faster than predicted – the most dramatic economic transformation the world has ever experienced.



Nanotech bills itself as a "green" technology – one that can clean up the environment, improve health worldwide, and even end hunger. Mindful of another technology – biotechnology – that made many of the same promises and ran afoul of public concerns, the industry repeats the mantra that it will not make, and is not making, the same mistakes. So far, they are mistaken.

STRIKING MISTAKES: First, despite a quarter-century of lab work on nanoparticles, scientists failed to establish a common laboratory protocol to ensure the safety of workers exposed to particles. Then government allowed nanoparticles into consumer products in the absence of regulatory mechanisms. Particles that had been approved for consumer products at the micro- or macro- scale were not tested again when introduced into the same products at the nanoscale. Indeed, nano companies pooh-poohed the notion that nanoparticles need to be evaluated for their health and environmental impacts, despite that the impetus for their development stemmed from the radical changes that can happen when a substance is reduced to the nanoscale. Because quantum mechanics takes over at the nanoscale, there may be changes to a substance's conductivity, elasticity, reactivity, strength, color, and tolerance to temperature and pressure. Some nanoparticles can slip past immune systems and even cross through the blood-brain barrier undetected – great news for drug delivery, really bad news if the particles given *carte blanche* turn out to be toxic.

> "Nanomaterials themselves may also have unintended environmental consequences. As a chemist I know all too well how unforeseen health effects can destroy industries based on complex materials. From asbestos to DDT we have, as a society, paid an enormous price for not evaluating toxicological and ecosystem impacts before industries develop. The real losers here are not environmentalists; instead they are the businesses who enthusiastically embrace new materials, only to face a decade later debilitating liability claims from employees, consumers and governments. And in the case of nanotechnology, the ultimate losers may be the American taxpayers who invested over one billion dollars in nanomaterials research without any hard data on their toxicological and environmental effects."
> *– Dr. Vicki Colvin, in testimony before the U.S. House of Representatives Committee on Science in regard to "Nanotechnology Research and Development Act of 2003," April 9, 2003.*

Second, fearful of a public backlash, industry attacked the theory that nanotechnologies could lead to the development of directed molecular self-assembly (nanoscale "robots" capable of manipulating molecules and reproducing). Critics raised concerns that, unless perfectly controlled, human-created self-assembly could pose a major threat to global survival, analogous to uncontrolled cancer cells self-replicating until they destroy a living organism. The threat has been named "global ecophagy" or, more simply and cinematically, "Grey Goo." Not an enticing image for venture capitalists or manufacturers thinking of going nano on the assembly line. But even if self-assembly could be controlled, the implications for the environment, the economy, labour, and democracy are enormous and need to be addressed openly. Now there is growing scientific evidence that directed molecular self-assembly is not only possible but relatively close at hand. If the industry's dismissals turn out to be short-sighted and/or self-serving, society will question whether or not scientists and industry cheerleaders can be trusted with so powerful a technology. If nanotech doesn't start getting things right, science is going to lose the Holy Grail of molecular management they have been dreaming about at least since the days of Watson and Crick's discovery of DNA fifty years ago.

GREY GLUE: In September 2001, *Scientific American* devoted an entire issue to the science of nanotechnology. The magazine featured a just-barely civil dispute over the prospects for molecular self-assembly between nano-wunderkind K. Eric Drexler and Nobel laureate Richard Smalley. Smalley, who has his own start-up nanotech enterprise as well as a prestigious post at Houston's Rice University, took the position that nanoscale machines are a physical impossibility because of the difficulty of manipulating individual atoms when they adhere so readily to any surface. Smalley calls it the "sticky fingers problem." Drexler (who is President of the Foresight Institute in Palo Alto, CA, USA, an organization with the mission to prepare society for nanotechnology) maintains that molecular self-replication is inevitable. The nanotech industry is happy to promote Smalley's view and to dismiss Drexler's vision: the fledgling industry is not pleased that first Drexler, and then Bill Joy of Sun Microsystems, raised the spectre of Grey Goo. Mark Modzelewski, director of the US nanotech lobby group (Nanobusiness Alliance), hyperbolised the likelihood of molecular manufacture thus: "…precision manipulation of atoms would be akin to assembling a wristwatch without instruments, wearing heavy gloves, and with every part soaked in glue."[2] While Smalley, Drexler, and others continue to debate the feasibility of non-biological molecular manufacture, scientists forge ahead with manipulating individual atoms by mechanical means.[3] An American Physical Society publication recently reported, for example, that a Japanese research team was able to pick up and move individual atoms without using electric current (all previous atom-relocations have been performed on conductive material using an electrically-charged tip of a scanning tunneling microscope).[4]

A ROYAL PAIN: Prince Charles has taken a royal bashing in the UK, where scientists and industry spokespeople rushed to judgement, ridiculing him for espousing concerns about Grey Goo. Only former Prime Minister John Major was willing to give him a break.[5] In an article in *The Times*, Jasper Gerard characterized Charles' "wee tizz over nanotechnology" as immature hysteria.[6] Dr. Ian Gibson, a Norwich MP, advised, "If I were him I'd stick to modern architecture and issues like that rather than those which need to have a depth of understanding."[7] Just as industry has attempted to paint self-replicating nanobots as "Wizard of Oz" tin men and Drexler and Joy as paranoid fringe futurists, it has done the same with Prince Charles. It is not yet clear how wide-ranging the royal concerns are. (ETC Group has not spoken with the Prince, but news articles reported that the Prince intervened after reading the ETC Group's report on nanotechnology, *The Big Down*.[8]) If Prince Charles' concerns reflect ETC's perspective at all, they will not be narrowly focused on Grey Goo, but on the very real dangers of unregulated nanoparticle production and on the implications of nanobiotechnology: Green Goo.

THE BIRDS AND BEES: Drexler and Bill Joy, and presumably Prince Charles, as well, are well aware that molecular self-assembly is as old as life itself. As the song goes, birds do it and bees do it — or, at least their cells do it. The big thing about living – whether you're a microbe or a mammal – is the ability of nanoscale bits and pieces of chemical elements that make up DNA to reproduce with remarkable speed. Molecular manufacture is all around us: the goal of nanobiotechnology is not to make it possible, but to find ways to make it commercially viable – to design living materials that do the work of machines. Why construct self-replicating mechanical robots when self-replicating biomaterials are cheaply available all around? Will the merger of living and non-living matter result in hybrid organisms and products that end up behaving in unpredictable and uncontrollable ways? The real threat is not Grey Goo – it is Green Goo.

DOUBLE-GREEN GOO REVOLUTION: Re-organizing nature is hardly a new idea. To increase yields during the Green Revolution, Northern scientists bred semi-dwarf plants that were better able to absorb synthetic fertilizers and, in the process, increased the plants' need for pesticides. To further the dependency, the agricultural biotechnology industry designed plants that could tolerate toxic chemicals. Agbiotech companies had a choice: they could have structured new chemicals to meet the needs of the plants or they could have manipulated plants to meet the needs of company herbicides. They opted for the sanctity of their herbicides. Now the fledgling nanotech companies are trotting down the same path – looking for new ways that life can serve the needs of industry.

"God for Dummies"

Through the nanoscale manipulation of biological materials, it is now possible (or scientists believe it soon will be possible) to:

- Craft synthetic DNA from the blueprint provided by a natural organism;
- Use the synthetic DNA to create unique living organisms;
- Construct new artificial amino acids that can be built into unique proteins;
- Add a fifth letter to DNA (A, C, T, G and now "F") thus increasing the potential diversity (or destructiveness) of life.
- "Write" DNA code in much the same way programmers write software;
- Use DNA to build nano machines capable of exponential self-assembly;
- Design exponentially self-assembling nanomachines that can become motors, pistons, tweezers, etc. in manufacturing processes.

"GOD FOR DUMMIES?" Despite the protestations of nervous nanos, nanotech's scientists on the cutting edge of innovation are searching for a recipe to build new life. Last year, researchers at Stony Brook (the high-tech institute at the State University of New York) synthesized the 7,500 letters in the poliovirus's genome using published gene sequence information and "off the shelf" commercially-available DNA material.[9] Ultimately, they were able to combine the poliovirus with catalysts and protein-building molecules so that the virus assembled autonomously.[10] For the first time in 4.5 billion years, God may be facing a contender.

UP THE DNA LADDER: Consider J. Craig Venter, whose personal DNA was sequenced by his Celera Genomics in the race with the publicly-funded Human Genome Project to complete the map of the human genome. Venter and Nobel Laureate Hamilton Smith launched the Institute for Biological Energy Alternatives a few months ago, which is partially funded by a $3 million US Department of Energy grant. The Institute aims to build, quite literally, a new life form. To do this, they are using the boiled-down DNA of the known world's most basic microbe, *Mycoplasma genitalium,* found (go figure!) in human genitalia, as scaffolding for piecing together the basic elements of synthetic DNA, which will then be modified to make novel life forms. In this way, so sayeth Venter, it could become possible for science to construct brand new carbon-cleaning, virus-vacuuming, or food-forming microbes. "We are wondering if we can come up with a molecular definition of life," Venter told the *Washington Post*.[11]

GUTENBERG'S GENES: Still, the Bible says it took six days to make the whole world. It took SUNY-Stony Brook researchers two years to construct 7,500 genetic letters, and Craig Venter will spend three years creating a single new life form.[12] At this pace, human-manufactured self-replicating organisms have a slow-motion future – but not if Egea Biosciences has its way. The California company has designed automated assembly systems that can already crank down Stony Brook's two years to less than a week – and the enterprise is just revving up. Eventually, Egea expects it will be able to accurately run off a hundred thousand synthetic DNA letters in a matter of weeks.[13] But the real beauty of Egea's new Genesis is a software programme that will allow researchers to literally write DNA that the company's hardware will then manufacture to specification. They call it "word processing for DNA."[14] Fiction could become fact.

THE LETTER OF THE FLAW: Researchers at the University of Florida and at the Scripps Research Institute in La Jolla, California, keen on writing their own bio stories, find the old script confining. Not content with the alphabet soup that makes up the base rungs of the DNA ladder (A [adenine], T, [thymine] C [cytosine] and G [guanine]), Scripps & Co. want to stir up life's "soup opera" with an F (standing for *fluorobenzene* or, perhaps, for Floyd – the name of the chemist manufacturing the artificial base).[15] Going into the lab to blend in a fifth letter is much like going to Las Vegas to gamble on the one-armed bandits – and giving yourself five fruits to organize instead of four. (Four building blocks provide 256 arrangement options; five bumps up the possibilities to 3125.) While this vastly increases the possible diversity of life, it also vastly reduces our chances of getting creation right! This is either the greatest thing since spliced DNA, or will end in the "second-going" from the Garden of Eden. Scripps hopes that expanding DNA's possibilities will allow pharmaceutical companies to roll up their sleeves and get down and dirty with DNA. Others fear they may be right. If this new wave of genetic engineering gives industry the green light to construct exotic new amino acids, proteins and life forms, the end products could contribute as much – or more – to biological weaponry (intentional or otherwise) or to Green Goo as to new medicines.

Plants too tough for bugs to bite? Fire-retardant fur? Or, perhaps, a mighty *Mycoplasma genitalium* that makes Viagra look wimpish? For now, we can only entertain ourselves with speculation.

PROTEIN PRODIGIES: Proteins, the smallest class of biological machines, are proving to be flexible enough to participate in all kinds of extracurricular activities. A team of researchers at Rice University has been experimenting with F-actin, a protein resembling a long, thin fiber, which provides a cell's structural support and controls its shape and movement.[16] Proteins like F-actin allow the transportation of electricity along their length. The researchers hope they can one day be used as biosensors — acting like electrically conductive nanowires. Protein nanowires could replace silicon nanowires, which have been used as biosensors but are more expensive to make and would seem to have a greater environmental impact than their protein counterparts.

Scientists at Duke University (USA) have designed a computer program that will allow them to predict how to change the shape of a protein so that it will bind with something different than it does in nature.[17] Researchers started with proteins from *Escherichia coli* bacteria and then the computer made changes in some of the protein's building blocks (i.e., amino acids) and then calculated how the changes would change its binding behavior. This is the first step toward designing proteins from scratch in order to carry out a particular task.

GOING CELLULAR? One of the most ambitious life-engineering projects to date is programming living cells so that they are able to receive and carry out orders from each other, their environment or human operators – in other words, turning cells into robots.[18] Ron Weiss, an electrical engineer at Princeton University, thinks he may be able to direct cells to build houses, sense toxic agents in the environment or repair damaged organs inside the body. Right now, his cellular robots are tweaked *E. coli* bacteria. He's already figured out how to make them perform digital logic (using proteins to carry signals instead of electrical circuitry) and to get them to communicate with one another. He points out that robots made from living organisms have great potential to succeed because scientists don't have to start from scratch. They can reuse existing mechanisms in the cells, which are already capable of growing, healing and communicating. Weiss has already 'birthed' beakers full of cellular robots – billions of robots of two different species – that can communicate with each other to light up in patterns or timed sequences.[19]

AGENT 0.007? Researchers want to combine the nonbiological capabilities of inorganic matter (such as electrical conductivity and strength) with the capabilities of biomaterial (self-assembly, self-repair and adaptability).[20] At the macro-scale, scientists are already harnessing biological organisms for miniaturized industrial functions. For example, scientists at Tokyo University are remote-controlling cockroaches that have been implanted with microchips in order to use the insects for surveillance functions. Other scientists are betting that whatever a big "coproach" can spy on, a nano-agent could spy on better. Then, last December, Günter von Kiedrowski (Ruhr University of Bochum, Germany) reported that his team is on the verge of making self-replicating nanoscale materials.[21] Researchers can copy the chemical information in complex molecules and instruct them to assemble themselves into pre-described formations through high frequency radio signals. Most importantly, the nano-machines seem to be capable of exponential self-replication. Drexler's nightmare scenario of global ecophagy just got a little closer.

PROMETHEUS UNGLUED: The "glue thing" seems to be a pesky perennial problem for nanotechnologists. Even in Phase 1 nanotech (bulk production of nanoparticles), manufacturers are having a tough time keeping the particles from aggregating. The problem renders the industrial use of carbon nanotubes, especially as transistors, unfeasible. Richard Smalley – one of the pioneers in commercializing carbon nanotubes – knows all about it. The "clump factor" makes Smalley's tubes entangle themselves with one another almost as fast as they are made. One might say that pulling carbon nanotubes apart is like trying to take apart a wristwatch wearing gloves dipped in honey… Recently, however, researchers at DuPont found a solution to the "clumping tube" problem.[22] When the tubes are exposed to strands of DNA, the strands surround individual tubes. An electrical exchange takes place between the DNA and the tubes that allow manufacturers to sort them efficiently by their conductive properties.

GLUELESS AND CLUELESS: With the merger of nanotechnology and biotechnology, we have a whole new set of problems for society – and for government regulators. Much to its own embarrassment, the nanotech industry would have to admit that it has spent more than two decades developing nanoparticle manufacture in the absence of commonly agreed upon laboratory protocols and without adequate government regulation. Now companies will be forced to confront the potential of molecular self-assembly as an industrial manufacturing process. After so many years of saying it couldn't be done, they will be the ones doing it. But molecular self-assembly raises enormous concerns for human well-being and for the environment. Governments must wake up to their obligations; invoke the Precautionary Principle; and establish the review and regulatory mechanisms necessary to protect us all. Times wasting, Watson, the wind is up!

Time Matters

If you think nanotechnology is still a long way off, think again. We made that mistake at the beginning of biotech. Here are a few examples of how rapidly scientific research has moved in the past10-20 years (some of these changes have come about because of nanoscale technologies)…

- In 1996, after 10 years, 1,000 scientists decoded the yeast genome. In 2003, a SARS genome was decoded in eight days.[23]
- In the mid-1970s it took two months to sequence 150 nucleotides. By the time the map of the human genome was completed, scientists could sequence 11 million nucleotides in a few hours.[24]
- Sequencing DNA letters cost $100 each in 1980; 1 Dollar by 2000; and a few pennies today.[25]
- The number of screened drug candidates have, in the last 10 years, increased by three orders of magnitude from 500,000 compounds to approximately 1.5 billion.[26]
- Three years ago, the price of buckyballs – carbon molecules thought to be useful for novel drug delivery systems – was around $600/gram; the cost has come down to $30/gram (a 20-fold decrease) and it's still dropping.[27]

Endnotes

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