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Nanotech News in Living Colour: An Update on White Papers, Red Flags, Green Goo, Grey Goo (and Red Herrings)

Issue: In sharp contrast to the political climate one year ago, the potential health and environmental risks of some nano-scale technologies are now being openly discussed in Europe and North America. In recent months, governments on both sides of the Atlantic have reluctantly conceded that current safety and health regulations may not be adequate to address the special exigencies of nano-scale materials. Ironically, they're talking about the need to be proactive, failing to admit that they're at least one decade late: nanotech products are already commercially available and laboratory workers and consumers are already being exposed to nanoparticles that could pose serious risks to people and the environment. Since mid-2002, ETC Group has called for a moratorium on the use of synthetic nanoparticles in the lab and in any new commercial products until governments adopt "best practices" for research. Even as governments and industry belatedly accept that engineered nanoparticles may require regulation, they insist that more advanced stages of nanotech involving the convergence of nano and bio – nanobiotechnology – are too far over the horizon to consider regulating. They're wrong.

Impact: Only a handful of toxicological studies exist on engineered nanoparticles, but not-so-tiny red flags are flapping everywhere. The world's second largest re-insurance company, Swiss Re, warns that the unknown and unpredictable risks associated with nanotoxicity or nanopollution could make nanotechnology un-insurable. Will governments that are spending billions of dollars of taxpayer money to promote nanotech research adopt rigorous regulatory oversight or will they simply tinker with existing regulations and propose voluntary guidelines? When will they address seriously the wider concerns related to social and economic impacts of technologies converging at the nano-scale?

Financial Stakes: The US government's oft-cited prediction that nanotechnology will generate $1 trillion in products worldwide by 2015 is now out-of-date. Nanotech insiders predict the $1 trillion mark will arrive four years earlier – by 2011.

Policy: Society is not ready for the technological and economic upheaval that nano-scale technologies will deliver. Government regulation is not enough: society must be fully engaged in a discussion of the socio-economic as well as health and environmental implications of nano-scale technologies. These issues must be considered by civil society in open, informed debates at the local, national and international levels. Rather than being forced to scramble and react to one technological wave after the other, the international community must create a new body dedicated to track, evaluate and accept or reject new technologies and their products through an International Convention on the Evaluation of New Technologies (ICENT).

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Introduction: At present there are no regulations explicitly targeting the products of nanotechnology anywhere in the world, even though hundreds of products have reached the market and hundreds more are in the pipeline. In recent months, governments in the USA and in Europe have reluctantly conceded that current safety and health regulations may not be adequate to address the special exigencies of nano-scale materials. Though it is often the case that the substances themselves have been well studied and controlled at larger scales, they have not been similarly vetted at the nano-scale.

NANOTECH 101:

For a basic introduction to nano-scale technologies and an analysis of their implications, see *The Big Down, From Genomes to Atoms: Technologies Converging at the Nano-scale* http://www.etcgroup.org/documents/TheBigDown.pdf

For a critique of the strategy of converging technologies and an analysis of its implications, see "The Little BANG Theory" http://www.etcgroup.org/documents/comBANG2003.pdf

For an introduction to the issues surrounding the toxicity of engineered nanoparticles, see "No Small Matter!" and ETC Group's Occasional Paper "Size Matters!" for a more detailed analysis and a list of products containing nanoparticles. http://www.etcgroup.org/documents/Occ.Paper_Nanosafety.pdf

For a short list of the most worrying scientific findings involving nano-scale technologies, see Ten Toxic Warnings in "Nano's Troubled Waters" http://www.etcgroup.org/documents/GT_TroubledWater_April1.pdf

For a brief analysis of nanotech governance, see "26 Governments Tiptoe Toward Global Nano Governance" http://www.etcgroup.org/documents/globalgovfinal.pdf

The crux of the issue is that a reduction in size – with no change in substance – can make a substance stronger or more reactive or lighter or more water-soluble or more heat-resistant or a better conductor of electricity. Property changes begin to happen with materials 100 nanometers or smaller (a nanometer is one-billionth of a meter). It is these "quantum effects" that make nano-scale materials interesting to scientists and potentially profitable to industry, who are taking advantage of unique property changes in order to create new products and new markets. It should be no surprise that toxicity is another property that can change with a reduction in size: a chemical compound at the micro-scale – titanium dioxide (TiO_2), for example – may be benign, but a nanoparticle of that same TiO_2 could be toxic.

From the few toxicological data that exist, it seems that a particle's size, shape, surface chemistry and composition can all contribute to a changed level of toxicity at the nano-scale. There are no labeling requirements for nanoparticles nor is special toxicity assessment required. And the usual method of controlling toxic substances – based on thresholds calculated by weight or percentage/weight – is not relevant since the toxicity of nanomaterials appears to depend on properties other than mass.[1] John Howard, director of the National Institute for Occupational Safety and Health (NIOSH) acknowledges, "Perhaps for the first time, we need to understand the quantum properties of materials to which people are being exposed."[2]

Nanotech's barren regulatory landscape: Governments appear to be warming up to the idea of regulatory oversight at some point in the future, however distant. Ironically, governments and industry are patting themselves on the back for being proactive, but that moment is long passed. Lawmakers in the US, not wanting to hamper commercial development, are advocating more research and study before Congress or federal agencies step in.[3] John Marburger, the White House's chief science adviser, recently expressed his satisfaction with the *status quo*, saying that he believes government agencies are "doing what is probably appropriate given the indications that we currently have about the dangers or safety of these things."[4]

In the UK, the Royal Society/Royal Academy of Engineering is collaborating with the Health and Safety Executive in preparing a report that will focus on risks associated with nanotechnology, including nanotoxicity, and will "make recommendations for further regulation structures if required."[5] The Royal Society expects to complete its report in the next few months.

Early Warnings and Late Listening

Early Warning	Problem	Late Listening	Action Delayed, years
1602	Tobacco[6]	1970s	>370
Early 1700s	Caffeine[7]	?	?
1866	Fish stocks	1970s	100
1896	Radiation	1928	32
1897	Benzene	1977	80
1898	Asbestos	1931	33
1899	PCBs	1972	73
1907	CFCs	1977	70
1938	Climate change[8]	1997	59
1938	DES	1971	33
1945	Antibiotics	>1970	>25
1952	Acid rain	1979	27
1954	MTBE	2000	46
1962	DDT	1969	7
1970	TBT	1982	12
1970	HGH	1982	12
>1970	BSE	1996	>20
1990	Gene flow from GM crops	>2004	?
2002	Nano-particles	>2004	?
Source: Adapted from *Late Lessons from Early Warnings*: *The Precautionary Principle 1896-2000*, Environmental Issues Report, EEA, 2001, with additional examples from ETC Group.			

The Office of Technology Assessment at the German Bundestag is also tracking nanotech and reported last summer that the state of research into potential environmental and health impacts is "unsatisfactory," that research into societal and ethical impacts "should be initiated now," that comprehensive information for the general public is needed and that "political decisions on the need for nanotechnology specific regulations will have to be taken in the foreseeable future."[9] In Canada, an interdepartmental working group has met twice to discuss nanotech regulation. On June 17-18, representatives from 26 countries met in Washington for a first-ever intergovernmental dialogue on "Responsible Research and Development of Nanotechnology."[10]

Amid these calls to action, more products are coming to market and more surprising findings related to the toxicity of nanoparticles are appearing in the scientific press. Historically, government action has lagged decades behind scientific evidence of harm. The table (left) illustrates the pattern of early warnings and late listening.

An unofficial document generated by the Environmental Protection Agency (EPA) lists well over 100 commercial products based on nanotechnologies (available at http://www.etcgroup.org/documents/nanoproducts_EPA.pdf). These are already on the market or soon will be and include a vast range of uses such as: stain-resistant fabrics for clothing and bedding, cosmetics and sunscreens, tennis balls and racquets, bowling balls, odor-eating socks, time-release perfumed fabrics, paints, capsules carrying hemoglobin (under development), sensors to test water impurities, spray-able vitamins, nanoparticle water purifiers, ski wax, Humvee turrets, long-lasting paper, nanotubes for flat panel display screens, artificial silicon retinas, several drug delivery systems, flash memory devices, diagnostic agents for use in MRI scans.

White Papers: Taken together, three reports released in Europe in May – two from the European Commission in Brussels and one from the insurance industry in Zurich – offer a vista onto the regulatory landscape that is at times obscure, contradictory, sharply focused or fanciful.

First, the European Commission's Health and Consumer Protection Directorate-General released a report based on a March workshop, "Mapping out Nano Risks," where seventeen experts, including toxicologists, philosophers, environmental scientists and risk assessors, convened "to reflect on the implications of these 'technologies of the tiny' for public health, health and safety at work, and the environment."[11] Acknowledging that nanotechnologies are already with us in the form of products on the market, the experts focused on the impacts of nanotechnologies over the next 3–5 years, and thus limited their discussion to the risks associated with manufactured nanoparticles. Given the revved-up research in the field of nanobiotech (see pp. 8-9, below), their narrow focus is inadequate, but at least their near-sighted vision was 20-20: they warned that "some engineered nanoparticles produced via nanotechnology may have the potential to pose serious concerns" and that "adverse effects of nanoparticles cannot be predicted (or derived) from the known toxicity of bulk material."[12] The experts recommended "striving for the elimination whenever possible and otherwise the minimization of the production and unintentional release of nanosized particles."[13] The report's recommendations with regards to policy are more equivocal. The hope is to make "maximum use...of existing legislation" with the understanding that, if, after examination, current legislation is deemed inadequate, it should be revised.[14] The report notes that "a proactive approach should be taken," an unrealistic and perhaps disingenuous recommendation given that elsewhere in the report it is acknowledged "that nanotechnologies have already entered the market and their ubiquitous and horizontal nature makes them difficult to control."[15]

"Currently, the toxicological studies of engineered nanomaterials can be counted on one hand, and more ambitious risk assessments are at least several years away." – **Vicki Colvin**, March 2004[16]

A second report from Brussels released in May – a Communication (an official document of the European Commission, equivalent to a white paper), "Towards a European strategy for nanotechnology" – seems to have been written in a time warp.[17] In the report, the Commission calls on the Member States "to promote the integration of assessment of risk to human health, the environment, consumers and workers at all stages of the life cycle of the technology (including conception, R&D, manufacturing, distribution, use, and disposal)" – a responsible proposal had it been made a decade ago.[18] The Commission's report calls for a three-fold increase in Europe's investment in nanotechnology as a way for European industry "to realise wealth generating products and services."[19]

Given the Commission's interest in creating "a favourable environment for innovation" in nanotechnology,[20] it should have taken notice of a third study (released earlier the same week) produced by the world's second largest re-insurer, Swiss Re. (Insurance companies buy insurance from re-insurers who cover a percentage of the cost of claims paid out to policy holders.) The Swiss Re report, *Nanotechnology: Small Matter, many unknowns*, strongly recommends that the precautionary principle "be applied whatever the difficulties" and that "no reasonable expense should be spared in clarifying the current uncertainties associated with nanotechnological risks."[21] While it may not be surprising for an insurance company to express discomfort with the scientific uncertainty surrounding nanotechnology risks (which could one day translate into product liability), the disconnect between the Commission's calm proposals[22] and Swiss Re's tone of urgency *is* surprising. Ironically, the Commission failed to consider insurer-confidence as one necessary component in a "favourable" commercial environment. Who will develop nano-products if insurance companies are unwilling to protect manufacturers against liability?

On the other side of the Atlantic, too, May 2004 was a month heavy on nanotech discussion:

The director of the US National Institute for Occupational Safety & Health (NIOSH) announced that NIOSH is preparing a "best practices" document for working with nanomaterials.[23] [ETC Group first called for best practices in January 2003] John Howard acknowledged,

> "Very little is known currently about how dangerous nanomaterials are, or how we should protect workers in related industries. Research over the past few

> years finds that nanometer-diameter particles are more toxic than larger particles on a mass basis. The combination of particle size, unique structures, and unique physical and chemical properties, suggests that a great deal of care needs to be taken to ensure adequate worker protection when manufacturing and using nanomaterials."[24]

The agency estimates that one million new US workers will be employed in nanotech-related industries within the next decade.[25]

> "Materials and devices [that] are under development are so far from our current understanding that we can not easily apply existing paradigms to protecting workers." – **John Howard**, Director, NIOSH[26]

A roundtable workshop, sponsored by the US Institute of Medicine (part of the National Academy of Sciences),[27] focused on the scientific uncertainty associated with nanomaterials and the need to educate and communicate with the public in order to prevent public resistance. Much of the same ground was covered in Washington as was covered in the Brussels Health and Consumer Protection meeting – the dearth of toxicological data on engineered nanoparticles, the inability to predict the toxicity of nanomaterials from known bulk behaviour, the need for new toxicology assessment strategies. And there was evidence of the same time warp: Vicki Colvin, the executive director of the Center for Biological and Environmental Nanotechnology at Rice University (CBEN), believes, "We are at an optimal time to study these problems. We are at the birth of a new market. We can shape this area with knowledge as it develops." NIOSH's Andrew Maynard echoed Colvin but opted for a different metaphor: "The train has yet to leave the station. We have the opportunity to work hand-in-hand with people in industry to ensure that regulations and policies are developed that allow the public to get the maximum benefits of nanotechnology." In reality, regulators missed both the train and the birth. It's time to acknowledge that nano's life cycle is nearing a mid-life crisis and that environmental, safety and social concerns demand immediate action.

The US EPA and the Occupational Safety and Health Administration (OSHA) are scrambling to formulate a standardized taxonomy for nanomaterials. Ideally, they want a naming system that is able to indicate a molecule's chemical structure and its behaviour.[28] The problem, according to Kristin Kulinowski of Rice University's CBEN, is "how do you go about naming materials that are chemically and atomically identical to larger structures but clearly have a different activity level?"[29] Without first determining which characteristics contribute to "activity" – such as surface chemistry, chemical structure and/or particle size – and in what ways, the usefulness of a taxonomy, unless it can encompass all these characteristics, is questionable. If, for example, it turns out that chemical structure contributes most to toxicity, a taxonomy that focuses on particle size will be of little use. The EPA has also launched a $4-million research project that will study manufactured nanomaterials, focusing on their fate in the environment and impact on human health.

Under the auspices of the National Nanotechnology Initiative (NNI), an interagency working group is helping coordinate research on health, safety and environmental issues, and another group is looking into future regulation of nanomaterials. According to Clayton Teague, director of the National Nanotechnology Coordination Office, over 11% of the NNI funding annually goes to federal agency efforts for basic research into interactions between nanotechnologies, the environment, and the human body and to applications and implications of this research.[30] (In FY 2004, this amount was $106 million – or 11% of total NNI funding of $961 million.) Given that "applications" and "implications" are lumped together in the US government's 11% estimate, it is difficult to tell how much funding is devoted to determining risk and toxicity and how much is devoted to developing products to be used in the environment or in medicine. The tandem goals of developing commercial products and determining impacts on human health only go hand-in-hand in the most responsible regulatory environment. Given the absence of regulatory oversight presently, the 11% figure is not reassuring.

The National Institute of Environmental Health Sciences' (NIEHS) National Toxicology Program has begun a $3-million project (in fiscal year 2004) to examine through inhalation exposure the toxic and carcinogenic potentials of quantum dots, titanium dioxide and carbon nanotubes. These materials were chosen because they are among the most promising nanomaterials for wide commercial use, even for applications inside the body. The data from these studies are urgently needed, especially since all three nano-scale substances are commercially available. While these studies may take several years to complete, John Bucher, director of federal toxicology research at NIEHS, said he believes the studies may provide short-term results as soon as next year.

Red Flags: More Toxic Warnings? In early April 2004, ETC Group reported on a new study revealing that engineered carbon molecules known as "buckyballs" cause brain damage in fish. (see "Nano's Troubled Waters," available at www.etcgroup.org). We also published "Ten Toxic Warnings" – a list of the biggest, reddest flags on the issue of engineered nanoparticle safety that have come to light over the last couple of years. Just after we published "Ten Toxic Warnings," an eleventh appeared. At the annual meeting of the American Chemical Society in late March, Mark Wiesner of Rice University's CBEN presented preliminary findings indicating that different kinds of nanoparticles do not flow in uniform ways in water.[31] Some nanoparticles are more mobile than others, and some tend to gum up before flowing very far. Wiesner's findings suggest that it will be difficult to predict how nanoparticles behave in groundwater environments or water treatment plants and that generalizations are not tenable – nanomaterials will have to be studied case-by-case, not as a class of materials. Wiesner's findings have the potential to deflate the sails of some nano-advocates who have been exploring the potential role of nanoparticles to clean up groundwater pollution.

Red Herrings: Goo Be Gone? The August 2004 issue of the journal *Nanotechnology* features an opinion piece by Eric Drexler of the Foresight Institute and Chris Phoenix of the Center for Responsible Nanotechnology entitled "Safe Exponential Manufacturing."[32] Drexler is the nanotech guru who is both revered and ridiculed (mostly ridiculed) for his theory that "molecular nanotechnology" (i.e., assembling macro-scale products from molecular-scale parts) could bring about global catastrophe in the form of "grey goo." Drexler's vision of both molecular nanotechnology and grey goo have been fiercely attacked by mainstream scientists on scientific grounds, most notably (and vocally) by Richard Smalley, 1996 Nobel Prize winner.[33]

Drexler's latest article reverses his earlier position. He now asserts that self-replication, while possible, is not a necessary component of MNT. Originally, Drexler imagined that MNT would resemble biological production: he reasoned that assembling molecular-sized pieces would require some kind of parallel manufacturing platform in order for it to be practical. Biology uses RNA and DNA to ensure that a cell contains all the information and equipment necessary to make a copy of itself. The cell carries out biological functions but can also make new cells; those new cells will also be able to carry out biological functions and make new cells, and so on. Drexler imagined a mechanical counterpart to the cell.

The trouble with mechanical self-replication, beyond how to make it work, is that it would require careful control. Drexler likened the danger to cancer cells multiplying unabated and ending in the death of the host organism. Similarly, self-replicating nano-scale machines could escape control and wreak havoc on the global ecosystem. This is what he called "grey goo" – a disaster scenario that captured the imagination of science fiction writers, among others. For the past fifteen years, Drexler's Foresight Institute has dedicated itself to insuring that MNT is developed safely.

In this latest article, Drexler and Phoenix do not renounce the possibility of mechanical self-replication, but say that it will be more efficient, less costly and easier to achieve nano-scale manufacturing using "nanofactories" that do not have a self-replicating capability.[34] The nanofactories would work like conveyor belts and assembly robots, joining nano-scale blocks to form larger ones. The absence of self-replication would vitiate the threat of grey goo.

Drexler's critics in the science community have yet to respond publicly to this revised vision of MNT and it is not clear if they will find his "nanofactories" any more plausible than his self-replicating nanobots. But the media's response to the Drexler-Phoenix article is interesting in its uniformity. The most salient "sound-bite" captured by journalists: grey goo is history. A quick survey of headlines:

Nanotechnology Pioneer Slays 'Grey Goo' Myths (*Science Daily*, June 9, 2004)
Nanotech guru turns back on 'goo' (Paul Rincon, *BBC News*, UK, June 9, 2004)
World safe from nanobot 'grey goo' (*The Register*, UK, June 9, 2004)
Civilisation safe as nanobot threat fades (*Guardian*, UK, June 8, 2004)
'Grey goo' destruction theorist changes tack (*The Scotsman*, UK, June 8, 2004)
Journalists completely missed Drexler and Phoenix's claim that taking away a nano-device's self-replicating capability makes MNT *more* dangerous, not less. They write: "Far more serious [than runaway replication], however, is the possibility that a powerful and convenient manufacturing capacity could be used to make powerful non-replicating weapons in unprecedented quantity, leading to an arms race, war, terrorism, or oppression…A non-replicating weapon could be more rapidly destructive and harder to find, and such a thing might well be created and released deliberately."[35]

Interestingly, about a week before this article in *Nanotechnology* appeared, a report was published by NASA Institute for Advanced Concepts and General Dynamics Advanced Information Systems called "Modeling Kinematic Cellular Automata."[36] It was written by Tihamer Toth-Fejel with Robert Freitas (a research fellow at Drexler's Institute for Molecular Manufacturing) and Matt Moses as consultants. The report concludes that machine self-replicating systems are possible. The "Cellular" in the title refers to modules, not to biological components. As of late June, Drexler and Phoenix have not publicly responded to the NASA report.

Whether Drexler and Phoenix meant to heighten or lessen concerns over MNT (or both) is not clear, but what they did *not* do is bring attention to the rapidly advancing field of nanobiotechnology, which is not *mimicking* biological manufacturing platforms, but *harnessing* them. It is the field of nanobio that poses the most urgent need for foresight and caution.

Look Who's Talkin' Goo:

The promoters of nanotech frequently complain that Drexler's Grey Goo, along with Michael Crichton's fictional novel *Prey*, fan the flames of public misunderstanding of nanotechnology and their fear of it. Philip Bond, US Department of Commerce Undersecretary for Science and Technology, for example, likes to put it this way: "The body politic is susceptible to the virus of fear."[37] But it's useful to look a little more closely at who's talkin' goo. An Internet search[38] produced 60 entries referring to the threat of grey goo as presented by Drexler and Crichton (we'll ignore that Crichton's book is about out-of-control biological organisms and Drexler's goo involved non-biological machines, since everyone seems to lump them together indiscriminately). Not a one of popular culture's usual suspects is represented – no *People Magazine*, *USA Today*, *Time* or *Newsweek*. But you do find *Nature*, *Small Times* (the nanotech industry trade journal), *The Economist*, nanotechweb.org, the testimony of scientists before the US Congress, the UK Parliament and on and on. These folks are wringing their hands over the impact of the "soon to be released" movie adaptation, even though, in reality, 20th Century-Fox has yet to find a director, a producer or any actors for the movie. It doesn't appear to be the naïve and gullible "public" who's glued to the goo saga. Compared to *Seabiscuit*'s 106 weeks on the paperback bestseller list and seven Academy Award nominations for its film adaptation, *Prey*'s measly 8 weeks on the list (never reaching number 1) would have relegated it to flash-in-the-pan status if it weren't for the nanotech boosters keeping it alive.[39] And look who's *not* talking Goo: No ETC Group documents showed up in the search results (we weren't impressed with Crichton's sci-fi effort); apparently Greenpeace wasn't either. And, of course, HRH Prince Charles isn't talking Goo, which should come as no surprise since he has yet to make a public statement regarding nanotech.

Green Goo on the Horizon?

Green goo refers to potential dangers associated with *nanobiotechnology* – the merging of the living and non-living realms at the nano-scale to make hybrid materials and organisms. Nanobiotechnology involves the integration of biological materials with synthetic materials to build new molecular structures or products. Researchers are coaxing living organisms to perform mechanical functions precisely because living organisms are capable of self-assembly and self-replication. With nanobiotech, researchers have the power to create completely new organisms that have never existed on Earth.

Nanobiotech raises many potential concerns: will new life forms, especially those that are designed to function autonomously in the environment, open a Pandora's box of unforeseen and uncontrollable consequences? That's the specter of green goo.

> "The Smalley–Drexler debate is a red herring, and we should refrain from taking a position about it, even if we had the scientific and technological expertise to do so. There is no doubt that molecular manufacturing is feasible once we regard molecular biology itself as a form of it…As soon as we construe the cell as natural machinery, the possibility of tampering with it becomes a forgone conclusion."[40] **– Jean-Pierre Dupuy**, Ecole Polytechnique, Paris and Stanford University, California, March, 2004

It is important to acknowledge that nanobiotechnology does not always involve self-replication, and biological materials can be harnessed for more mundane applications. It is wrong to assume that all nanobiotech research will spawn uncontrollable green goo. Some applications will be more risky than others. For example, nanobio products that incorporate living organisms and are intended for environmental applications are higher "green goo" risks than those that simply incorporate biological proteins in synthetic materials. However, propelled by venture capital and taxpayer dollars, the field of nanobiotech is advancing rapidly, in the absence of public debate or regulatory oversight. For most government policymakers, the implications of nanobiotech aren't even on the radar. The following examples offer a glimpse of current research in nanobiotech:

> "A nanotechnological dream machine is one that can replicate." **– Nadrian C. Seeman**[41]

The June 2004 cover story of *Scientific American*, "Nanotech and DNA," provides an in-depth look at the nascent goal of molecular construction using the double helix.[42] New York University chemist, Nadrian Seeman, explains that DNA is the ideal molecule for building nano-scale structures because scientists know a lot about how DNA functions, it can be easily synthesized and manipulated and DNA strands interact in programmable and predictable ways. "Materials could be constructed – either made of the DNA or made by it – with structures precisely designed at the molecular level," explains Seeman.[43] Potential applications include nanoelectronic components, nanomechanical sensors, switches and tweezers, or more elaborate robotic functions. Researchers are also experimenting with DNA scaffolding to facilitate "rational drug design." (Rather than develop new drugs through trial and error, researchers are studying the three-dimensional structures of molecules, and designing new drugs based upon the structure of its protein target. The idea is that if you know precisely which protein is the culprit for an illness, you can tailor-make another to combat it.)

In November 2003, Israeli scientists became the first researchers to use DNA to construct a working electronic device – they built transistors out of carbon nanotubes using DNA as a template.[44] Physics professor, Dr. Erez Braun, told the *New York Times*, "What we've done is to bring biology to self-assemble an electronic device in a test tube…DNA serves as a scaffold, a template that will determine where the carbon nanotubes will sit. That's the beauty of using biology."[45]

Chemists at New York University announced recently that they've created a two-legged, DNA robot capable of bipedal motion.[46] The nanowalker's legs are 10 nanometers long, made from two strands of DNA that pair up to form a double helix. In the future, the researchers hope that they can coax cells to manufacture DNA-based robots. If nanoscale manufacturing is to become a reality, molecular-scale robots will need to assemble other nanomachines and be able to move molecules and atoms. The next challenge for the DNA nanowalker is to move atomic cargo – possibly a metal atom.

"Don't build a factory. Get a virus to do the work for you." – **Angela Belcher**, MIT professor of material science, and co-founder of Semzyme, Inc.[47]

Angela Belcher, professor of material science at MIT, reported earlier this year that her research team has genetically engineered the DNA of viruses and induced them to produce inorganic materials in the form of tiny wires with magnetic and semiconducting properties.[48] The wires produced by the viruses could one day provide extremely small circuitry in high-speed electronic components. "We programmed the virus to grow a particular material at a particular length," Belcher told *the New York Times*.[49] "Then we burned off the virus and were left with single-crystal semiconductor wires." Belcher refers to her viruses as "a genetic tool kit for growing and organizing nanowires." Belcher has so far induced viruses to grow roughly 30 different inorganic materials, and she plans to work her way through the entire periodic table. She emphasizes that her engineered viruses are benign and don't self-replicate; they are programmed only to self-assemble in a particular place and shape.

Nanobiotechnology is the merging of the living and non-living realms at the nano-scale to make hybrid materials and organisms.

"Biology is the nanotechnology that works." – **Tom Knight**, Senior research scientist, MIT's Computer Science and Artificial Intelligence Laboratory.[50]

The world's first "synthetic biology" conference was held in June 2004. The goal of synthetic biology is to engineer and build machines that work inside cells. Biologists are already crafting libraries of interchangeable DNA parts – so-called "BioBricks" – and assembling them inside microbes to create programmable, living machines.[51] Using BioBricks as raw materials, researchers can now custom design biological manufacturing systems. Synthetic biology sometimes involves the reverse-engineering of life. For example, researchers can design a protein on a computer and then use software to construct the DNA sequence that would produce the protein inside a cell – even if the protein and DNA do not exist in nature.[52] The application of engineering principles to biological systems is becoming a new molecular playing field, but researchers acknowledge that bioengineering is not always a precise and predictable business. "That isn't the way biological systems operate," explains Tom Knight, senior research scientist at MIT's Computer Science and Artificial Intelligence Laboratory. "They reproduce – something that is not part of engineering – and they mutate."[53]

The most high profile practitioner of synthetic biology, perhaps, is Craig Venter of human genome-mapping fame. Back in November 2002, Venter and Nobel Laureate Hamilton Smith announced that they had received a $3 million dollar grant from the US Department of Energy (DOE) to create a new, "minimalist" life form in the lab, which would ultimately be used in "carbon sequestration and energy production." Since then, they've received $9 million more in DOE funds and in November 2003 they announced that they had assembled a bacteriophage consisting of 5,386 base pairs of synthetically produced, commercially available DNA. The researchers at Venter's Institute for Biological Energy Alternatives (IBEA) were able to create the synthetic virus in just 14 days. IBEA researchers are confident that because this virus infects bacteria and is not harmful to humans, animals or plants, it "poses no health or ethical concerns."[54] Once their synthetic microorganisms are ready to be commercialized for the "many vital energy and environmental purposes" they envision, governments should be ready with their own regulations in place and not rely on the self-vetting of scientists and entrepreneurs.

Conclusion:

Nanotech boosters pride themselves on having learned the lessons of biotech, insisting that they won't repeat the missteps and mistakes associated with the introduction of genetically modified crops. Based on current trends, it looks like they're *en route* to a disastrous technology introduction. Are we about to see the low-budget sequel to Biotech Bungles?

Recent history suggests a repeat performance. Thanks to government myopia, for example, the UN biosafety protocol for GM crops came into force eight years after crops were in the field. Unless action is taken now, it looks as though we'll be breathing, wearing and eating the products of nanotechnology, including nanobiotechnology, well before any safeguards are put in place.

On June 17-18 government representatives from over 25 countries met in Washington to discuss "Responsible Research and Development of Nanotechnology." The dialogue was an important first step for national governments to recognize that nanotech's global socio-economic health and environmental impacts must be addressed. Future intergovernmental meetings must be inclusive, transparent and take place under the auspices of the United Nations. A meeting of technical experts from 26 countries is not adequate to address the interests of all countries and civil society – whether engaged in or affected by nanotech activities. In addition to the pressing need to regulate nanoparticles, governments – separately and collectively – need to evaluate, monitor and regulate the impact of nanotech on the socio-economic infrastructure; human rights (especially marginalized people, including the disabled); and on defense and trade.

Rather than being forced to scramble and react to one technological wave after the other, the international community must create a new body dedicated to track, evaluate and accept or reject new technologies and their products through an International Convention on the Evaluation of New Technologies (ICENT).

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Nano-Grammar

Nanotechnology refers to the manipulation of matter at the scale of the nanometer (nm), which is one-billionth of a meter. Atoms and molecules are measured in nanometers.

Nanobiotechnology is the merging of the living and non-living realms at the nano-scale to make hybrid materials and organisms.

Nanoparticles are chemical elements or compounds that measure less than 100 nm in size. Particles less than 100 nm may exhibit "quantum effects," meaning that their physical and chemical and electrical properties may change.

The Action Group on Erosion, Technology and Concentration, formerly RAFI, is an international civil society organization headquartered in Canada. The ETC group is dedicated to the advancement of cultural and ecological diversity and human rights. www.etcgroup.org. The ETC group is also a member of the Community Biodiversity Development and Conservation Programme (CBDC). The CBDC is a collaborative experimental initiative involving civil society organizations and public research institutions in 14 countries. The CBDC is dedicated to the exploration of community-directed programmes to strengthen the conservation and enhancement of agricultural biodiversity. The CBDC website is www.cbdcprogram.org.

As of July 1, 2004, the ETC Group headquarters will have moved from Winnipeg to Ottawa.

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