DOWN ON THE FARM

The Impact of Nano-scale Technologies on Food and Agriculture

November 2004

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SUMMARY

Issue: Nanotechnology, the manipulation of matter at the scale of atoms and molecules (a nanometer [nm] is one-billionth of a meter), is rapidly converging with biotech and information technology to radically change food and agricultural systems. Over the next two decades, the impacts of nano-scale convergence on farmers and food will exceed that of farm mechanisation or of the Green Revolution. Converging technologies could reinvigorate the battered agrochemical and agbiotech industries, igniting a still more intense debate – this time over "atomically-modified" foods. No government has developed a regulatory regime that addresses the nano-scale or the societal impacts of the invisibly small. A handful of food and nutrition products containing invisible, unlabeled and unregulated nano-scale additives are already commercially available. Likewise, a number of pesticides formulated at the nano-scale are on the market and have been released in the environment.

Impact: From soil to supper, nanotechnology will not only change *how* every step of the food chain operates but it will also change *who* is involved. At stake is the world's $3 trillion food retail market, agricultural export markets valued at $544 billion, the livelihoods of some 2.6 billion farming people and the well-being of the rest of us who depend upon farmers for our daily bread.[1] Nanotech has profound implications for farmers (and fisher people and pastoralists) and for food sovereignty worldwide. Agriculture may also be the proving ground for technologies that can be adapted for surveillance, social control and biowarfare.

Policies: The GM (genetically modified) food debate not only failed to address environmental and health concerns, it disastrously overlooked the ownership and control issues. How society will be affected and who will benefit are critical concerns. Because nanotech involves all matter, nano patents can have profound impacts on the entire food system and all sectors of the economy. Synthetic biology and nano-materials will dramatically transform the demand for agricultural raw materials required by processors. Nano-products came to market – and more are coming – in the absence of regulation and societal debate. The merger of nanotech and biotech has unknown consequences for health, biodiversity and the environment. Governments and opinion-makers are running 8-10 years behind society's need for information, public debate and policies.

Recommendations: By allowing nanotech products to come to market in the absence of public debate and regulatory oversight, governments, agribusiness and scientific institutions have already jeopardised the potential benefits of nano-scale technologies. First

No government has developed a regulatory regime that addresses the nano-scale or the societal impacts of the invisibly small.

A handful of food and nutrition products containing invisible and unregulated nano-scale additives are already commercially available. Likewise, a number of pesticides formulated at the nano-scale are on the market and have been released in the environment.

Any efforts by governments or industry to confine discussions to meetings of experts or to focus debate solely on the health and safety aspects of nano-scale technologies will be a mistake. The broader social and ethical issues must also be addressed.

and foremost, society – including farmers, civil society organisations and social movements – must engage in a wide debate about nanotechnology and its multiple economic, health and environmental implications. In keeping with the Precautionary Principle, all food, feed and beverage products (including nutritional supplements) that incorporate manufactured nanoparticles should be removed from the shelves and new ones prohibited from commercialisation until such time as laboratory protocols and regulatory regimes are in place that take into account the special characteristics of these materials, and until they are shown to be safe. Similarly, nano-scale formulations of agricultural input products such as pesticides, fertilisers and soil treatments should be prohibited from environmental release until a new regulatory regime specifically designed to examine these products finds them safe. Governments must also move immediately to establish a moratorium on lab experimentation with – and the release of – "synthetic biology" materials until society can engage in a thorough analysis of the health, environmental and socio-economic implications. Any efforts by governments or industry to confine discussions to meetings of experts or to focus debate solely on the health and safety aspects of nano-scale technologies will be a mistake. The broader social and ethical issues must also be addressed.

At the intergovernmental level, the Food and Agriculture Organization's (FAO) standing committees and commissions on agriculture, fisheries, forestry and genetic resources should be monitoring and debating the new technologies – with active input and feedback from peasant and small farmers' organisations. FAO's Committee on Commodity Problems should immediately begin to examine the socio-economic implications for farmers, food safety and national governments. The UN/FAO Committee on World Food Security should be discussing the implications for agro-terrorism as well as food sovereignty. Additionally, the UN Convention on Biological Diversity should review nanobiotech's potential impact, especially on biosafety. Other UN agencies such as the United Nations Conference on Trade and Development (UNCTAD) and International Labour Organization (ILO) should join with FAO to examine the impact of nanotech on the ownership and control of the world's food supply, commodities and labour. The international community should establish a body dedicated to tracking, evaluating and monitoring new technologies and their products through an International Convention for the Evaluation of New Technologies (ICENT).

INTRODUCTION – THE LAY OF THE LAND

In an interview last year, Nobel laureate and nanotech entrepreneur Richard Smalley expressed his frustration with what he viewed as exaggerated concerns over the safety of nanotechnology: "After all, we're not advising that you eat nanotech stuff," Smalley told *The New Statesman*.[2]

Oops! About the time Dr. Smalley was telling consumers not to worry, the nanotech market for food and food processing was estimated to be in excess of $2 billion and projected to surge to more than $20 billion by 2010.[3] Like Dr. Smalley, most of us don't have a clue that food products containing nano-scale additives are already on the grocery store shelf. But don't blame Dr. Smalley for failing to notice nano-scale ingredients in his fruit juice – after all, they're invisible, products aren't labelled and require no special regulatory oversight.

In January 2003, ETC Group published *The Big Down*, civil society's first effort to describe and analyse technological convergence at the nano-scale. Our report had a remarkable impact – catalysing public debate and media attention around the world and prompting many governments and scientific institutions to undertake their own studies and to critique their own research initiatives. *Down on the Farm* is a first look at applications of nanotech to food and agriculture – technologies with the potential to revolutionise and further consolidate power over the global food supply. This report is the first in a series that ETC will issue over the next two years on the potential impacts of nanotechnologies on different economic and social sectors.

Down on the Farm is not an invective against technological change or a call to preserve the *status quo*. Rather, it is an attempt to confront the reality that significant technological changes are already underway and that they will affect the whole of society. Some of the reverberations are easily predicted; others are not. At the same time, this report does not accept that nanotech's "extreme makeover" of food and agriculture is a foregone conclusion. Our report looks at the state of the art and the potential implications for the future. *Down on the Farm* is offered as a starting place for a much wider societal debate that must include farmers' organisations, social movements, civil society and South governments. Until now, participants in the discussion have been largely limited to scientists, investors and industry executives, primarily in OECD nations.

ETC Group acknowledges that in a just and judicious context, nanotech could bring useful advances that might benefit the poor (the fields of sustainable energy, clean water and clean production appear promising; applications to food and agriculture appear less so). History shows

"After all, we're not advising that you eat nanotech stuff."

–Nobel laureate and nanotech entrepreneur Richard Smalley

Based on current trends, atom-scale technologies will further concentrate economic power in the hands of giant multinational corporations. How likely is it that the poor will benefit from a technology that is outside their control?

The nano-scale moves matter out of the realm of conventional chemistry and physics into "quantum mechanics" – imparting unique characteristics to traditional materials – and unique health and safety risks.

that the introduction of major new technologies results in sudden economic upheavals. The poor and marginalised are seldom in a position to foresee or adjust quickly to abrupt economic changes. Among the most vulnerable will be small-scale farmers and agricultural workers who produce raw commodity exports in the developing world. Based on current trends, atom-scale technologies will further concentrate economic power in the hands of giant multinational corporations. How likely is it that the poor will benefit from a technology that is outside their control?

Global demand for nano-scale materials, tools and devices was an estimated $7.6 billion in 2003,[4] with $1 trillion pretensions by 2011.[5] Nanotechnology has elbowed itself into pole position in the research budgets of the world's largest economies and companies. Nanotech applications in the high-tech industries – computers, medicine and defense – are the poster children for tiny tech's awesome potential. By contrast, the applications of nanotech to food and agricultural industries are just beginning to attract attention and are often overlooked, even by nanotech insiders. (The *2004 Nanotech Report*, a 650-page, two-volume market research report produced by Lux Research barely mentions applications related to food and agriculture.) Though the full implications of nanotech in food and agriculture can't be known in late 2004, they are sure to be profound.

Converging Technologies, aka BANG

In *Down on the Farm*, we attempt to identify the key nano-scale technologies that are enabling industry to reshape our agricultural and food systems. Our focus is on those technologies migrating to the nano-scale and converging with biotech, information technologies and cognitive sciences. (See Converging Technologies box on facing page.) In both Europe and the USA, researchers and policy makers have recognised the transformative potential of converging technologies. More than the individual technologies described in this report, it is their synergetic nature that will fundamentally change food and farming as we know it.

Size Matters: The nano-scale moves matter out of the realm of conventional chemistry and physics into "quantum mechanics" – imparting unique

Converging Technologies: NBIC, CTEKS or BANG

In both Europe and the USA, researchers and policy makers have recognised the potential of converging technologies to transform every sector of the economy as well as our own understandings of what it means to be human.

The US government refers to convergence as **NBIC** (the integration of Nanotechnology, Biotechnology, Information Technology and Cognitive Science) and envisions that the mastery of the nano-scale domain will ultimately amount to the mastery of all of nature.[6] At the molecular level, in the NBIC worldview, there exists a "material unity" so that all matter – *life* and *non-life* – is indistinguishable and can be seamlessly integrated. The goal of NBIC is to "improve human performance," both physically and cognitively (e.g., on the battle-field, on the wheat field, on the job).

The European Commission recently released a report on Converging Technologies prepared by the High Level Expert Group "Foresighting the New Technology Wave."[7] Distancing itself from the US agenda of "improving human performance," the Group emphasised a "specifically European approach to CTs."[8] The Group proposed *Converging Technologies for the European Knowledge Society* (**CTEKS**), envisioning different research programs that address specific problems such as "CTs for natural language processing" or "CTs for the treatment of obesity."[9] The Group notes that while CT applications offer "an opportunity to solve societal problems, to benefit individuals, and to generate wealth," they also pose "threats to culture and tradition, to human integrity and autonomy, perhaps to political and economic stability."[10]

ETC Group refers to converging technologies as **BANG**, an acronym derived from *bits*, *atoms*, *neurons* and *genes*, the basic units of transformative technologies. The operative unit in information science is the **Bit**; nanotechnology manipulates **Atoms**; cognitive science deals with **Neurons** and biotech exploits the **Gene**. Together they make B.A.N.G. In early 2003, ETC Group warned that BANG will profoundly affect national economies, trade and livelihoods – including food and agricultural production – in countries of both the South and North.[11] BANG will allow human security and health – even cultural and genetic diversity – to be firmly in the hands of a convergent technocracy.

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characteristics to traditional materials – and unique health and safety risks. With only a reduction in size (to under 100 nm) and no change in substance, a material's properties can change dramatically. Characteristics – such as electrical conductivity, reactivity, strength, colour and, especially importantly, toxicity – can all change in ways that are not easily predicted. For example, a substance that is red when it is a meter wide may be green when its width is only a few nanometers; carbon in the form of graphite is soft and malleable; at the nano-scale, carbon can be stronger than steel. A single gram of catalyst material that is made of 10-nanometer particles is about 100 times more reactive than the same amount of the same material made of one-micrometer sized particles (a micron is 1,000 times bigger than a nanometer).

Aside from the serious toxicity implications of quantum property changes, it is not always necessary or useful to draw a distinct line between nano-scale and micro-scale applications: "nano-scale" is not necessarily the goal in every case; "micro-scale" may be adequate for some purposes and for others, both nano-scale and micro-scale devices, materials or particles may serve equally well. Both may prove disruptive.

Keeping Nanoparticles Out of the Environment

In 2002, ETC Group called for a moratorium on the release of manufactured nanoparticles until lab protocols are established to protect workers and until regulations are in place to protect consumers. (The life expectancy of Ph.D. chemists working in US labs is already about ten years less than their non-lab counterparts.[12] Given that history, why delay in taking precautionary steps?) The body of evidence supporting the call for a moratorium is steadily growing.[13]

Applying nanoparticles in agriculture raises environmental and health concerns since nanoparticles appear to demonstrate a different toxicity than larger versions of the same compound. In 2003, Dr. Vyvyan Howard, founding editor of the *Journal of Nanotoxicology,* undertook a review of scientific literature on nanoparticle toxicity for ETC Group. Dr. Howard concluded that nanoparticles as a class appear to be more toxic as a result of their smaller size, also noting that nanoparticles could move more easily into the body, across protective membranes such as skin, the blood brain barrier or perhaps the placenta.

A study published by Dr. Eva Oberdörster in July 2004 found that large mouth bass (fish) exposed to small amounts of buckyballs (manufactured nanoparticles of 60 carbon atoms) resulted in rapid onset of damage in the brain and the death of half the water fleas living in the water in which the fish lived.[14] Other studies show that nanoparticles can move in unexpected ways through soil, and potentially carry other substances with them. Given the knowledge gaps, many expert commentators are recommending that release of engineered nanoparticles be minimized or prohibited in the environment:

"Release of nano-particles should be restricted due to the potential effects on environment and human health." – Haum, Petschow, Steinfeldt, "Nanotechnology and Regulation within the framework of the Precautionary Principle. Final Report for ITRE Committee of the European Parliament," February 2004.[15]

"There is virtually no information available about the effect of nanoparticles on species other than humans or about how they behave in the air, water or soil, or about their ability to accumulate in food chains. Until more is known about their environmental impact we are keen that the release of nanoparticles and nanotubes to the environment is avoided as far as possible. Specifically we recommend as a precautionary measure that factories and research laboratories treat manufactured nanoparticles and nanotubes as if they were hazardous waste streams and that the use of free nanoparticles in environmental applications such as remediation of groundwater be prohibited." – Royal Society and Royal Academy of Engineering, "Nanoscience and Nanotechnologies: Opportunities and uncertainties," July 2004

"Release of nano-particles should be restricted due to the potential effects on environment and human health."

– "Nanotechnology and Regulation within the framework of the Precautionary Principle. Final Report for ITRE Committee of the European Parliament," February 2004

"Crop genetic resources exist in two complementary and intertwined forms – crop genes and human knowledge about the species, including the knowledge that has been transmitted over generations of farmers. Indigenous knowledge, as much as crop genes, is part of the evolutionary system of a crop species, determining traits that will or will not be passed on."

– Stephen B. Brush, *Farmers' Bounty*, 2004

I. NANO-AGRICULTURE: DOWN ON THE FARM

In December 2002, the United States Department of Agriculture (USDA) drafted the world's first "roadmap" for applying nanotechnology to agriculture and food.[16] A wide collection of policy makers, land grant university representatives and corporate scientists met at Cornell University (New York, USA) to share their vision of how to remake agriculture using nano-scale technologies. The USDA's nanotech research has been supported by the US government's National Nanotechnology Initiative (NNI) since 2003. But USDA receives a relatively tiny sliver of the funding pie – the agency is expected to receive $5 million in nanotech funds in FY2005 – a mere 0.5% of the total NNI funds.

Agriculture, according to the new nano-vision, needs to be more uniform, further automated, industrialized and reduced to simple functions. In our molecular future, the farm will be a wide area biofactory that can be monitored and managed from a laptop and food will be crafted from designer substances delivering nutrients efficiently to the body. Nanobiotechnology will increase agriculture's potential to harvest feedstocks for industrial processes. Meanwhile tropical agricultural commodities such as rubber, cocoa, coffee and cotton – and the small-scale farmers who grow them – will find themselves quaint and irrelevant in a new nano-economy of "flexible matter" in which the properties of industrial nanoparticles can be adjusted to create cheaper, "smarter" replacements.

Just as GM agriculture led to new levels of corporate concentration all along the food chain, so proprietary nanotechnology, deployed from seed to stomach, genome to gullet, will strengthen the grasp of agribusiness over global food and farming at every stage – all, ostensibly, to feed the hungry, safeguard the environment and provide consumers with more choice.

For two generations, scientists have manipulated food and agriculture at the molecular level. Agro-Nano connects the dots in the industrial food chain and goes one step further down. With new nano-scale techniques of mixing and harnessing genes, genetically modified plants become atomically modified plants. Pesticides can be more precisely packaged to knock-out unwanted pests, and artificial flavourings and natural nutrients engineered to please the palate. Visions of an automated, centrally-controlled industrial agriculture can now be implemented using molecular sensors, molecular delivery systems and low-cost labour.

Downsized Seeds

Re-organising natural processes 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 fertilisers and, by doing so, 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 to preserve their herbicides. Now nanotech companies are going down the same path – looking for new ways that life and matter can serve the needs of industry.

Farmers conduct most of the world's plant breeding through selecting, saving and breeding seeds and, in addition, are the first conservers of the plant genetic diversity essential to the world's food supply, both present and future. This process – thousands of years old – requires neither an atomic force microscope nor a Ph.D. in biochemistry. If farmers have neither control over new technologies affecting them, nor the opportunity to participate in setting research priorities, trends in nano-scale science like those identified below are likely to consolidate corporate power and marginalize Farmers' Rights.

Gene therapy for plants:
Researchers are developing new techniques that use nanoparticles for smuggling foreign DNA into cells. For example, at Oak Ridge National Laboratory, the US Department of Energy lab that played a major role in the production of enriched uranium for the Manhattan Project, researchers have hit upon a nano-technique for injecting DNA into millions of cells at once. Millions of carbon nanofibres are grown sticking out of a silicon chip with strands of synthetic DNA attached to the nanofibres.[17] Living cells are then thrown against and pierced by the fibres, injecting the DNA into the cells in the process:

"It's like throwing a bunch of baseballs against a bed of nails...We literally throw the cells onto the fibers, and then smush the cells into the chip to further poke the fibers into the cell." – Timothy McKnight, engineer, Oak Ridge Laboratory[18]

Once injected, the synthetic DNA expresses new proteins and new traits. Oak Ridge has entered into collaboration with the Institute of Paper Science and Technology in a project aimed to use this technique for genetic manipulation of loblolly pine, the primary source of pulpwood for the paper industry in the USA.

Unlike existing genetic engineering methods, the technique developed by Oak Ridge scientists does not pass modified traits on to further generations because, in theory, the DNA remains attached to the carbon nanofibre, unable to integrate into the plants' own genome. The implication is that it would be possible to reprogram cells for one time only. According to Oak Ridge scientists, this relieves concerns about gene flow associated with genetically modified plants, where genes are

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"We don't consider atomically modified rice any safer or more socially acceptable than genetically modified rice. It sounds like the same high-tech approach that does not address our needs and could cause severe hardships for Thai rice farmers."[26]

– Witoon Lianchamroon, Biodiversity Action Thailand (BIOTHAI)

transferred between unrelated organisms or are removed or rearranged within a species. If the new technique enables researchers to selectively switch on or off a key trait such as fertility, will seed corporations use the tiny terminators to prevent farmers from saving and re-using harvested seed – compelling them to return to the commercial seed market every year to obtain the activated genetic trait they need?

This approach also raises a number of safety questions: what if the nanofibres were ingested by wildlife or humans as food? What are the ecological impacts if the nanofibres enter the cells of other organisms and cause them to express new proteins? Where will the nanofibres go when the plant decomposes in the soil? Carbon nanofibres have been compared to asbestos fibres because they have similar shapes. Initial toxicity studies on some carbon nanofibres have demonstrated inflammation of cells. A study by NASA found inflammation in the lungs to be more severe than in cases of silicosis,[19] though Nobel laureate Richard Smalley, Chairman of Carbon Nanotechnologies Inc. gives little weight to these concerns: "We are confident there will prove out to be no health hazards but this [toxicology] work continues."[20]

Atomically Modified Seeds: In March 2004, ETC Group reported on a nanotech research initiative in Thailand that aims to atomically modify the characteristics of local rice varieties.[21] In a three-year project at Chiang Mai University's nuclear physics laboratory, researchers "drilled" a hole through the membrane of a rice cell in order to insert a nitrogen atom that would stimulate the rearrangement of the rice's DNA.[22] So far, researchers have been able to alter the colour of a local rice variety from purple to green. In a telephone interview, Dr. Thirapat Vilaithong, director of Chiang Mai's Fast Neutron Research Facility, told Biodiversity Action Thailand (BIOTHAI) that their next target is Thailand's famous Jasmine rice.[23] The goal of their research is to develop Jasmine varieties that can be grown all year long, with shorter stems and improved grain colour.[24]

One of the attractions of this nano-scale technique, according to Dr. Vilaithong, is that, like the Oak Ridge project, it does not require the controversial technique of genetic modification. "At least we can avoid it," Dr. Vilaithong, said.[25] Civil society

organisations in Thailand are sceptical of the benefits.

Nanocides: Pesticides via Encapsulation

Pesticides containing nano-scale active ingredients are already on the market, and many of the world's leading agrochemical firms are conducting R&D on the development of new nano-scale formulations of pesticides (see below, Gene Giants: Encapsulation R&D). For example:

BASF of Germany, the world's fourth ranking agrochemical corporation (and the world's largest chemical company), recognizes nanotech's potential usefulness in the formulation of pesticides.[27] BASF is conducting basic research and has applied for a patent on a pesticide formulation, "Nanoparticles Comprising a Crop Protection Agent," that involves an active ingredient whose ideal particle size is between 10 and 150 nm.[28] The advantage of the nano-formulation is that the pesticide dissolves more easily in water (to simplify application to crops); it is more stable and the killing-capacity of the chemical (herbicide, insecticide or fungicide) is optimized.

Bayer Crop Science of Germany**,** the world's second largest pesticide firm, has applied for a patent on agrochemicals in the form of an emulsion in which the active ingredient is made up of nano-scale droplets in the range of 10-400 nm.[29] (An emulsion is a material in which one liquid is dispersed in another liquid – both mayonnaise and milk are emulsions.) The company refers to the invention as a "microemulsion concentrate" with advantages such as reduced application rate, "a more rapid and reliable activity" and "extended long-term activity."

Syngenta, headquartered in Switzerland, is the world's largest agrochemical corporation and third largest seed company. Syngenta already sells pesticide products formulated as emulsions containing nano-scale droplets. Like Bayer Crop Science, Syngenta refers to these products as microemulsion concentrates. For example, Syngenta's Primo MAXX Plant Growth Regulator (designed to keep golf course turf grass from growing too fast) and its Banner MAXX fungicide (for treating golf course turf grass) are oil-based pesticides mixed with water and then heated to create an emulsion. Syngenta claims that both products' extremely small particle size of about 100 nm (or 0.1 micron) prevents spray tank filters from clogging, and the chemicals mix so completely in water that they won't settle out in the spray tank.[30] Banner MAXX fungicide will not separate from water for up to one year, whereas fungicides that contain larger particle size ingredients typically require agitation every two hours to prevent misapplications and clogging in the tank.[31] Syngenta claims that the particle size of this formulation is about 250 times smaller than typical pesticide particles. According to Syngenta, it is absorbed into the plant's system and cannot be washed off by rain or irrigation.[32]

Many of the world's leading agrochemical firms are conducting R&D on the development of new nano-scale formulations of pesticides.

According to the US Environmental Protection Agency (EPA), a pesticide newly formulated as a nano-emulsion would not require regulatory re-examination since it would not be "a new chemical, new chemical form, nor a 'significant' new use."[33]

ETC Group is not questioning the Gene Giants' compliance with current pesticide regulations. Pesticides that contain nano-scale active ingredients do not require special regulatory review according to the US Environmental Protection Agency (EPA): a pesticide newly formulated as a nano-emulsion would not require regulatory re-examination since it would not be "a new chemical, new chemical form, nor a 'significant' new use."[33] Dr. Barbara Karn at the Office of Research & Development at EPA states that "the pesticide will not behave any differently chemically when in an emulsion."[34] She explains further that "there are no differences in properties of the bulk pesticide solution due to the incorporation of these droplets, and the pesticide chemicals themselves do not exhibit different properties."[35] Surprisingly, EPA does not consider Syngenta's nano-emulsions as nano-material based or nanotechnology. EPA's response highlights the lack of clarity regarding what is considered nanotechnology. While the agrochemical industry is exploiting size to change the characteristics and behaviour of its pesticides, the EPA concludes that, in the case of nano-emulsions, size does not matter.

Gene Giants – Encapsulation R&D: A more sophisticated approach to formulating nano-scale pesticides involves encapsulation – packaging the nano-scale active ingredient within a kind of tiny "envelope" or "shell." Both food ingredients and agrochemicals in microencapsulated form have been on the market for several decades. According to industry, the reformulation of pesticides in microcapsules has triggered "revolutionary changes," including the ability to control under what conditions the active ingredient is released (see box below). According to the agrochemical industry, re-formulating pesticides in microcapsules can also extend patent protection, increase solubility, reduce the contact of active ingredients with agricultural workers[36] and may have environmental advantages such as reducing run-off rates.

US-based **Monsanto,** the world's largest purveyor of GM seed technology and the manufacturer of blockbuster herbicide RoundUp, already sells a number of microencapsulated pesticides. In 1998 Monsanto entered an agreement with Flamel Nanotechnologies to develop "Agsome" nanocapsules of Roundup, which might be more chemically efficient than the conventional formula. However, according to a spokesman for Flamel, the real driver for the deal was Monsanto's desire to secure a patent on Roundup for another 17-20 years.[37] Monsanto's agreement with Flamel broke down two years later for unspecified reasons.

Syngenta is a self-described "world leader" in microcapsule technology and claims to have pioneered their use in pesticides.[38] Each liter of Syngenta's trademarked Zeon microencapsulated formulation contains about 50 trillion capsules that are

designed to be 'quick release,' breaking open on contact with the leaf of the plant.[39] Because the capsules strongly adhere to leaves they resist being washed away by rainfall. A similar microencapsulated product from Syngenta is being applied to seeds as a treatment to control soil pests of germinating seedlings.

Syngenta has developed another encapsulated insecticide for household pests like cockroaches, ants and beetles as well as one designed as a long-lasting treatment for mosquito-netting. Syngenta scientists are researching triggered-release capsules whose outer shell can be opened only in special conditions. For

Encapsulating Control

Nanotechnology enables companies to manipulate the properties of the outer shell of a capsule in order to control the release of the substance to be delivered.' Controlled release' strategies are highly prized in medicine since they can allow drugs to be absorbed more slowly, at a specific location in the body or at the say-so of an external trigger. With potential applications across the food chain (in pesticides, vaccines, veterinary medicine and nutritionally-enhanced food), these nano- and micro-formulations are being developed and patented by agribusiness and food corporations such as Monsanto, Syngenta and Kraft.

Examples of nano and microcapsule designs:

- **Slow release** – the capsule releases its payload slowly over a longer period of time (e.g., for slow delivery of a substance in the body)[45]
- **Quick-release** – the capsule shell breaks upon contact with a surface (e.g. when pesticide hits a leaf)[46]
- **Specific release** – the shell is designed to break open when a molecular receptor binds to a specific chemical (e.g., upon encountering a tumour or protein in the body)[47]
- **Moisture release** – the shell breaks down and releases contents in the presence of water (e.g., in soil)[48]
- **Heat-release** – the shell releases ingredients only when the environment warms above a certain temperature[49]
- **pH release** – nanocapsule breaks up only in specific acid or alkaline environment (e.g., in the stomach or inside a cell)[50]
- **Ultrasound release** – the capsule is ruptured by an external ultrasound frequency[51]
- **Magnetic release** – a magnetic particle in the capsule ruptures the shell when exposed to a magnetic field[52]
- **DNA nanocapsule** – the capsule smuggles a short strand of foreign DNA into a living cell which, once released, hijacks cell machinery to express a specific protein (used for DNA vaccines)[53]

Nanotechnology enables companies to manipulate the properties of the outer shell of a capsule in order to control the release of the substance to be delivered.

example, Syngenta holds a patent on a "gutbuster" microcapsule that breaks open in an alkaline environment such as the stomachs of certain insects.[40]

Syngenta boasts that "microencapsulation stands out as a technique capable of producing such new and surprising effects from known ingredients that sales grow as rapidly as if a brand new active ingredient had been invented!"[41] In other words, formulating encapsulated pesticides offers more bang for the pesticide buck because the small size optimizes the effectiveness of the pesticide and the capsule can be designed to release its active ingredient under a variety of conditions. Syngenta is also researching nano-encapsulated pesticides.[42]

It is clear that the impetus for formulating pesticides on the nano-scale is the changed behavior of the reformulated product: the strength of the active ingredient can be maximized and biological activity is longer-lasting.

ETC Group is not in a position to evaluate whether or not pesticides formulated as nano-sized droplets – either encapsulated or in the form of nano-emulsions – exhibit property changes akin to the "quantum effects" exhibited by engineered nanoparticles. However, it is clear that the impetus for formulating pesticides on the nano-scale is the changed behavior of the reformulated product: the strength of the active ingredient can be maximized and biological activity is longer-lasting (and, in the case of encapsulated pesticides, the release of the active chemical can be controlled).

In other areas of use such as cosmetics, nano-emulsions are regarded as a very effective mechanism for delivering oils across the skin.[43] They can also exhibit antibacterial properties as a mechanical result of the small droplets fusing with and rupturing bacterial cell walls. Nano-emulsions can be used to damage blood cells and sperm cells (e.g., as contraceptives).[44] In the case of nano-emulsion pesticides, it is not clear whether the anti-bacterial properties are relevant and/or have been assessed for their impacts on soil and other microbes.

Sizing Up Nanocaps and Microcaps: According to industry, encapsulation offers the following advantages:[41]

- Longer-lasting biological activity
- Less soil binding for better control of pests in soil
- Reduces worker exposure
- Improves safety by removing flammable solvents
- Reduces damage to crops
- Less pesticide lost by evaporation
- Less effect on other species
- Reduced environmental impact
- Prevents degradation of active ingredients by sunlight
- Makes concentrated pesticide safe and easy to handle by growers

Concerns raised by encapsulation:

- Both biological activity and environmental/worker exposure can be longer-lasting; Beneficial insects and soil life may be affected.
- Could nano-scale pesticides be taken up by plants and smuggled into the food chain?

• Pesticides can be more easily aerosolized as a powder or droplets – therefore inhale-able, and perhaps a greater threat to human health and safety.

• Could pesticides formulated as nanocapsules or nano-scale droplets exhibit different toxicity and enter the body and affect wildlife through new exposure routes, for example, across skin (see box on page 7, Keeping Nanoparticles Out of the Environment).

• Potential for use as a bioweapons delivery vehicle.

• What other external triggers might affect the release of the active ingredient (e.g., chemical binding, heat or break down of the capsule)?

• Microcapsules are similar in size to pollen and may poison bees and/or be taken back to the hives and incorporated in honey. Because of their size, "micro-encapsulated insecticides are considered more toxic to honey bees than any formulation so far developed."[55] Will nanocapsules be more lethal?

• It is not known how 'unexploded' nanocapsules will behave in the human gut if ingested with food.

Implications of Encapsulation for Nanobioweaponry:
Nanocapsules and microcapsules make an ideal vehicle for delivering chemical and biological weapons because they can carry substances intended to harm humans as easily as they can carry substances intended to kill weeds and pests. By virtue of their small size, DNA nanocapsules may be able to enter the body undetected by the immune system and then become activated by the cells' own mechanisms to produce toxic compounds. The increased bioavailability and stability of nano-encapsulated substances in the environment may offer advantages to the Gene Giants, but the same features could make them extremely potent vehicles for biological warfare. In addition, because of their increased bioavailability only a small quantity of the chemical is needed.

When programmed for external triggers such as ultrasound or magnetic frequencies, activation can be controlled remotely, suggesting a number of grim scenarios. Could agrochemical/seed corporations remotely activate triggers to cause crop failure if the farmer infringes the company's patent or fails to follow prescribed production practices? What if nanocapsules containing a potent compound are added to a regional water supply by a foreign aggressor or terrorist group?

According to The Sunshine Project, the "Australia Group" (a group of 24 industrialized nations) recently proposed that microencapsulation technologies be added to a common list of technologies banned from export to 'untrustworthy' governments for fear of use as bioweapons.[57] Documents obtained by Sunshine Project also show that the US military funded the University of New Hampshire in 1999-2000 to develop microcapsules containing corrosive and anaesthetic (that is, to

"The ultimate expression of this technology would be development of a vector that encapsulates, protects, penetrates, and releases DNA-based BW [biological warfare] agents into target cells but is not recognised by the immune system. Such a 'stealth' agent would significantly challenge current medical counter-measure strategies."

– Defense Intelligence Agency analysts, US government, Washington, DC.[56]

Could agrochemical/seed corporations remotely activate triggers to cause crop failure if the farmer infringes the company's patent or fails to follow prescribed production practices?

produce unconsciousness) chemicals. The documents describe how the microcapsules could be fired at a crowd, corrode protective gear and then break open in contact with the moisture on human skin.[58]

Precision Agriculture: from Smart Dust to Smart Fields

Robo-farming with Nano-sensors: "Precision farming," also known as site-specific management, describes a bundle of new information technologies applied to the management of large-scale, commercial agriculture. Precision farming technologies include, for example: personal computers, satellite-positioning systems, geographic information systems, automated machine guidance, remote sensing devices and telecommunications.

"It is 5 a.m. A Midwest farmer sips coffee in front of a computer. Up-to-the-minute satellite images show a weed problem in a field on the northwest corner of the farm. At 6:30 a.m., the farmer drives to the exact location to apply a precise amount of herbicide." – Illinois Laboratory for Agricultural Remote Sensing press release[59]

Precision farming relies upon intensive sensing of environmental conditions and computer processing of the resulting data to inform decision-making and control farm machinery. Precision farming technologies typically connect global positioning systems (GPS) with satellite-imaging of fields to remotely sense crop pests or evidence of drought and then automatically adjust levels of irrigation or pesticide applications as the tractor moves around the field. Yield monitors fitted to combine harvesters measure the amount and moisture levels of grains as they are harvested on different parts of a field, generating computer models that will guide decisions about application or timing of inputs. Precision agriculture promises higher yields and lower input costs by streamlining agricultural management and thereby reducing waste and labour costs. It also offers the potential to employ less skilled, and therefore cheaper, farm machinery operators since, theoretically, such systems can simplify and centralize decision-making. In the future, precision farming will resemble robotic farming as farm machinery is designed to operate autonomously, continuously adapting to incoming data.

If they function as designed, ubiquitous wireless sensors (see below) will become an essential tool for bringing this vision of precision farming to maturity. When scattered on fields, networked sensors are expected to provide detailed data on crop and soil conditions and relay that information in real time to a remote location so that crop scouting will no longer require the farmer (or agribusiness executive) to get their boots dirty. Since many of the conditions that a farmer may want to monitor (e.g., the presence of plant viruses or the level of soil nutrients) operate at the nano-scale, and because surfaces can be altered at the

nano-scale to bind selectively with particular biological proteins, sensors with nano-scale sensitivity will be particularly important in realizing this vision.

Leading the choir of enthusiasm for "smart fields" laced with wireless nanosensors is the US Department of Agriculture (USDA). In what they originally dubbed "Little Brother Technology,"[61] the agency identifies agricultural sensor development as one of their most important research priorities.[62] The USDA is working to promote and develop a total "Smart Field System" that automatically detects, locates, reports and applies water, fertilisers and pesticides – going beyond sensing to automatic application.

Industry is already experimenting with wireless sensor networks for agriculture. Computer chip maker Intel, whose chips have nano-scale features,[63] has installed larger wireless sensor nodes (called 'motes') throughout a vineyard in Oregon, USA.[64] The sensors measure temperature once every minute and are the first step towards fully automating the vineyard. Intel also employs ethnographers and social scientists who study behaviour of vineyard workers to help design the system. Intel's vision for wireless networks is 'proactive computing' – ubiquitous systems that anticipate the needs of the farmer and act before they are asked to do so. In a similar venture, multinational consulting firm Accenture has partnered with mote-maker Millennial Net to run a network of sensors across a vineyard in California.[65]

According to Crossbow Technologies, their motes can be used on the farm for irrigation management, frost detection and warning, pesticide application, harvest timing, bio-remediation and containment and water quality measurement and control.

"Smart Dust" and "Ambient Intelligence:" The idea that thousands of tiny sensors could be scattered like invisible eyes, ears and noses across farm fields and battlefields sounds like science fiction. But ten years ago, Kris Pister, a professor of Robotics at University of California Berkeley secured funding from the US Defense Advanced Research Projects Agency (DARPA) to develop autonomous sensors that would each be the size of a match head. Using silicon-etching technology, these motes ("smart dust" sensors) would feature an onboard power supply, computa-

The USDA is working to promote and develop a total "Smart Field System" that automatically detects, locates, reports and applies water, fertilisers and pesticides – going beyond sensing to automatic application.

"Improvements in sensor technology will take us to a completely new level of measuring the growth process, the surrounding environment, the operation of machinery and much more. It will automate the processes that used to require human intervention. So rather than adjust the power levers on our tractor, the environment is sensed and implements adjust automatically. In some cases, reduced skills will be needed to accomplish certain tasks."

– Mike Boehlje, Purdue University's Center for Food and Agricultural Business[60]

tion abilities and the ability to detect and then communicate with other motes in the vicinity. In this way the individual motes would self-organize into *ad hoc* computer networks capable of relaying data using wireless (i.e., radio) technology. DARPA's immediate interest in the project was to deploy smart dust networks over enemy terrain to feed back real time news about troop movements, chemical weapons and other battlefield conditions without having to risk soldiers' lives. However, like that other groundbreaking DARPA project, the Internet, it swiftly became clear that tiny surveillance systems would have endless civilian uses, from monitoring energy-use in office buildings to tracking goods through a supply chain to environmental data monitoring.

Today, wireless micro and nanosensors like the ones pioneered by Kris Pister are an area of intense research for large corporations from Intel to Hitachi, a focus of development at all US national defence laboratories and in fields as wide apart as medicine, energy and communications. Touted by *The Economist*, *Red Herring* and *Technology Review* as the 'next big thing,' ubiquitous wireless sensors embedded in everything from the clothes we wear to the landscapes we move through could fundamentally alter the way we relate to everyday goods, services, the environment and the State. The aim is to develop what researches call 'ambient intelligence' – smart environments that use sensors and artificial intelligence to predict the needs of individuals and respond accordingly: offices that adjust light and heating levels throughout the day or clothes that alter their colours or warmth depending on the external environment. A simple example of ambient intelligence already in use is an airbag system in newer cars, which "senses" an imminent crash and deploys a pillow to soften the blow to the driver.

Kris Pister's dust motes are currently far from nano (they are roughly coin-sized), but they have already been licensed to commercial companies. In 2003 Pister established a "smart dust" spin-off company, Dust, Inc. For a light taster of a society steeped in ambient intelligence, Kris Pister makes the following speculations:[67]

- "In 2010 a speck of dust on each of your fingernails will continuously transmit fingertip motion to your computer. Your computer will understand when you type, point, click, gesture, sculpt, or play air guitar.
- In 2010 infants will not die of SIDs [Sudden Infant Death Syndrome], or suffocate, or drown, without an alert being sent to the parents. How will society change when your neighbors [sic] pool calls your cell phone to tell you that Johnny is drowning and you're the closest adult that could be located?
- In 2020 there will be no unanticipated illness. Chronic sensor implants will monitor all of the major circulator systems in the human body, and provide you with early warning of an

impending flu, or save your life by catching cancer early enough that it can be completely removed surgically."

Nanosensors: With ongoing technical advances, microsensors are shrinking in size and their sensor capabilities are expanding. Market analysts predict that the wireless sensor market will be worth $7 billion by 2010.[68]

Nanosensors made out of carbon nanotubes or nano-cantilevers (balanced weighing devices) are small enough to trap and measure individual proteins or even

Current state of the (sm)ART (dust):

Currently available from: Crossbow Technologies, Dust, Inc., Ember, Millennial Net

Coming soon: Motorola, Intel, Philips

Current Size: Crossbow's motes are currently the size of a bottletop. According to the CEO of Crossbow, Mike Horton, the size is expected to shrink to the size of an aspirin tablet – even a grain of rice – over the next few years.[70]

Current Price: Crossbow Motes (the entire smart dust sensor – processor, radio, battery, and sensor) range from $40 to $150 depending on quantity ordered. Crossbow expects prices to fall below $10 in near future.[71]

Current Uses: Smart dust has so far been sprinkled on:

• **Oil tankers**: The 885-foot oil tanker, *Loch Rannoch,* operated by BP in the North Atlantic, has been outfitted with 160 wireless sensor motes that measure vibrations in the ship's engine to predict equipment failures. The company is also considering using smart dust networks in over 40 other projects in the next three years.

• **Wildlife Habitats**: At Great Duck Island off the coast of Maine (USA) a network of 150 wireless sensor motes have been monitoring the microclimates in and around nesting burrows used by seabirds. The aim is to develop a habitat monitoring kit that allows researchers to monitor sensitive wildlife and habitats in non-intrusive and non-disruptive ways.[72]

• **Bridges**: In San Francisco (USA) a network of sensor motes has been installed to measure the vibration and structural stresses on the Golden Gate Bridge as a form of proactive maintenance.[73]

• **Redwood trees**: In Sonoma County, California (USA), researchers have strapped 120 motes to redwood trees in order to wirelessly and remotely monitor the microclimate around the trees from Berkeley, over 70 km away.[74]

• **Supermarkets:** Honeywell is testing the use of motes to monitor grocery stores in Minnesota (USA)[75]

• **Ports:** The US Department of Homeland Security plans to test the use of motes in Florida ports and in shipping containers.[76]

"…[I]magine smart farmlands where literally every…vine plant will have its own sensor… making sure that it gets exactly the right nutrients, exactly the right watering. Imagine the impact it could have on difficult areas of the world for agricultural purposes."

– Pat Gelsinger, Intel Chief Technology Officer[66]

Ultimately, sensors are likely to increase productivity, drive down farm prices, reduce labour and win a small advantage in the global marketplace for the largest industrial farm operators.

Will smart dust be packaged along with patented seeds to police farmers' growing practices and patent compliance?

molecules. Nanoparticles or nanosurfaces can be engineered to trigger an electrical or chemical signal in the presence of a contaminant such as bacteria. Other nanosensors work by triggering an enzyme reaction or by using nano-engineered branching molecules called dendrimers as probes to bind to target chemicals and proteins.

Not surprisingly, a great deal of government funded research in nanosensors aims to detect minute quantities of biowarfare agents such as anthrax or chemical toxins to counter terrorist attacks on US soil as well to warn soldiers on a battlefield of possible risks. For example, the US government's "SensorNet" project attempts to cast a net of sensors across the entire United States that will act as an early warning system for chemical, biological, radiological, nuclear and explosive threats.[69] The SensorNet will integrate nano, micro and conventional sensors into a single nationwide network that will feed back to an existing US network of 30,000 mobile phone masts, forming the skeleton of an unparalleled national surveillance network. Oak Ridge National Laboratory is now field-testing SensorNet. US government defense laboratories such as Los Alamos and Sandia are developing the nano-sensors themselves.

Sizing up Sensors: Sensor technology could benefit large-scale, highly industrialized farms that are already adopting GPS tractors and other precision farming techniques. Ultimately, sensors are likely to increase productivity, drive down farm prices, reduce labour and win a small advantage in the global marketplace for the largest industrial farm operators.

It is not small-scale farmers who will benefit from ubiquitous sensor networks, but the giant grain traders such as Cargill and ADM, who are positioned to aggregate data from several thousand farms in order to determine which crops are grown, by whom and what price will be paid, depending on market demand and global prices. Sensors will marginalize farmers' most unique assets – their intimate local knowledge of place, climate, soils, seeds, crops and culture. In a wirelessly monitored world all of this is reduced to real-time raw data, interpreted and leveraged remotely. Why employ smart farmers when sensors and computers can make 'smart farms' operate without them?

High-tech production by large-scale producers usually means depressed prices and hardship for those outside the industrial agribusiness loop, including small-scale, indigenous and peasant farmers. As sensors shrink to a size smaller than seeds, legal, security and environmental safeguards will be needed to prevent abuses of smart dust, including surveillance of foreign crops. Will smart dust be packaged along with patented seeds to police farmers' growing practices and patent compliance? Will corporate seeds or other inputs be laced with inexpensive sensors for companies to collect information in much the same

way Internet companies collect confidential data by infecting personal computers with invisible monitoring programs and tags (known as 'spyware' and 'cookies')?

Agricultural sensor networks may also be pressed into use as civil surveillance systems in the interest of 'homeland security.' Wireless sensor networks – whether in agriculture or any other application – threaten to stifle dissent and invade privacy. Michael Mehta, a sociologist at the University of Saskatchewan (Canada), believes that the environment equipped with multiple sensors could destroy the notion of privacy altogether – creating a phenomenon that he calls "nano-panopticism" (i.e., all seeing) in which citizens feel constantly under surveillance.[77] In a recent report, the UK Royal Society also highlighted privacy concerns raised by nanosensors:

"…[Sensor] devices might be used in ways that limit individual or group privacy by covert surveillance, by collecting and distributing personal information (such as health or genetic profiles) without adequate consent, and by concentrating information in the hands of those with the resources to develop and control such networks." – Royal Society, "Nanoscience and nanotechnologies: opportunities and uncertainties"[78]

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Swing low… Down with farmers

In the early 19th century the notion of farming without farm labour was an unthinkable proposition. As English rural labourers returned from the Napoleonic wars, however, they discovered that a new era in industrial agriculture had begun without them. In their absence, labour had been replaced by mechanised threshing machines, pushing down agricultural wages and rendering workers redundant over the winter months. In the resulting "Swing riots" of 1830-32 (named after the mythical leader Captain Swing – referring to the swinging motion of the hand scythe), hundreds of threshing machines were smashed and burned across Southern England in the first popular, if short lived, act of resistance against industrial agriculture. Since then successive waves of technology, from tractors and combine harvesters to herbicides and GM crops, have moved agriculture ever closer towards an industrial ideal in which agricultural production more closely mirrors the factory system and agricultural labourers are left under-paid, under-employed and unemployed.

Two decades before the Swing Riots, skilled British textile workers struggled against their increasingly desperate conditions in much the same way – by smashing newly-introduced machinery. Steam-powered looms and large knitting frames allowed less skilled workers to produce inferior products, depressing wages and prices. The technoclast cotton-weavers, spinners, croppers and knitters – better known as Luddites – were protesting low wages, the high cost of food and threats to their reputations as skilled artisans.[79]

"Just as the British Industrial Revolution knocked handspinners and handweavers out of business, nanotechnology will disrupt a slew of multibillion-dollar companies and industries."
– Lux Research, Inc., *The Nanotech Report 2004*

Trading Down: Nano-Commodities

Commodity Roulette: In its 2004 report on nanotechnology, Lux Research, Inc. highlights the potential of nanotech to cause "dramatic shifts in supply and value chains."[80] In the agricultural sector, farm commodities and the livelihoods of over 1.3 billion people engaged in agriculture – half of the world's working population – are at stake. The South's primary raw commodities are particularly vulnerable: natural fibres such as cotton and jute; tropical beverages (cocoa, coffee, tea); tropical oils (coconut, palm, etc.); and farm products ranging from exotic spices to cashew nuts and vanilla. According to UNCTAD, the value of agricultural raw material exports in the developing world is $26.7 billion.[81] Commodities and markets in the North will also be affected as nanotech's designer materials displace conventional materials. However, it is generally the poorest nations and those most dependent on agricultural exports that will face the greatest disruption from the adoption of new, nano-structured materials.

It is not the first time that new technologies have threatened to eliminate the production of primary export commodities in the South. In the 1980s, biotech promised to transfer production of many tropical commodities to bio-fermentation facilities in the North. Why source vanilla (or rubber or cocoa or coffee) from tropical countries when cell cultures can be coaxed to produce the same product in the laboratory? But fermentation produced materials of inconsistent quality, and the cost of production couldn't compete with the perennially rock-bottom prices paid to producers of tropical commodities. Will nanotech succeed where biotech fell short?

The following section takes a closer look at the potential impacts on cotton and rubber markets from nanoproducts already on the market, or currently in development:

Nanofibres vs. Cotton – Perfecting the Perfect Pants: In the 1952 comedy film "The Man in the White Suit," a maverick textile scientist played by Alec Guinness invents a fabric that never gets dirty and never wears out. Far from welcoming this shiny innovation, his co-workers and bosses recognise this new wonder fabric as a threat to their own jobs and business and form mobs to hunt him down. Today, as invisible nanofibres and nanoparticles are incorporated into "miracle" products (including clothes), the symbolic White Suit shines with a new relevance.

If there is a poster child for commercial nanotech, it's the pants. Reminiscent of the doorstop tricks of travelling salesmen, it seems that every nano-proselytizer has at some point whipped out their magical nano pants and spilt coffee on them to a bemused audience (if all goes well the coffee beads up like mercury and rolls off without staining). Leading the way in nano-fashion is US-

based Nano-Tex, which is 51%-owned by Burlington Industries (BI). In its glory days, BI was the largest textile company in the world, but by 2001 it had filed for bankruptcy. When Wilbur Ross bought BI for $620 million in 2003 – outbidding market mogul Warren Buffet – his plan for reviving BI was to use Nano-Tex technology on BI's fabrics and license the technology to other producers.[82] So far, Nano-Tex has licensed its technology to 40 textile mills and its nano-fabrics have been successfully incorporated into clothing from some of the world's best-known brands – including Eddie Bauer, Lee, Gap, Old Navy and Kathmandu.

Nano-Tex engineered a way to attach "nanowhiskers" to textile fibres using "nanohooks." The "whiskers" prevent liquids from penetrating the surface of the fabric making it stain-resistant. A second technology from Nano-Tex – "Coolest Comfort" – attempts to re-produce the qualities of natural cotton (e.g., fast drying and moisture-wicking) in synthetic fabrics. A third technology – Nano-Touch – is a synthetic fibre manipulated at the nano-scale that has the texture of cotton but is much stronger. According to the founder of Nano-Tex, "This will be our blockbuster."[83]

Blockbusters for Nano-Tex, perhaps, but not necessarily good news for the world's 100,000,000 families engaged in cotton production – the majority of whom farm in the South.[84] As a commodity, cotton has been in a bad way for some time. A century of price declines was in part the result of cheaper synthetic fibres taking away market share. These manufactured fibres ranged from cellulose-based rayon (commercialised in 1891) to Dupont's petroleum-based fibres such as nylon. Today, despite record harvests, cotton accounts for only 40% of the world's total fibre consumption of around 52 million tonnes. Other natural fibres have fared no better: wool accounts for a mere 2.5% and silk for a tiny 0.2%. Total fibre use is expected to reach almost sixty million tonnes per year by 2010 but demand for artificial fibres is growing twice as fast as the demand for cotton – even setting aside the potential impacts of new nano-fabrics.

"The implications of reverse-engineering Mother Nature's designs for our own technological devices will be most profound on the economies of manufacturing. When companies can cheaply and chemically assemble materials and devices in the same manner that beer, cheese, and wine are manufactured today, it spells disruption and dramatic shifts in supply and value chains."

– Lux Research, Inc., *The Nanotech Report 2004*

Cotton: What's at Stake?[85]

- Cotton is grown in more than 100 countries
- 35 of the 53 African countries produce cotton; 22 are exporters
- The value of world cotton production is estimated at $24 billion in 2002/03
- Over 100 million families are engaged directly in cotton production
- Over one billion people are involved in the cotton sector worldwide – including family and hired labour to produce, transport, gin, bale and store cotton

It is generally the poorest nations and those most dependent on agricultural exports that will face the greatest disruption from the adoption of new, nano-structured materials.

Besides Nano-Tex's nano-fabrics, there are others under development. A group led by chemist Ray Baughman at the University of Texas-Dallas has developed carbon nanotube-based fabrics which are 17 times tougher than Kevlar and that also carry an electrical charge so that they can run equipment such as cell phones.[86] A team at Clemson University in South Carolina (USA) led by Professor Nader Jalili is developing carbon nanofibre fabrics that would generate electricity as the wearer moves.[87]

In another application being developed at MIT in conjunction with the Institute for Soldier Nanotechnologies, material science professor Yoel Fink has developed glass nanofibres that exhibit different colours depending on the thickness of the threads, potentially affecting the market for clothing dyes. Fink and his colleagues envision that their glass nanothreads woven into clothing will enable wearers to change the colour of their clothing on a whim – a sober grey for a business meeting and then a bright fuschia for an evening date. First (perhaps within two years), the US Army will weave the nano-thread into military uniforms to help soldiers distinguish between 'us' and 'them.'[88]

Nanoparticles vs. Rubber: Rubber, like cotton, is an agricultural commodity sourced primarily in its natural form from southern producers such as India, Indonesia, Thailand and Malaysia. Unlike cotton, natural rubber has proven more resilient to the challenge of synthetic counterparts developed during World War II. Although 75% of world rubber was synthetic in 1964, the introduction of radial car tyres helped revive the market for natural rubber. In 2004, total global rubber production is expected to be 19.61 million tonnes of which 8.26 million will be natural rubber (42%).[89]

Currently around 50% of a car tyre is made from natural rubber.[92] Small particles of carbon black (including nanoparticles) have long been mixed with the rubber to improve the wear and strength of tyres. Many leading tyre manufacturers are now developing engineered nanoparticles to further extend tyre life. Cabot, one of the world's leading tyre-rubber producers, successfully tested "PureNano" silica carbide nanopar-

Rubber – What's at Stake?

- The South's natural rubber exports were valued at $3.6 billion in 2000. The world's top five producers are Thailand, Indonesia, India, Malaysia and China.
- Thailand accounts for more than one-third of the world's natural rubber.[90]
- 90% of Thailand's rubber is produced on holdings of less than 4 hectares. An estimated six million farmers produce natural rubber in Thailand.[91]

ticles designed by Nanoproducts Corporation of Colorado. Added to tyres, the "PureNano" particles reduced abrasion by almost fifty percent – a simple improvement that if widely adopted should help tyres last up to twice as long and thereby significantly reduce the need for new tyre-rubber. At present, 16.5 million tyres are retread every year in the US alone.[93] Presumably that number would shrink by almost half. Other companies are looking to incorporate carbon nanotubes, boasting of tyres that would outlive the car entirely. According to rumours in Silicon Valley, a contraceptive manufacturer is also looking at the possibility of adding carbon nanotubes to similarly strengthen condoms.[94]

Nano changes are scheduled inside tyres as well. Companies such as Inmat and Nanocor produce nanoparticles of clay that can be mixed with plastics and synthetic rubber to create an air-tight surface. Inmat's nanoclay has already been used as a sealant for "double core" tennis balls produced by sports manufacturer Wilson. The Double Core balls are said to have twice the bounce because the nano-particles lock in air more effectively. Inmat, which was originally set up in co-operation with Michelin, the world's leading tyre manufacturer, believes the same technology could be used to seal the inside of tyres, reducing the amount of butyl rubber required and making tyres lighter, cheaper and cooler running.[95]

The real prize is to replace rubber altogether. One option is a super lightweight nanomaterial known as an aerogel, which was proposed as a solid tyre material for the Mars lander (in the end they went with normal tyres). As the name suggests, aerogels are largely composed of air (98%) – billions of nano-air bubbles in a silica matrix.[96] Besides being light, aerogels are extremely heat resistant and make exceptional insulators. University of Missouri-Rolla (USA) chemists claim to have developed a new waterproof aerogel that could be used in place of tyre-rubber.[97] At least one tyre company, Goodyear, holds a patent on a tyre that incorporates silica aerogels for its tread.[98] The global tyre market is dominated by five multinational firms: Michelin, Bridgestone, Goodyear, Continental and Sumitomo. In 2001, the top 5 tyre manufacturers accounted for over two-thirds of global tyre sales.[99]

The real prize is to replace rubber altogether.

"Cellulose is the most abundant renewable resource polymer on earth. It forms the structure of all plants. Although researchers have predicted that fibres with strength approaching Kevlar could be made from this fibre, no one has yet achieved it."
– Margaret Frey, assistant professor of textiles at Cornell University.[104]

Growing new nano-commodities: As mass production of nanomaterials steps up into multi-tonne quantities, new production methods are emerging that may open new markets for some agricultural feedstocks – albeit in rather small quantities:

Spinning a nano-yarn: Scientists at Cambridge University in England are exploring methods of making carbon nanotubes out of maize-derived ethanol.[102] While most fabrication processes for nanotubes use petroleum or graphite as a raw material, Dr. Alan Windle and his team inject ethanol into a fast-flowing stream of hydrogen gas that is carried into a 1000ºC furnace. The high temperature breaks down the ethanol and the carbon atoms reassemble into nanotubes, each about a micron in length, which float in the stream of hydrogen, loosely linked to each other as an "elastic smoke." Nanotubes are then drawn out of this amorphous cloud, much as a spinning wheel pulls thread from wool. This method is able to make continuous threads of carbon nanotubes up to 100 metres long, although currently only at a very low quality.

It's not just maize ethanol that can be converted into useful nanofibres. At Cornell University, another team is refining an older process called "electrospinning."[103] In this method, plant cellulose is dissolved in a solvent and then squeezed through a pinhole with an electrical current producing a fibre of less than 100 nm in diameter. The scientists are now experimenting with altering the properties of those nanofibres for improved strength.

According to Margaret Frey, assistant professor of textiles at Cornell University, "Cellulose is the most abundant renewable resource polymer on earth. It forms the structure of all plants. Although researchers have predicted that fibres with strength approaching Kevlar could be made from this fibre, no one has yet achieved it."[104]

Food = Nature's Nanomaterials

In a recent article in the journal *Nature Materials*, a researcher at the Cavendish Laboratory of Cambridge University urged her material scientist colleagues to consider agriculture not as a "feedstock with an essentially uncontrollable composition," but as "a rich and diverse category of materials," many of them "nanostructure composites, in which self-assembly may play a key role."[100] Athene Donald points out that the variability of feedstocks, an unavoidable characteristic of all natural products due to regional differences of soil, climate and cultivar, produce "unreliable" ingredients that nanotechnologists will be able to make more uniform, stable and even more nutritious. Recognizing that, at least in Europe, "science has lost out to emotion" in the GM debate, she has greater hopes for nanotechnology to "improve raw products" in a way that will be acceptable to the public.[101]

The Cornell researchers are focusing on recovering cellulose from the waste discarded in cotton production, but, theoretically, they could harvest cellulose from any plant waste.[105] That may be good news for textile companies who could shop around for cheap plant material waste, but is unlikely to be an economic boon to farmers because cellulose is so abundant.

Particle Farming: In the future, industrial nanoparticles may not be produced in a laboratory, but grown in fields of genetically engineered crops – what might be called "particle farming." It's been known for some time that plants can use their roots to extract nutrients and minerals from the soil but research from the University of Texas-El Paso confirms that plants can also soak up nanoparticles that could be industrially harvested. In one particle farming experiment, alfalfa plants were grown on an artificially gold-rich soil on university grounds. When researchers examined the plants, they found gold nanoparticles in the roots and along the entire shoot of the plants that had physical properties like those produced using conventional chemistry techniques, which are expensive and harmful to the environment.[106] The metals are extracted simply by dissolving the organic material.

Initial experiments showed that the gold particles formed in random shapes, but changing the acidity of the growing medium appears to result in more uniform shapes.[107] The researchers are now working with other metals and with wheat and oats in addition to alfalfa to produce nanoparticles of silver, Europium, palladium, platinum and iron.[108] For industrial-scale production, the researchers speculate that the particle plants can be grown indoors in gold-enriched soils, or they can be farmed nearby abandoned gold mines.[109]

Meanwhile nanobiotech researchers at the National Chemistry Laboratory in Pune, India have been carrying out similar work with geranium leaves immersed in a gold-rich solution.[110] After 3-4 hours, the leaves produce 10 nm-sized particles shaped as rods, spheres and pyramids which, according to researcher Murali Sastry, appear to be shaped according to the aromatic compounds in the leaves. By altering those aromatic compounds Sastry believes it will be possible to alter the shape of the nanoparticles (and their properties).

Sizing Up the Impacts of Commodity Roulette: It's too early to map with confidence how a new nano-economy of designer particles will alter production of traditional agricultural commodities – but it's clear that it will. With nanotech patents and innovation driven from the North (especially the US), there will be a push to replace tropical commodities such as rubber and high quality cotton with cheaper raw materials that can be sourced and manipulated closer to home (maize, oats, cotton leftovers). We are not arguing that the *status quo* should be preserved, or that peasant farmers

In the future, industrial nanoparticles may not be produced in a laboratory, but grown in fields of genetically engineered crops – what might be called "particle farming."

With nanotech patents and innovation driven from the North (especially the US), there will be a push to replace tropical commodities such as rubber and high quality cotton with cheaper raw materials that can be sourced and manipulated closer to home (maize, oats, cotton leftovers).

New nanomaterials could bring environmental benefits; however, nanomaterials designed to replace natural rubber could introduce new disposal problems and new contaminants in the environment.

and agricultural workers should be forever dependent on notoriously fickle export crops. The point is that tiny tech will bring titanic socio-economic disruptions for which society is ill-prepared. As always, it is the poor who are most vulnerable.

New nanomaterials could bring environmental benefits. For example, a reduction in the number of used tyres could alleviate the burden of discarded tyres in dumps and landfills. Nanosceptics will note, however, that nanomaterials designed to replace natural rubber could introduce new disposal problems and new contaminants in the environment.

In the short term, well-positioned industrial farmers who are able to provide large amounts of cellulose may find themselves with a niche market and extra income from what was previously considered trash. And perhaps at some point ethanol markets might see a blip, but even North American farmers would be misled to think they are going to be at the heart of the new nano-economy. If spinning nanofibres from cellulose or ethanol really takes off, the real winners will be the large grain processors who could offer these commodities cheaply.

Extracting nanoparticles from mineral-rich land by growing specially bred or engineered plants could become significant for poorer regions, especially those that have mining economies. If it becomes feasible to extract minerals using particle-processing plants, it could provide an alternative to a hazardous occupation, and provide new income opportunities for developing nations. But particle farming is not an approach that is likely to be suitable for small-scale and peasant farmers. Recapturing and characterising nanoparticles requires high-tech processing facilities of a sort not available to small-scale producers. It is also an approach that could significantly affect land use patterns with previously marginal lands becoming sought after for particle-farming of rare minerals – a process that could displace traditional cultures and sensitive ecologies. The release of plants genetically engineered to improve nanoparticle production would raise significant biosafety concerns, as could the prospect of crops containing bioactive nanoparticles mixing with the food supply.

Other Nanomaterial uses down on the farm: A number of projects around the world are exploring the use of nanoparticles on the farm for purposes other than pesticides – from enhanced photosynthesis to better germination and soil management.

• ***Buckyball fertiliser?*** Researchers at Kyoto university (Japan) have discovered a method of producing ammonia using buckyballs. Ammonia is a key component of fertiliser but it is not clear if the resulting product for use in the fields would contain buckyballs.[111]

• ***TiO_2 nano mixture:*** Scientists at the University of Korea have applied for a patent on a liquid

mixture composed of titanium dioxide nanoparticles which they claim will destroy harmful pests, enhance photosynthesis and stimulate growth when applied to rice plants.[112]

• ***Seeding Iron:*** The Russian Academy of Sciences reports that they have been able to improve the germination of tomato seeds by spraying a solution of iron nanoparticles on to fields.[113]

• ***Soil Binder***: In 2003, ETC Group reported on a nanotech-based soil binder called SoilSet developed by Sequoia Pacific Research of Utah (USA).[114] SoilSet is a quick-setting mulch which relies on chemical reactions on the nano-scale to bind the soil together. It was sprayed over 1,400 acres of Encebado mountain in New Mexico to prevent erosion following forest fires as well as on smaller areas of forest burns in Mendecino County, California.

• **Soil cleanup:** A number of approaches are being developed to apply nanotechnology and particularly nanoparticles to cleaning up soils contaminated with heavy metals and PCBs. Dr. Wei-xang Zhang has pioneered a nano clean-up method of injecting nano-scale iron into a contaminated site.[115] The particles flow along with the groundwater and decontaminate *en route*, which is much less expensive than digging out the soil to treat it. Dr. Zhang's tests with nano-scale iron show significantly lower contaminant levels within a day or two. The tests also show that the nano-scale iron will remain active in the soil for six to eight weeks, after which time it dissolves in the groundwater and becomes indistinguishable from naturally-occurring iron.

Nanomal Pharm

Livestock and fish will also be affected by the nanotechnology revolution. While the great hopes of nanomedicine are disease detection and new pharmaceuticals for humans, veterinary applications of nanotechnology may become the proving ground for untried and more controversial techniques – from nanocapsule vaccines to sex selection in breeding.

Biochips: Using biochips, biological samples such as blood, tissue and semen can be instantaneously analysed and manipulated. In fewer than five years, biochips have become a standard technology for genomics and drug discovery and they are now moving into commercial health-care and food safety applications.

A biochip (or microarray) is a device typically made of hundreds or thousands of short strands of artificial DNA deposited precisely on a silicon circuit. In DNA arrays, each DNA strand acts as a selective probe and when it binds to material in a sample (e.g., blood) an electrical signal is recorded. Rather like conducting a word search across a piece of text, the biochip is able to report back on found genetic sequences based on the DNA probes built into it. The best-known biochips are those produced by Affymetrix, the company that pioneered the technology and was first to

The Russian Academy of Sciences reports that they have been able to improve the germination of tomato seeds by spraying a solution of iron nano-particles on to fields.[113]

"Enthusiastic researchers say that the miniaturization and integration of chemistry and biology will fuel a revolution. What electronics did for computation, microfluidics can do for biology."
– Kyle James, *Small Times*[121]

produce a DNA chip that analyses an entire human genome on a single chip the size of a dime.[116]

In addition to DNA biochips there are other variations that detect minute quantities of proteins and chemicals in a sample, making them useful for detecting biowarfare agents or disease. Biochip analysis machines the size of an inkjet printer are commercially available from companies such as Agilent (Hewlett-Packard) and Motorola – each able to process up to 50 samples in around half an hour.

Chips can be used for early disease detection in animals. Researchers at the University of Pretoria, for example, are developing biochips that will detect common diseases borne by ticks.[117] Biochips can also be used to trace the source of food and feeds. For example, bioMérieux's "FoodExpert-ID" chip rapidly tests feed to detect the presence of animal products from forty different species as a means to locate the source of pathogens – a response to public health threats such as avian flu and mad cow disease.[118]

One goal is to functionalise biochips for breeding purposes. With the mapping of the human genome behind them, geneticists are now rapidly sequencing the genomes of cattle, sheep, poultry, pig and other livestock hoping to identify gene sequences that relate to commercially valuable traits such as disease resistance and leanness of meat. By including probes for these traits on biochips, breeders will be able to speedily identify champion breeders and screen out genetic diseases.

Micro / Nanofluidics:
Microfluidics is a newer technology platform on the same scale as biochips. Microfluidic and nanofluidic systems analyse by controlling the flow of liquids or gases through a series of tiny channels and valves, thereby sorting them, much as a computer circuit sorts data through wires and logic gates. Microfluidic channels, often etched into silicon, can be less than 100 nm wide. This allows them to handle biological materials such as DNA, proteins or cells in minute quantities – usually nano-liters or pico-liters (1000 times smaller than a nanoliter). Microfluidics not only enable very precise analysis, they also open up the potential for manipulation of living matter by mixing, separating and handling different components at the nano-scale.

Microfluidics is being used in livestock breeding to physically sort sperm and eggs. Leader in this field is XY, Inc. of Colorado (USA), which is using a microfluidic technique called flow cytometry to segregate male and female sperm for sex selection. XY has successfully bred sex-selected horses, cattle, sheep and pigs and now provides its technology to commercial breeders. Nanotech startup Arryx, which has developed a new microfluidic system called MatRyx, uses a nano-technique in which tiny laser tractor beams trap individual sperm and then sort them by weight. MatRyx can sort around

3,000 sperm per second, and aims for commercialisation in cattle breeding. "This way dairy farmers can have cows and beef farmers can have bulls that have more meat," explains Arryx's CEO Lewis Gruber.[119] His goal is to produce a simple one-button sex sorter.

Matthew Wheeler, University of Illinois professor of animal science, has gone one further in developing a microfluidic device that not only sorts sperm and eggs but also brings them together in a way that mimics the movement of natural reproduction and then handles the resulting embryo. According to Dr. Wheeler, such a technique would make mass production of embryos cheap, quick and reliable.[120] He and his colleagues have started a spin-off company, Vitaelle, to commercialise this technology.

Nano-Veterinary Medicine: The field of nanomedicine offers ever more breathless promises of new diagnoses and cures as well as ways of improving human performance. The US National Science Foundation expects nanotechnology to account for around half of all pharmaceutical industry sales by 2010. What is less hyped is that the same impact is likely to hit the animal health market – either as nanotechnologies show their worth in human medicine or as a proving ground for more controversial approaches to nanomedicine, such as using DNA nanocapsules. Companies such as SkyePharma, IDEXX and Probiomed are currently developing nanoparticle veterinary applications. A full assessment of how pharmaceutical companies are using nanotechnology in drug development and delivery is beyond the scope of this report. Briefly summarised below are some of the key technologies that are also relevant to animal pharmaceuticals:

Drug Discovery: The ability to image and isolate biological molecules on the nano-scale opens the door for more precise drug design as well as much faster genomic screening and screening of compounds to assess their suitability as drugs. Pharma companies are particularly interested in using biochips and microfluidic devices (see above) to screen tissues for genetic differences so that they can design genetically targeted drugs (pharmacogenomics).[122]

Disease Detection: Nanoparticles, which are able to move easily around the body, can be used for diagnosis. Of particular interest are quantum dots – cadmium selenide nanocrystals which fluoresce in different colours depending on their size. Quantum dots can be functionalised to tag different biological components, like proteins or DNA strands, with specific colours. In this way a blood sample can be quickly screened for certain proteins that may indicate a higher propensity for disease. A similar effect can be achieved with gold nanoshells, tiny beads of glass covered with a layer of gold that change colours depending on the thickness of the gold. Both nanoshells and quantum dots can be designed to bind

"In the era of new health related technologies, Veterinary Medicine will enter a phase of new and incredible transformations. The major contributor to those changes is our recent ability to measure, manipulate and organize matter at the nano-scale level..."

– Dr. Jose Feneque, Miami, Florida

Pharmaceutical compounds reformulated as nanoparticles not only reach parts of the body that today's formulations cannot, their large surface area can also make them more biologically active. Increased bioavailability means that lower concentrations of expensive drug compounds would be required, with potentially fewer side effects.[124]

to tumours and malignant cells when introduced into the body, allowing them to be more precisely identified. Scientists at Rice University who have pioneered this technique have also shown, in animals, that the nanoshells can be heated up by lasers so that they selectively destroy the diseased tissue they lock onto, without harming skin or nearby healthy tissue. This technology has been commercially licensed to a startup called Nanospectra.[123]

New Delivery Mechanisms: Drugs themselves are set to shrink. Nano-sized structures have the advantage of being able to sneak past the immune system and across barriers (e.g., the blood-brain barrier or the stomach wall) the body uses to keep out unwanted substances.

Pharmaceutical compounds reformulated as nanoparticles not only reach parts of the body that today's formulations cannot, their large surface area can also make them more biologically active. Increased bioavailability means that lower concentrations of expensive drug compounds would be required, with potentially fewer side effects.[124] Nanoparticles can also be used as carriers to smuggle attached compounds through the body. Leading nanopharma companies such as SkyePharma and Powderject (now a wholly owned subsidiary of Chiron) have developed methods of delivering nanoparticle pharmaceuticals across skin or via inhalation. Researchers in Florida are working on nano delivery systems that diffuse drugs across the eye from specially impregnated contact lenses. As with pesticide delivery, the big interest is in 'controlled release.' Many of the big pharma and animal pharma companies working on nano-drugs are using encapsulation technologies such as nanocapsules to smuggle active compounds into and around the body. The capsules can be functionalised to bind at specific places in the body, or be activated by an external trigger, such as a magnetic pulse or ultrasound. The USDA compares these functionalised drug nanocapsules, called "Smart Delivery Systems," to the postal system, where molecular-coded "address labels" ensure that the packaged pharmaceutical reaches its intended destination.[125]

Besides capsules, other nanomaterials being used to deliver drugs include:

• ***BioSilicon*** is a highly porous silicon-based nanomaterial product, which can release a medicine slowly over a period of time. Developed by Australian company pSivida, the company uses its BioSilicon technology to fashion tiny capsules (to be swallowed) and also tiny needles that can be built into a patch to invisibly pierce the skin and deliver drugs.[126]

• ***Fullerenes,*** the so called "miracle molecules" of nanotechnology (buckyballs and carbon nanotubes are included in this class of carbon molecules), are hollow cages of sixty carbon atoms less than a couple of nanometers wide.

Because they are hollow, pharma companies are exploring filling the fullerenes with drug compounds and then functionalising them to bind in different parts of the body.

• ***Dendrimers*** are branching molecules that have a tree-like structure and are becoming one of the most popular tools in nanotechnology. Because of their shape and nano-size, dendrimers have three advantages in drug delivery: first, they can hold a drug's molecules in their structure and serve as a delivery vehicle; second, they can enter cells easily and release drugs on target; third, and most importantly, dendrimers don't trigger immune system responses. Dendrimers can also be used for chemical analysis and diagnosis – raising the future possibility of synthetic molecules that can locate, diagnose and then treat tumours or other sick cells.

• ***DNA nanocapsules*** smuggle strands of viral DNA into cells. Once the capsule breaks down, the DNA hijacks the cells' machinery to produce compounds that would be expected in a virus attack, thus alerting and training the immune system to recognise them. DNA nanocapsule technology could also be used to hijack living cells to produce other compounds such as new proteins or toxins. As a result, they must be carefully monitored as a potential biowarfare technology.

Sizing Up Nano-Pharmaceuticals: Nanotechnology could offer the pharmaceutical industry the key to unleashing a torrent of new and old drug compounds. Not only are profits and patents to be gained by shrinking existing drugs to the nano-scale, but there is also the opportunity to resurrect drugs that previously failed clinical trials in a larger form. By encapsulating pharmacologically active compounds and claiming that they will be targeted to a very specific site in the body, companies could argue that general side-effects are no longer a concern, and that old safety assessments are no longer relevant.

Nano-scale pharmaceuticals approved for animal use must also be carefully tested and monitored to prevent them from entering the food chain. It is not understood how nanoparticles persist in and move around the body, nor whether they can migrate to milk, eggs and meat. Existing animal pharma drugs will need to be reevaluated by regulatory authorities if they are re-formulated in a nano-scale form since the properties of materials can change at this size.

Chicken Little Particles: *Campylobacter jejeuni* is a group of spiral-shaped bacteria that cause abdominal cramps and bloody diarrhoea in humans, and are usually contracted from contaminated poultry products. With pathogens gaining alarming levels of resistance to traditional antibiotics, the poultry industry is turning to nanotech for new means of fighting bacterial pathogens such as *Campylobacter*. At Clemson University (South Carolina, USA), researchers funded by USDA have been experimenting with specially designed

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The USDA envisions the rise of 'smart herds' – cows, sheep and pigs fitted with sensors and locators relaying data about their health and geographical location to a central computer.

polystyrene nanoparticles to fight contamination on the farm. The nanoparticles are ingested by chickens and are designed to bind to *Campylobacter* in the gut of the chicken. Researchers hope that the particles will dislodge bacteria from the intestine and then be excreted along with feces, reducing the rate of contamination in the birds sent for processing.[127] According to Clemson researcher Dr. Robert Latour, the method's safety and efficacy is being tested on small numbers of animals.[128]

Smart Herds: Livestock tracking has been a problem for farmers since before Little Bo Peep lost her sheep. Nano-Bo-Peep, however, would have no such problems. Just as converging technologies in crop production will use nanosensor networks to continuously monitor the health of plants, so, too, will sensors monitor livestock. The USDA envisions the rise of 'smart herds' – cows, sheep and pigs fitted with sensors and locators relaying data about their health and geographical location to a central computer.

This is a vision of precision agriculture on the hoof. The long-term aim is not merely to monitor, but also to automatically and autonomously intervene with pharmaceuticals using small drug delivery devices that can be implanted into the animal in advance of illness. The notion of linking in-built sensors to in-built smart delivery systems has been called "the fuel injection principle" since it mimics the way modern cars use sensors to time fuel-delivery to the engine. The closest applications to market are implantable insulin-delivery devices or "drug chips" that will be linked with glucose sensors for (human) diabetics to automatically regulate blood sugar levels. Over time, this could become the model for all drug delivery, in both humans and animals.

One of the current barriers to implantable medical devices is that their composite materials (e.g., metal or plastics) are often incompatible with living tissue. New materials, engineered at the nano-scale to be biocompatible, seek to address this problem.

Sizing Up the "Nanomal" Farm: Implanting tracking devices in animals is nothing new – either in pets, valuable farm animals or for wildlife conservation. Injectable microchips are already used in a variety of ways with the aim of improving animal welfare and safety – to study animal behaviour in the wild, to track meat products back to their source or to reunite strays with their human guardians. In the nanotech era, however, retrofitting farm animals with sensors, drug chips and nanocapsules will further extend the vision of animals as industrial production units. Animals also are likely to be used as the testing ground for less savoury or more risky applications that could later be extended to human beings. Using microfluidics for breeding is likely to accelerate genetic uniformity within livestock species and also opens the possibility of applying new nano-eugenic technologies to humans in the future. The ability to remotely regulate animals may have adverse affects

as livestock go longer periods without direct human care.

The same technologies transferred to humans raises profound concerns about quality of life and civil liberties. In October 2004 the US Food and Drug Administration approved the use of implantable microchips in humans to provide easy access to an individual's medical records – the first approval of microchips for medical uses in the United States.[129]

As healthcare is driven more and more by the bottom line, the future use of implantable chips for automated drug delivery may become economically preferable to nursing. When dealing with the elderly or those with different cognitive abilities or with any condition requiring regular treatment, ethical questions may arise about who decides to make an individual 'fuel injected.' Automated drug delivery could allow some people to live independently who would otherwise be institutionalised. However, the absence of human caretakers is also a factor.

Nano-Aquaculture: The world's fastest growing area of animal production is the farming of fish, crustaceans and molluscs, particularly in Asia. According to the FAO there were 45.7 million tonnes of aquaculture production in 2000 and it is growing at a rate of more than 9% per year.[130] With a strong history of adopting new technologies, the highly integrated fish-farming industry may be among the first to incorporate and commercialise nanotech products.

Emerging applications include:

• **Cleaning fishponds:** Nevada-based Altair Nanotechnologies makes a water cleaning product for swimming pools and fishponds called 'NanoCheck.' It uses 40 nm particles of a lanthanum-based compound which absorbs phosphates from the water and prevents algae growth. NanoCheck is currently undergoing large-scale testing in swimming pools and Altair is expected to launch a swimming pool cleaner in early 2005.[131] Altair has its eye on a potentially large demand for NanoCheck for use in thousands of commercial fish farms worldwide where algae removal and prevention is costly at present. According to Altair, the company plans to expand its tests to confirm that its nanoparticles will not harm fish, but no mention is made of the tests that will be undertaken to examine the impacts of nanoparticle-laden run-off on human health or on the environment.[132]

• ***DNA Nano-vaccines***: The USDA is completing trials on a system for mass vaccination of fish using ultrasound.[133] Nanocapsules containing short strands of DNA are added to a fishpond where they are absorbed into the cells of the fish. Ultrasound is then used to rupture the capsules, releasing the DNA and eliciting an immune response from the fish. This technology has so far been tested on rainbow trout by Clear Springs Foods (Idaho, US) – a major aquaculture company that produces about one third of all US farmed trout.

Nanocapsules containing short strands of DNA are added to a fishpond where they are absorbed into the cells of the fish. Ultrasound is then used to rupture the capsules, releasing the DNA and eliciting an immune response from the fish.

"Whereas now we grow a tree, cut it down, and build a table, in fifty years we might simply grow a table. As more engineers work on biological systems, our industrial infrastructure will be transformed. Fifty years ago it was based on coal and steel. Now it is based on silicon and information. Fifty years from now it will be based on living systems. Sort of like a new agricultural age, only of a radically different kind."

– Rodney Brooks, MIT's Computer Science and Artificial Intelligence Laboratory[135]

• ***Fast growing fish***: Scientists from the Russian Academy of Sciences have reported that young carp and sturgeon exhibited a faster rate of growth (30% and 24% respectively) when they were fed nanoparticles of iron.[134]

The Future of Farming: Nanobiotech and Synthetic Biology

At the dawn of the 21st century, genetic engineering is suddenly old hat. The world's first synthetic biology conference convened in June 2004. Two months later, the University of California at Berkeley announced the establishment of the first synthetic biology department in the United States.[136] According to science reporter W. Wayt Gibbs, synthetic biology involves "designing and building living systems that behave in predictable ways, that use interchangeable parts, and in some cases that operate with an expanded genetic code, which allows them to do things that no natural organism can."[137] One of the goals, writes Gibbs, is to "stretch the boundaries of life and of machines until the two overlap to yield truly programmable organisms."[138]

Although synthetic biology is not always synonymous with nanobiotechnology (i.e., the merging of the living and non-living realms at the nano-scale to make hybrid materials and organisms), the programming and functioning of "living machines" in the future will frequently involve the integration of biological and non-biological parts at the nano-scale. Scientists at Berkeley's new synthetic biology department, for example, are particularly interested in the design and construction of "biobots" – autonomous robots designed for a special purpose that are the size of a virus or cell, and composed of both biological and artificial parts.[139]

Scientists have been taking steps to build life from the nano-scale for some time. In 1968, Indian-American chemist Har Gobind Khorana received a Nobel Prize for synthesising nucleotides (the chemical subunits – A, T, C, G – that make up the DNA molecule), stringing them together into synthetic DNA. By February 1976, a California research team (that later founded Genentech) developed an automated process for synthesising DNA and constructed a fully functioning synthetic gene. Synthetic genes and synthetic DNA are now a staple of genetic engineering in medicine and agriculture.

In 2002 researchers at Stony Brook (the State University of New York) synthesised the 7,440 letters in the poliovirus's genome using mail-order segments of DNA. It took the Stony Brook researchers three years to build a live polio virus from scratch. Less than two years later, a team led by Craig Venter (formerly of the Human Genome Project) was able to synthesise a slightly smaller virus in just three weeks, raising the prospect of rapid assembly of artificial micro-organisms – and the possibility of designing dangerous biowarfare agents from scratch.

Venter, who heads the Institute of Biological Energy Alternatives

(IBEA), is now building a new type of bacterium using DNA manufactured in the laboratory. His team is modifying DNA from *Mycoplasma genitalium,* a bacterium that has the smallest number of genes of any living cell, with the goal of reducing it to only those genes necessary for life. The researchers will insert the minimal life form back into a normal bacterial cell that has been stripped of its DNA. According to Professor Clyde Hutchison, a biochemist who helped sequence the *Mycoplasma* genome, "The advantage of a synthetic organism over manipulating natural organisms ... is then you would have a lot more control over the properties of the cell than if you rely on natural mechanisms. For either good purposes or bad purposes ... you'd be in a better position to design exactly what you want."[140]

With funding from the US Department of Energy (DOE), Venter's eventual goal is to build synthetic organisms that could produce energy and mitigate climate change. Both Venter and the DOE point to the wider applications of synthetic life, noting that benefits could include "the development of better vaccines and safer strategies for gene therapy; improving agricultural crop yields that are better disease resistance [sic] and improving strategies for combating agricultural diseases and even enhancing our ability to detect and defeat potential biothreat agents which is important to homeland security."[141] Venter has hinted that he will unveil a novel, artificial genome in late 2004 that is larger than a virus but smaller than a bacterium.[142]

In the summer of 2003, ETC Group reported on research at the University of Florida to create an artificial nucleotide, a human-made counterpart to one of the four chemical components that make up DNA (A, G, C and T).[143] Since then, other researchers at the University of Florida have been able to add a second artificial letter – so that there are six in all – and, more remarkably, to coax the newly-expanded DNA molecule to make copies of itself.[144] The research team was able to "evolve" its artificial DNA through five generations. According to the lead scientist on the project, the advance "will enhance our ability to detect unwanted genetic material from viruses, bacteria and even biological warfare agents. It will also streamline our ability to detect defects in natural DNA, such as those responsible for cancers and genetic diseases."[145] As ETC Group pointed out last year, these advances are either the greatest thing since spliced DNA or they could create end products that contribute as much to biological weaponry as to disease detection and new medicines.

Green Goo: "Green Goo" is the term ETC Group uses to describe potential dangers associated with synthetic biology or nanobiotechnology. Researchers are coaxing living organisms to perform mechanical functions precisely because living organisms are capable of self-assembly and self-replication. They envision harnessing living cells and custom-made

"I suspect that, in five years or so, the artificial genetic systems that we have developed will be supporting an artificial life form that can reproduce, evolve, learn and respond to environmental change."

– Professor Steven Benner, Chemist, University of Florida[146]

"If biologists are indeed on the threshold of synthesizing new life forms, the scope for abuse or inadvertent disaster could be huge."

Philip Ball, Nature, *October 7, 2004.*[147]

Though calls are being made to hold a new Asilomar-type gathering, ETC Group believes that Asilomar is an unacceptable model for today's world.

living organisms to perform specific biochemical tasks, such as producing hydrogen or sequestering carbon dioxide. But what if new life forms, especially those that are designed to function autonomously in the environment, prove difficult to control or contain? What if something goes wrong? That's the specter of Green Goo.

Asilomar+30? Some researchers in the field of synthetic biology have begun to acknowledge potential risks and ethical implications of their work. A recent editorial in *Nature* suggests that it may be time for an Asilomar-type summit to demonstrate publicly that members of the synthetic biology community "are willing to consult and reflect carefully about risk – both perceived and genuine – and to moderate their actions accordingly."[148]

What is Asilomar? In 1974 a committee of molecular biologists and biochemists was established by the US National Academy of Sciences to address mounting concerns over potential hazards associated with genetic engineering in the laboratory. The committee released an open letter in July 1974 calling for a voluntary and partial moratorium on genetic engineering lab experiments, and for an international meeting of scientists to address potential biohazards. Asilomar refers to the California conference center where prominent molecular biologists gathered in February 1975. The scientists drafted guidelines for genetic engineering research and recommended that the partial moratorium be lifted.

Though calls are being made to hold a new Asilomar-type gathering, ETC Group believes that Asilomar is an unacceptable model for today's world. Thirty years ago, participation at Asilomar was limited to a hand-picked group of elite scientists who promoted an agenda of self-regulation for genetic engineering as a means of preempting the specter of government action; the scope of discussion was limited to questions of hazards and safety – explicitly excluding broader social and ethical issues.[149] According to University of Michigan historian, Susan Wright, several reporters who covered the Asilomar meeting concluded the conference "was intended to avoid public involvement rather than to encourage it."[150]

While there is an urgent need to address the social and ethical implications and potential risks associated with synthetic biology and nanobiotechnology – any efforts to confine discussions to meetings of experts or to focus debate solely on the environmental, health and safety aspects of nano-scale technologies will be a mistake. Similarly, efforts to "educate" or "consult" with citizens for the sake of improving public relations or of pre-empting regulatory scrutiny are likely to backfire. In its recent report, *See-Through Science*, UK-based Demos asserts that public engagement in science and technology issues must not simply inform decisions made by governments – it must actively shape them.[151]

II. NANO FOOD AND NUTRITION OR "NANOTECH FOR TUMMIES"

Introduction: A handful of food and nutrition products containing invisible nano-scale additives are already commercially available. Hundreds of companies are conducting research and development (R&D) on the use of nanotech to engineer, process, package and deliver food and nutrients to our shopping baskets and our plates. Among them are giant food and beverage corporations, as well as tiny nanotech start-ups.

According to Jozef Kokini, the Director of the Center for Advanced Food Technology at Rutgers University (New Jersey, USA), "every major food corporation has a program in nanotech or is looking to develop one."[153] A 2004 report produced by Helmut Kaiser Consultancy, "Nanotechnology in Food and Food Processing Industry Worldwide," predicts that the nanofood market will surge from $2.6 billion today to $7 billion in 2006 and to $20.4 billion in 2010.[154] In addition to a handful of nano food products that are already on the market, over 135 applications of nanotechnology in food industries (primarily nutrition and cosmetics) are in various stages of development.[155] According to Helmut Kaiser, more than 200 companies worldwide are engaged in nanotech research and development related to food. Among the 20 most active companies are five that rank among the world's 10 largest food and beverage corporations, Australia's leading food corporation, and Japan's largest seafood producer and processed food manufacturer. (See Annex 1).

Despite the obvious enthusiasm for nano-scale science and its applications to food engineering and processing, the food & beverage industry is generally conservative and cautious when talking about the future of nanotech and food. Most industry representatives interviewed by ETC Group declined to provide specific details about the level of funding and industry partners. We spoke to scientists at giant food and beverage corporations (Kraft and Nestlé), as well as university researchers and representatives from small nanotech start-ups (often one and the same). After witnessing widespread rejection of genetically modified foods, the food industry may be especially skittish about owning up to R&D on "atomically modified" food products. "The food industry is more traditional than other sectors like IBM" [where nanotechnology can be applied], explains Gustavo Larsen, a professor of chemical engineering and a former consultant to Kraft.[156] "My take is that there are good opportunities and it's often more feasible to realise these opportunities [in the food sector]. You can make nanoparticles and use them in foods – you don't have to assemble them first."[157] When

"Every major food corporation has a program in nanotech or is looking to develop one."[153]

– Jozef Kokini, Director of the Center for Advanced Food Technology , Rutgers University

"It is possible that it is only a matter of time until we see the products of nanotechnology on our plate."

–*Food Technology,* December 2003[152]

Producing food by molecular manufacturing is the most ambitious goal of nanotech – and the least likely to materialize anytime soon.

asked what he believes will be the first products of nanotech R&D related to food, Larsen said that consumers are likely to see packaging composed of nano-scale materials before novel food products. "I think the packaging is a safer bet," said Larsen.

Molecular Food Manufacturing

Some people claim that in the future, molecular engineering will enable us to "grow" unlimited quantities of food without soil, seed, farms or farmers – and that it will wipe-out global hunger in the process. Consider the following views:

• "Nanomachines could create unlimited amounts of food by synthesis at the atomic level, which would eradicate hunger." – Carmen I. Moraru *et al.,* professor of food science, Cornell University (USA), on nanotech's potential impact on food science[158]

• "Molecular biosynthesis and robotic replenishment may allow quick replacement of production, so we wouldn't have to depend on centralized systems to grow and deliver our food. In the first, primitive stages of molecular assembly, we'd build packaged greenhouses, radically different from those today, that would allow local or individualized production by millions who know nothing about farming…At the next stage of molecular manufacturing, food synthesis could occur directly, without growing crops or livestock." – Douglas Mulhall, *Our Molecular Future*

• "Why can't human beings imitate nature's methodology? Instead of harvesting grain and cattle for carbohydrates and protein, nanomachines (nanobots) could assemble the desired steak or flour from carbon, hydrogen, and oxygen atoms present in the air as water and carbon dioxide. Nanobots present in foods could circulate through the blood system, cleaning out fat deposits and killing pathogens." – Dr. Marvin J. Rudolph, Director, DuPont Food Industry Solutions, in *Food Technology*, January 2004.

Producing food by molecular manufacturing[159] is the most ambitious goal of nanotech – and the least likely to materialize anytime soon. To those who have followed the biotech debate over the past two decades, enthusiastic claims that a new technology will feed hungry people is a tired and empty refrain. Nano-optimists see the future through the biotech industry's rose- (and green-) coloured glasses: now it's nanotech, they claim, that will eradicate hunger by increasing agricultural yields, enhancing the nutritional content of food and eliminating the risk of food allergens.[160]

ETC Group concludes that present-day "nanotech for tummies" is following the same trajectory as other nano-scale R&D, with the earliest applications in the area of "smart" materials and sensors. More revolutionary applications, such as the atomic modification of food, are perhaps more distant. But it's worth noting that a few ambitious scientists are trying to create food in the lab.

Tissue engineers at Touro College (New York City) and at the Medical University of South Carolina (USA) are experimenting with growing meat by "marinating" fish myoblast (muscle) cells in liquid nutrients to encourage the cells to divide and multiply on their own. The first goal is to keep astronauts in space from going hungry.[161]

Packaging

Today, food-packaging and -monitoring are a major focus of food industry-related nanotech R&D. Packaging that incorporates nanomaterials can be "smart," which means that it can respond to environmental conditions or repair itself or alert a consumer to contamination and/or the presence of pathogens. According to industry analysts, the current US market for "active, controlled and smart" packaging for foods and beverages is an estimated $38 billion – and will surpass $54 billion by 2008.[167] The following examples illustrate nano-scale applications for food & beverage packaging:

• Chemical giant Bayer produces a transparent plastic film (called Durethan) containing nanoparticles of clay. The nanoparticles are dispersed throughout the plastic and are able to block oxygen, carbon dioxide and moisture from reaching fresh meats or other foods.[168] The nanoclay also makes the plastic lighter, stronger and more heat-resistant.

• Until recently, industry's quest to package beer in plastic bottles (for cheaper transport) was unsuccessful because of spoilage and flavour problems. Today, Nanocor, a subsidiary of Amcol International Corp., is producing nanocomposites for use in plastic beer bottles that give the brew a six-month shelf-life.[169] By embedding nanocrystals in plastic, researchers have created a molecular barrier that helps prevent the escape of oxygen. Nanocor and Southern Clay Products are now working on a plastic beer bottle that may increase shelf-life to 18 months.[170]

• Kodak, best known for producing camera film, is using nanotech to develop antimicrobial packaging for food products that will be commercially available in 2005. Kodak is also developing other 'active packaging,' which absorbs oxygen, thereby keeping food fresh.[171]

• Scientists at Kraft, as well as at Rutgers University and the University of Connecticut, are working on nano-particle films

"Tomorrow we will design food by shaping molecules and atoms. Nano-scale biotech and nano-bio-info will have big impacts on the food and food processing industries."

– Helmut Kaiser, nanotech consultant and market analyst

To those who have followed the biotech debate over the past two decades, enthusiastic claims that a new technology will feed hungry people is a tired and empty refrain.

and other packaging with embedded sensors that will detect food pathogens. Called "electronic tongue" technology, the sensors can detect substances in parts per trillion and would trigger a colour-change in the packaging to alert the consumer if a food has become contaminated or if it has begun to spoil.[172]

• Researchers in the Netherlands are going one further to develop intelligent packaging that will release a preservative if the food within begins to spoil. This "release on command" preservative packaging is operated by means of a bioswitch developed through nanotechnology.[173]

• Developing small sensors to detect food-borne pathogens will not just extend the reach of industrial agriculture and large-scale food processing. In the view of the US military, it's a national security priority.[174] With present technologies, testing for microbial food-contamination takes two to seven days and the sensors that have been developed to-date are

Historical Cue: On the Eve of an Anniversary

Regulations for food safety date back to Babylonian days but the modern era of governmental regulation is, more or less, a century old. In 1906 the US government established the Pure Food and Drug Act.[162] Confronted by corporate chicanery on all sides, the US Congress attempted to lay down some basic ground rules for food and agricultural quality. History shows that food safety regulations and related technologies have a chequered past:

Late 1940s: The post-World War II chemical boom saw the wide use of DDT and other pesticides on crops around the world. Originally billed as a health and production "miracle," regulators eventually realised that chemicals that kill weeds and insects might also kill people. DDT was taken off the market in the 1970s as were many of its chemical cousins.

1960s-1970s: Some chemical colorants, preservatives, additives and artificial sweeteners were taken off grocery shelves almost as fast as they were put on as regulators discovered their carcinogenic qualities.

Late 1970s: In 1978, the US government discovered that the major private sector laboratory evaluating new pesticides and other chemicals, Industrial Bio-Test Ltd., systematically falsified animal test data over a 10-year period, compromising the safety of several hundred crop chemicals.[163] Three of the company's top officials were later convicted of fraud. Rather than take all pesticides off the shelf that were based on invalid safety data, US regulators allowed many to remain unless there was convincing evidence that the products were dangerous.[164]

1980s-1990s: Health research on endocrine disrupters indicates that a large number of crop chemicals and food additives as well as

too big to be transported easily.[175] Several groups of researchers in the US are developing biosensors that can detect pathogens quickly and easily, reasoning that "super sensors" would play a crucial role in the event of a terrorist attack on the food supply. With USDA and National Science Foundation funding, researchers at Purdue University are working to produce a hand-held sensor capable of detecting a specific bacteria instantaneously from any sample. They've created a start-up company called BioVitesse.[176]

While devices capable of detecting food-borne pathogens could be useful in monitoring the food supply, sensors and smart packaging will not address the root problems inherent in industrial food production that result in contaminated foods: faster meat (dis)assembly lines, increased mechanisation, a shrinking labour force of low-wage workers, fewer inspectors, the lack of corporate and government accountability

While devices capable of detecting food-borne pathogens could be useful in monitoring the food supply, sensors and smart packaging will not address the root problems inherent in industrial food production that result in contaminated foods.

pharmaceuticals – but especially growth hormones – could damage human health.[165] Many researchers associate the growing cancer epidemic, asthma, attention deficit problems and other neurological disorders with chemicals introduced into the food chain and/or the environment since World War II.[166]

1996: When genetically-modified (GM) crops were approved for commercial sale in the US, a fast-spreading consumer backlash in Europe and many parts of the South prompted the UN Convention on Biological Diversity to begin deliberations on a Biosafety Protocol. A weak Biosafety Protocol came into force seven years later – in 2003.

1996: The UK government concedes that a variant of bovine spongiform encephalopathy (popularly known as Mad Cow Disease) has spread to humans, resulting in mass culling of British cattle herds. Regulators and scientists wrongly believed that feeding cow parts to cows did not pose a health hazard.

Late 1990s: Multinational tobacco enterprises – facing multi-billion dollar lawsuits – finally concede that tobacco is dangerous to health – but only after these companies spread their risk by diversifying into food and beverage processing.

2000: Confounded by a consumer revolt against GM foods, many food retailers and processors refuse GM products vowing that they "won't take a bullet" for Monsanto.

2002: World Health Organization warns of "Globesity." Fast food lifestyle is leading to a pandemic of overweight and obese middle-class in the North and South.

2004: Farmers and consumers learn that nanoparticles are being developed or marketed for crop and livestock production and for use in processed foods in the absence of size-specific regulation.

Are better sensors the best answer? "If 19 million pounds of meat distributed to half of [the US] had been contaminated with a deadly strain of E. coli *bacteria by terrorists, we'd go nuts. But when it's done by a Fortune 100 corporation, we continue to buy it and feed it to our kids."*

– Diane Carmen, commenting in *The Denver Post* (July 26, 2002) on ConAgra's tainted beef recall

and the great distances between food producers, processors and consumers. Just as it has become the consumer's responsibility to make sure meat has been cooked long enough to ensure that pathogens have been killed, consumers will soon be expected to act as their own meat inspectors so that industry can continue to trim safety overhead costs and increase profits.

Tagging and Monitoring

Radio Frequency ID tags (RFid): An RFid tag is a small, wireless integrated-circuit (IC) chip with a radio circuit and an identification code embedded in it. The advantages of the RFid tag over other scan-able tags – such as the UPC barcodes pasted on most consumer products today – are that the RFid tag is small enough to be embedded in the product itself – not just on its package; it can hold much more information, can be scanned at a distance (and through materials, such as boxes or other packaging) and many tags can be scanned at the same time. RFid tags are already being used for livestock tracking, attached to the ear or injected into the animal. The entire chip can be about the size of a dust mote – closer to micro-scale than nano-scale, though incorporating nano-scale components. Developers of the technology envision a world where they can "identify any object anywhere automatically."[177]

RFid tags could be used on food packaging to perform relatively straightforward tasks, such as allowing cashiers in supermarkets to tally all of a customer's purchases at once or alerting consumers if products have reached their expiration dates. RFid tags are controversial because they can transmit information even after a product leaves the supermarket. Privacy advocates are concerned that marketers will have even greater access to data on consumer-behavior. They want the tags to be disabled at the cash register (what is known as "tag killing") to insure that personal data won't be obtained and stored. Wal-Mart in the US and TESCO in the UK have already tested RFid tagging on some products in some stores.[178]

A "nanobarcode" is an alternative tagging or monitoring device that works more like the UPC code, but on the nano-scale. One type of nanobarcode – developed by Nanoplex Technologies – is a nanoparticle consisting of metallic stripes, where variations in the striping provide the method of encoding information.[179] Nanoplex changes the length and width of the particles and the number, width and composition of each stripe to make billions and billions of variations. So far they've put barcodes into ink, fabric, clothing, paper, explosives and on jewellery. The codes can be read using a handheld optical reader or a microscope that measures the difference in reflectivity of the metallic stripes. Silver and gold reflect light in different ways, for example, and it is the patterns of reflection that give each particle its unique code. In addition to gold and silver, Nanoplex makes

codes out of platinum, palladium, nickel and cobalt.

Nanoplex also produces "Senser" tags (Silicon Enhanced Nanoparticles for Surface Enhanced Raman Scattering) – 50 nm metal nanoparticles that exhibit unique codes similar to nanobarcodes. Senser tags can also be incorporated into packaging and read by an automated reader up to a metre away, allowing items to be read at a checkout like RFID tags or to be read covertly at ports.[180]

The tagging of food packages will mean that food can be monitored from farm to fork – during processing, while in transit, in restaurants or on supermarket shelves and eventually, even after the consumer buys it. Coupled with nanosensors, those same packages can be monitored for pathogens, temperature changes, leakages, etc.

Nano-Food: What's Cooking at the Bottom?[181]

In 1999, Kraft Foods, the $34 billion Altria (formerly known as Phillip-Morris) subsidiary, established the industry's first nanotechnology food laboratory. The next year, Kraft launched the NanoteK consortium, enveloping fifteen universities and public research labs from around the globe.[182] None of the scientists involved in the consortium are food scientists by training; rather, they're a mix of molecular chemists, material scientists, engineers and physicists.[183]

Looking at food from an engineering perspective is nothing new. For the last three decades, scientists have introduced genes from one species of plant or animal into another using genetic modification (GM) technologies, but at least for a thousand years before that, people have introduced specially formulated additives to food to impart new flavours, textures, colours or other qualities. Nano-scale technologies will take food engineering "down" to a new level, with the potential to change dramatically the way food is produced, grown, processed, packaged, transported and even eaten.

Nano-scale food additives: In fact, the products of nanotechnology have already begun to "appear" in food (though they are too small to see – and consumers would have no way of knowing since there is no requirement for labeling and no size-specific regulation). BASF, for example, produces a nano-scale version of carotenoids, a class of food additives that imparts an orange colour and that occurs naturally in carrots and tomatoes. Some types of carotenoids are antioxidants and can be converted to Vitamin A in the body. BASF sells its nano-scale synthetic carotenoids to major food & beverage companies worldwide for use in lemonades, fruit juices and margarines.[184] Nano-scale formulation makes them more easily absorbed by the body but also increases shelf-life.[34] (BASF's carotenoid sales are US$210 million annually. This figure includes both nano-scale and other carotenoids.)[185]

In 2002, BASF submitted a GRAS

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ETC Group has identified only a handful of nano-scale food additives on the market today, but we can't be certain how widespread their use is since there are no requirements that they be labeled as such.

(Generally Recognized as Safe) Notice to inform the FDA of its sale of a synthetic carotenoid called lycopene (which occurs naturally in tomatoes) as a food additive. BASF's synthetic lycopene is formulated at the nano-scale. According to BASF, the question of specialized testing for nano-particulated lycopene was not raised and was not required because "BASF demonstrated safety in a variety of...toxicological evaluations."[187] The FDA accepted BASF's notice without question.[188] In a telephone interview, Robert Martin of the FDA confirmed that size was not taken into account in the review of BASF's synthetic lycopene and he explained further that "size per se" is "not a major consideration" in regulatory review, but would be addressed "on a case-by-case basis" if there appeared to be implications for health and safety.[189]

Is it safe to add nanoparticles to foods? The short answer to the question is "No one knows for sure." The issue has yet to be confronted head on by either regulators or the scientific community. ETC Group has identified only a handful of nano-scale food additives on the market today, but we can't be certain how widespread their use is since there are no requirements that they be labeled as such. Just as in other regulatory arenas such as cosmetics and chemicals, the question of safety has not been approached from the perspective of size. So far, manufacturers have been the only ones to consider size – primarily in terms of the market advantages that extremely small size offers (e.g., a decrease in size increases bioavailability in foods; a decrease in size increases transparency in cosmetics).

In the case of additives that also occur naturally in foods, it is not clear what the nano-specific safety issues are. Discussing nano-scale lycopene, for example, Dr. Gerhard Gans of BASF explained that once the synthetic, nano-scale lycopene reaches the gut, it behaves in exactly the same way the lycopene in a tomato behaves: it is broken down by digestive enzymes and taken into the bloodstream and further to the liver and other organs as individual molecules.[190] In other words, by the

time it enters the blood stream, all food is nano-scale – whether it started out as a slice of tomato or a glass of lemonade containing BASF's synthetic lycopene. (Perhaps because of health concerns related to nanoparticles, Dr. Gans emphasised that the synthetic lycopene handled by BASF employees and supplied to their customers was not in the form of nanoparticles; at that stage, he said, the particles have clumped together in aggregates of micron-level size, which will partially dissolve in the final product. Ultimately, the consumer's digestive enzymes bring the particles back down to nano-scale.)

While the explanation that all food is nano-scale by the time it reaches the bloodstream makes sense *a priori,* it is important to note that BASF conducted toxicological testing of its lycopene not because it was a nano-scale formulation, but because it was produced through chemical synthesis (rather than derived from lycopene-containing fruits and vegetables). Had synthetic lycopene already been vetted as a food ingredient, BASF would not have been compelled by regulators to test the safety of a nano-scale version. This is what makes the prospect of adding nanoparticles to foods – in the absence of specific regulatory attention paid to size – alarming: what nano-scale substances are in the pipeline that have already been approved as food additives at larger scales but may now be formulated at the nano-scale with altered properties and unknown consequences? Of particular concern would be nano-scale formulations of substances that do not already occur naturally in food.

Take titanium dioxide (TiO_2) as an example: TiO_2 was approved as a food colour additive by the US FDA in 1966 with the only stipulation being "not to exceed 1% by weight."[191] (Micron-sized TiO_2 imparts a bright white colour and is added to icings on cookies and cakes). The FDA has also approved TiO_2 as a "food contact substance" as well, meaning that if it comes into contact with food when it is incorporated into packaging, it won't cause harm. TiO_2 has been used as a colorant (white) in paper used for food packaging.[192]

With advances in nanotech techniques, TiO_2 can now be formulated at the nano-scale. The quantum property changes that take place with the reduction in size offer advantages for certain applications. But some of nano-scale TiO_2's property changes – such as increased chemical reactivity – have caused concern in applications where the nano-scale substance comes in intimate contact with the human body, (e.g., as an ingredient in cosmetics).[193] Nano-scale TiO_2 particles are no longer white (they are transparent), but they still block ultraviolet (UV) light in the way their larger siblings do. Transparent, nano-scale TiO_2 is now being used in clear plastic food wraps for UV protection. Because TiO_2 has already been approved as a food colour additive and as a food

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There is kind of a "particle nepotism" that could have dangerous consequences: if Big Brother passes the safety test, Little Brother doesn't even have to take the exam.

contact substance, its nano-scale use in foods does not require additional toxicity testing. And the percent-by-weight limits set back in the 1960s aren't necessarily relevant to today's nano-scale formulations since tiny amounts can produce large effects.

Silicon dioxide (SiO_2), also known as silica, is another example of an FDA-approved food additive that doesn't occur naturally in foods. Silica is a common substance in nature – beach sand and quartz are almost-pure forms of crystalline silica.[194] In addition to a crystalline form, silica occurs naturally in an amorphous form (e.g., diatomaceous earth) and it is this form of silica that is produced synthetically and is an FDA-approved food ingredient as an anti-caking agent.[195] (Amorphous silica is also known as "fumed" silica.) The regulation states that the silica content must be less than 2% of the weight of the food. Food-grade fumed silica with particles sizes in the nanometer range are commercially available.[196] Again, it is not clear what food products contain synthetic nano-scale silica as there are no labelling requirements.

Mars, Inc., one of the world's largest private food corporations, was issued US patent 5,741,505 in 1998 on "edible products having inorganic coatings." The coatings create a barrier to prevent oxygen or moisture from reaching the product under the coating, thereby increasing shelf life. The patent claims the invention will keep hard candy from getting sticky, cookies from getting stale, cereals from becoming soggy in milk, etc. The coatings can be made from various chemical compounds of which SiO_2 and TiO_2 are specifically mentioned. According to the inventors, the coating should be extremely thin because of regulatory requirements and because of texture and "mouthfeel" considerations. The patent states that the ideal coating would be somewhere between .5 nm and 20 nm thick. While the coating could be made of any inorganic material, the inventors state that it is preferable to use a substance that has already been GRAS-certified by the FDA, such as SiO_2 and TiO_2. The patent application describes an example of their invention, in which they coated M&Ms, Twix and Skittles brand candies with an inorganic nano-film.

ETC Group is not in the position to assess the safety of nano-scale food additives. We want to highlight the regulatory vacuum, where size does *not* matter and nano-scale formulations do not trigger any special regulatory scrutiny. It's a kind of "particle nepotism" that could have dangerous consequences: if Big Brother passes the safety test, Little Brother doesn't even have to take the exam.

Special Delivery

The food industry aims to engineer food so it is more "functional" – meaning more nutritious (or perceived to be) or serving some other purpose beyond its biological purpose of providing energy through calorie consumption. Many companies believe that nano-scale technologies will help in this quest and they are focusing on "delivery."

Most of us don't think very much about delivery when it comes to food (unless we're waiting for a pizza to arrive from across town): we bite, chew, swallow and our digestive tracts take care of the rest. But in order to benefit from delivery – whether it's the Vitamin C from an apple we've just bitten into or the synthetic lycopene in our lemonade – the nutrient must go to the right place in the body and it must be active when it gets there.[197] Controlling and engineering nutrient delivery is a challenge and its mastery will be enormously profitable. According to industry analysts, in the US alone, the market for functional foods containing medically-beneficial nutrients – worth $23 billion in 2003 – will exceed $40 billion in 2008.[198]

In December 2000, ETC Group reported on the biotech's industry quest to develop a new generation of biotech products, genetically-modified "nutraceuticals" and functional foods, that seek to deliver clear (or at least perceived) consumer benefits.[199] Tainted by the wider controversy over GM crops, however, the GM nutraceutical products have been largely stuck in the pipeline. Will nanotech deliver where biotech failed?

Like the pharmaceutical, agrochemical and cosmetics giants, food and beverage companies are also experimenting with the use of nanocapsules to deliver active ingredients. One way to preserve an active component is by putting it in a protective 'envelope.' The envelope can be engineered to dissolve or the active ingredient can be made to diffuse through the envelope triggered by the right stimulus. There are already several hundred types of 'microcapsules' being used as food additives in the US alone,[200] some to achieve the controlled release of active ingredients. George Weston Foods of Australia, for example, sells a version of its popular Tip Top bread, known as

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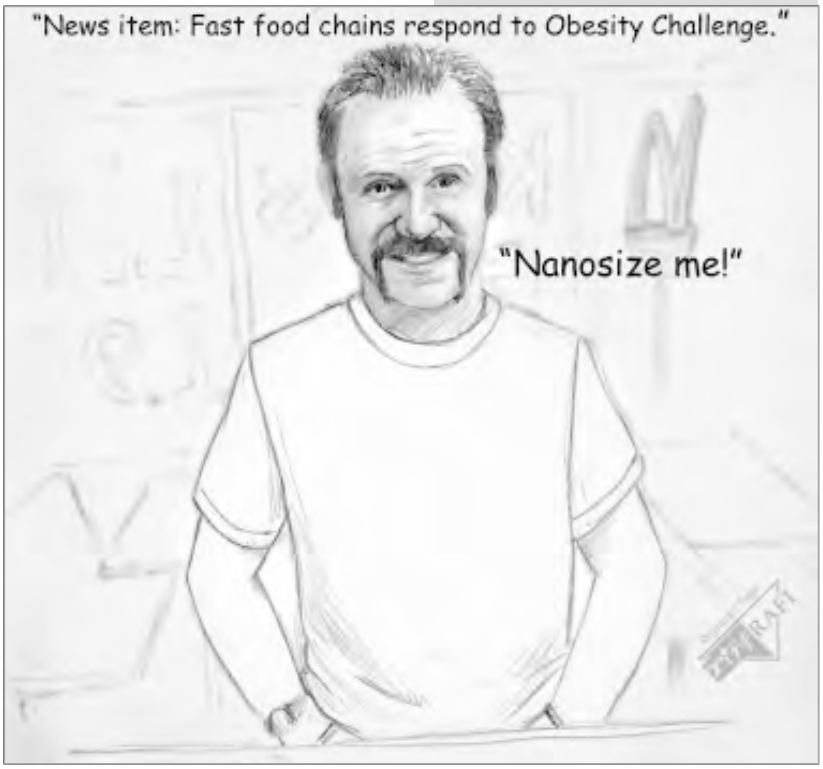

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'Tip Top-up,' which contains microcapsules of tuna fish oil high in Omega-3 fatty acids. Because the tuna oil is contained in a microcapsule, the consumer doesn't taste the fish oil, which is released in digestion once it has reached the stomach. The same technology is also being employed in yogurts and baby foods.

Companies large (Unilever, Kraft) and small (see below) are now developing "nano-capsules:"

• Researchers at Hebrew University in Jerusalem created a start-up company called Nutralease. They've applied for a patent[201] on a nano-scale self-assembled structure that can carry active components into and through the human body. According to the company's patent application, their "nanovehicle" can be diluted in either oil or water without affecting its active ingredient. The company's nanovehicles are already on the market in a cholesterol-reducing canola oil.[202] Nutralease has just signed a deal with an Israeli meat company that wants to inject a little health in its hot dogs and another deal with an ice cream manufacturer is in the works.[203]

• Royal BodyCare, a company based in Texas (USA), has created what it calls "nanoceuticals" (and has applied for a trademark on the name) – using a different kind of envelope to deliver "powerful, tiny mineral clusters that are believed to increase the absorption of nutrients into our cells."[204] Royal BodyCare puts these nanoceutical particles into its line of "SuperFoods" nutritional supplements.

• BioDelivery Sciences International (BDSI) has developed and patented "nanocochleates" – coiled nano-scale particles (as small as 50 nm in diameter) derived from soy (not genetically modified, they emphasise!) and calcium that can carry and deliver pharmaceutical compounds as well as nutrients such as vitamins, lycopenes and omega fatty acids directly to cells. The company claims that its nanocochleates can deliver Omega-3 fatty acids to cakes, muffins, pasta, soups and cookies without altering the product's taste or odour.[205] No products containing the nanocochleate delivery system are currently on the market, but the company actively seeks to license its technology. "We have some [food] companies that are clearly enthusiastic," said Raphael Mannino, chief scientific officer of BDSI.[206] Mannino told ETC Group that it is not yet clear what regulatory hurdles his company's nano-scale nutrient delivery system would need to clear before commercialisation. "Nobody is really sure yet," said Mannino.[207] Before it becomes a commercial reality, BDSI must achieve large-scale manufacture of the nanoencochleation technology. Under the most optimistic scenario, Mannino said that "we could be in food in one year."

• With funding from the USDA, LNKChemsolutions is developing nano-scale capsules of edible polymers to prevent the flavour and aroma of food molecules

from degrading. The goal is to increase the shelf life of sensitive food products, but the company declines to reveal which ones.[208] LNK Chemsolutions was founded by Dr. Gustavo Larsen, a professor of chemical engineering of the University of Nebraska.

• Other companies are working on using nano-scale technologies to create "interactive foods" that operate using "on-demand" delivery. The idea is that the consumer will be able to choose – based on her individual aesthetics, nutritional needs or flavor preferences of the moment – which components will be activated and then delivered and which won't be. Kraft's NanoteK consortium scientists are developing nanocapsules whose walls burst at different microwave frequencies so the consumer can 'switch on' new tastes or colours. Countless nanocapsules would remain dormant and only the desired ones would be called into action. Kraft is also working on sensors that will be able to detect an individual's nutritional deficiencies and then respond with smart foods that release molecules of the needed nutrients.[209]

Early next year, food scientists will meet to discuss nano and micro-scale approaches for controlled release and nutrient absorption in foods – at the first International Symposium on the "Delivery of Functionality in Complex Food Systems: Physically-Inspired Approaches from Nano-scale to Microscale," at the Nestlé Research Center in Lausanne, Switzerland.[210]

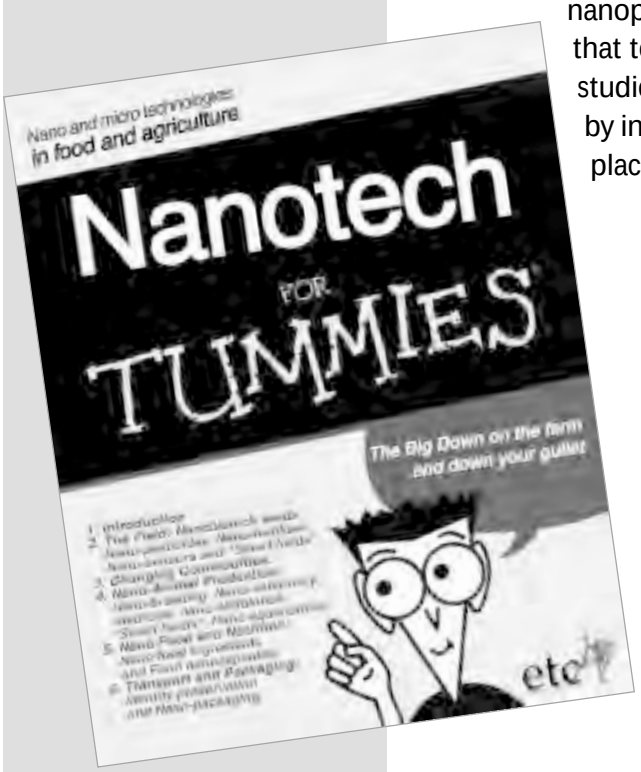
In addition to aiding nutrient delivery, nanoparticles may be used in foods to alter other properties. For example, margarine, ice cream, butter and mayonnaise all belong to a class of foods known as colloids, where small particles are dispersed in some other medium – liquid, gas or solid. Unilever, Nestlé and others are conducting research and already hold patents on new ways to make colloids using nano-particles that will extend shelf-life, prolong flavour sensation in the mouth, alter texture and improve stability (see Annex 2).

Nutricosmetics: Eating is just one way to deliver active ingredients. Paris-based L'Oréal, the world's leading cosmetics firm, already markets skin care products

Kraft's NanoteK consortium scientists are developing nanocapsules whose walls burst at different microwave frequencies so the consumer can 'switch on' new tastes or colours.

Food and cosmetic alliances illustrate the tendency to blur boundaries between food, medicine and cosmetics, a trend that nanotech will likely accelerate.

containing nano-scale particles.[211] (Nestlé holds a 49% stake in L'Oréal.[212]) The company's "nanosomes" are tiny intercellular delivery systems that penetrate the skin and then release Vitamin E. According to L'Oréal, "Given that the interstices of the outer layer of skin measure about 100 nanometers, nanovectors offer the best solution to the problem of transporting and concentrating active ingredients in the skin."[213] Cosmetics containing invisible nanoparticles have not escaped notice in recent European reports on potential risks associated with manufactured nanoparticles. A Royal Society (UK) report released in July 2004 notes the dearth of toxicological data on manufactured nanoparticles.[214] Because they are used in some cosmetics and sunscreens, the report recommends further studies of skin penetration by manufactured nanoparticles and that toxicological studies conducted by industry be placed in the public domain – no doubt causing some wrinkles for L'Oréal.



Food and cosmetic companies are now collaborating to develop "cosmetic nutritional supplements." L'Oréal and Nestlé recently formed Laboratoires Innéov, a 50/50 joint venture. Innéov's first product, called "Innéov Firmness," contains lycopene. The supplement is taken orally and is marketed to women over 40 who are concerned about lost skin elasticity.[64] Shortly after Nestlé cemented its collaboration with L'Oréal, Procter & Gamble and Olay announced they would be creating two lines of nutritional supplements together – one for "Beauty" and one for "Wellness."[216] While these particular supplements are not advertised as using nano-scale technologies, it is difficult to be sure since there are no labelling requirements. In any case, the food and cosmetic alliances illustrate the tendency to blur boundaries between food, medicine and cosmetics, a trend that nanotech will likely accelerate.

III. RECOMMENDATIONS

Genetically modified crops came to market less than one decade ago with virtually no public discussion of their risks and benefits, and within regulatory frameworks that civil society organisations have described as inadequate, non-transparent or non-existent. As a result, questions and controversies surrounding socio-economic, health and environmental impacts of GM foods are unresolved, and millions of people have spurned GM products. The parallels between the introduction of biotech and nanotech are undeniable. Despite the nanotech community's persistent vows not to repeat the same clumsy mistakes, it has been following in biotech's footsteps.

By allowing nanotech products to come to market in the absence of public debate and regulatory oversight, governments, agribusiness and scientific institutions have already jeopardised the potential for nano-scale technologies to be used beneficially. That there are no regulations in place anywhere in the world today to evaluate new nano-scale products in the food chain represents unacceptable and culpable negligence. Given widespread societal concerns over GM foods, pesticide residues, growth hormones and "mad cow" disease, farmers and consumers will be dismayed to learn that novel nano-scale materials are either already on the sideboard or on the drawing board. Steps must be taken to restore confidence in food systems and to make sure that nano-scale technologies, if introduced, are done so under rigorous health and safety standards.

The most important single recommendation we make is that society become fully engaged in a wide discussion of the role of converging (nano-scale) technologies in food and agriculture. Any effort to sideline this discussion into a meeting of experts or to focus solely on the health or environmental aspects of the new technologies will be a mistake, both for society and industry proponents. Unlike the early GM debate, discussion must not be confined to technical issues alone. Intellectual property and other forms of technological monopolies must also be on the table. Who will control the technologies? Who will benefit from them? Who will play a role in deciding how nanotechnologies affect our future?

Recognising that governments are already compromised by their convoluted relationships with agribusiness and the nanotech industry, ETC Group addresses its first and most important recommendations to our partners in civil society. Beyond this, we offer recommendations for governments and for intergovernmental organisations.

"What kind of industrial strategist – and we must assume there was strategy at some point – would try to stealthily bring to market products that no one needs but everyone has to consume, that the most industry-friendly politician would have difficulty justifying and whose only apparent redeeming feature is to improve the market positioning of the companies that make them?"

– Reflections on the introduction of agricultural biotechnology, Editorial, *Nature Biotechnology*, September 2004

It is urgent that civil society work together to encourage the widest possible public discussion of the new nano-scale technologies and to ensure that policy-makers take appropriate steps to safeguard the health, well-being and livelihoods of farmers and consumers – and the well-being of the environment.

To Civil Society: NGOs and social movements are now beginning to recognise the potential impacts of converging technologies at the nano-scale. Particularly in the areas of food and agriculture, it is urgent that civil society work together to encourage the widest possible public discussion of the new nano-scale technologies and to ensure that policy-makers take appropriate steps to safeguard the health, well-being and livelihoods of farmers and consumers – and the well-being of the environment. Specifically:

• Organisations of small farmers must begin to monitor nano-scale technologies affecting their regions and livelihoods. In addition to internal discussions and debate, these organisations should participate in discussions with the rest of civil society and with governments.

• Consumers' organisations should not only be tracking nano-scale technologies but also acquainting their membership with the food and agricultural products and processes that involve nanotechnology. Together with environmental organisations, consumers' organisations should be applying political pressure on governments to create appropriate regulatory regimes for these technologies and to encourage public debate.

• Environmental organisations should work closely with farmers' organisations and Indigenous Peoples to assess the impact of nano-scale technologies on the farm and for biological diversity. In the absence of appropriate regulation, the products of nano-scale technologies should not be released into the environment.

To Governments: In the near and medium-term, action will have to be taken at the national level:

• National governments must establish a *sui generis* regulatory regime specifically designed to address the unique health and environmental issues associated with nano-scale materials used in food and agriculture.

• In keeping with the Precautionary Principle, all food, feed and beverage products (including nutritional supplements) incorporating manufactured nanoparticles should be removed from the shelves until such time as regulatory regimes are in place that take into account the special characteristics of these materials, and until the products have been shown to be safe.

• Nanoscale formulations of agricultural input products such as pesticides, fertilisers and soil treatments should be prohibited from environmental release until such time as a new regulatory regime specifically designed to examine these products finds them safe.

• There must be an immediate moratorium on laboratory experimentation and the environmental release of synthetic biology materials until society can engage in a thorough analysis of the health, environmental and socio-economic implications.

To Intergovernmental Bodies:
In order to prevent international regulatory gaps or distortions, governments must work together through the Specialised Agencies of the United Nations to ensure worker and consumer health and safety; to safeguard the environment and biological diversity; and to ensure the socio-economic well-being of people in every country. In particular:

• The World Health Organization (WHO) and the Food and Agriculture Organization (FAO) of the United Nations must ensure that the Codex Alimentarius is updated to take into account the use of nanoparticles and other nano-scale technologies in food and agriculture;

• The United Nations Environment Programme (UNEP) and the Convention on Biological Diversity (CBD) should examine the possible impact of nanotechnology on biological diversity and the environment;

• WHO should undertake short- and long-term studies on the potential health effects of nanoparticles and nanotechnology on researchers, production workers and consumers;

• The International Labour Organization (ILO) and UNESCO (the UN Educational, Scientific and Cultural Organization) should study the possible impact of nanoparticles and nanotechnology on agricultural labour, education and the economic well-being of countries heavily dependent upon agricultural production or exports;

• FAO and the UN Conference on Trade and Development (UNCTAD) should study the potential impacts of nanoparticles and nanotechnology on production and trade including potential changes in production sources and prices;

• FAO's Commission on Genetic Resources for Food and Agriculture should undertake an immediate study of the potential impact of nano-scale technologies on plant and animal genetic diversity and enhancement;

• UNESCO and FAO should undertake studies to determine the implications of nano-scale technologies in food and agricultural research for the South with a view to recommendations on priorities for national and international agricultural research;

• The World Intellectual Property Organization (WIPO) should explore implications of intellectual property with respect to products and processes resulting from manipulation of elements in the periodic table, which could lead to monopolisation and distortions in food and agriculture markets;

• The United Nations should begin negotiations to establish an International Convention for the Evaluation of New Technologies (ICENT) to give governments and society, for the first time, an early warning/early listening system that allows society and science to break free from the cycle of crises that accompany each new technology introduction.

The fate of converging technologies at the nanoscale will be

In keeping with the Precautionary Principle, all food, feed and beverage products (including nutritional supplements) incorporating manufactured nanoparticles should be removed from the shelves until such time as regulatory regimes are in place that take into account the special characteristics of these materials, and until the products have been shown to be safe.

The fate of converging technologies at the nanoscale will be determined within the next two years.

determined within the next two years. Currently, industry and governments are scrambling to recover from serious blunders that jeopardise nanotech's future. At the end of 2004, there are at least three global initiatives underway to create "multi-stakeholder dialogues" involving civil society, industry and governments. However, these attempts will fail unless there is a clear commitment to reach beyond environmental organisations to involve social movements, both South and North – especially Indigenous Peoples, farmers' organisations, unions, the disability rights movement, women and consumer organisations. For its part, ETC Group will not participate in any dialogue process that does not include the full range of civil society actors and does not encourage the fullest possible societal debate.

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ANNEX 1: Nanotech R&D at Major Food and Beverage Corporations

Company	World Food & Beverage Sales 2003 (US million)*	Nanotech-Related Activity (if known)
Nestlé (Switzerland)	$54,200	Supports nanotech food research group; few details publicly available.
Altria (Kraft Foods) USA	$29,700	Established the industry's first nanotechnology food laboratory in 1999. Funds and sponsors the Nanotek Consortium – R&D on "smart drinks" and nanocapsules.
Unilever (UK & Netherlands)	$25,700	R&D on nanocapsules. In 1997, Unilever entered a joint venture with Cambridge University to form the Unilever Cambridge Center for Molecular Informatics. In 2002, Unilever announced that it would invest €30 million over three years in Unilever Technology Ventures, based in Santa Barbara, California, to identify and invest in technology-based funds and start-up companies. Its aim will be to enhance Unilever's own R&D activities by exploiting new technologies, including genomics and nanotechnology.
PepsiCo (USA)	$25,100	Ranks # 4 on the list of top 10 food & beverage companies.
Cargill (USA)	$20,500	Ranks #7 on the list of top 10 food & beverage companies. Partnering with EcoSynthetix to develop nanoscale cornstarch for cardboard packaging.
ConAgra (USA)	$19,800	Ranks # 8 on the list of top 10 food & beverage companies.
General Mills	$10,500	Devotes $6-9,000 million to nanotech-related R&D.†
Sara Lee	$9,800	Ranks #19 on list of top 100 food & beverage companies.
H. J. Heinz	$8,200	Flavour and colour enhancement. Foodservice sector is incorporating nanotech into smart dispensers and smart meals, and the use of nanomaterials in packaging.†
Campbell Soup (USA)	$6,700	One goal is flavour enhancement.†
Maruha (Japan)	$6,300	Japan's top seafood producer.
Associated British Foods (UK)	$6,000	International food, ingredients and retail group with annual sales of £4.9 billion.
Ajinomoto (Japan)	$5,800	Nanotech R&D includes better nutrition absorption and delivery system – for both food and pharma.†
DuPont Food Industry Solutions (USA)	$5,500 (Dupont's ag. & nutrition sales, 2003, source: DuPont)	Strategic partner for food, beverage & food ingredients, established May, 2003. Dupont conducts food engineering research based on particle size at its Particle Size and Technology Research Group in Wilmington, Delaware (USA). Company declined to discuss details.
McCain Foods (Canada)	$4,600	Privately-owned Canadian food corporation. Ranked seventh in frozen food worldwide in 2002.
Nippon Suisan Kaisha (Japan)	$4,000	Second-largest marine products firm in Japan; fishing operations account for more than 45% of its sales.
Nichirei (Japan)	$2,800	Japan's #1 producer of frozen foods.
BASF (Germany)	€5,021 million (agricultural products and nutrition division)	BASF's annual sales of nanotechnology based products currently amount to around €2,000 million The majority of these sales do not involve food, although BASF sells nano-scale carotenoid food additives.
Goodman Fielder	N/A	Australia's largest food manufacturer.
John Lusty Group, PLC	N/A	UK-based food importer and distributor.
La Doria	N/A	A leading Italian processor of tomato-based products.
Northern Foods	N/A	One of UK's largest food manufacturers.
United Foods	N/A	US-based, privately-held producer and processor of vegetables

The companies listed above (with the exception of Dupont and Cargill) are identified by Helmut Kaiser Consultancy as being active in food-related nanotech research.

* Source: "The World's Top 100 Food and Beverage Companies," *Food Engineering Magazine*, November 1, 2003.

† Source: Helmut Kaiser Consultancy.

ANNEX 2: Nano Patents for Food and Food Packaging

Patent Assignee	Area of Application, Patent/ Application #, Date Issued or Published	Patent Excerpt
Atofina, France	Packaging WO04012998A3 2004-02-12	"Composition for food packaging based on vinyl aromatic resin containing a mineral platy filler in the form of nanoparticles."
Nutralease, Ltd. (Israel)	Bio-Delivery US20030232095A1 2003-12-18	"The nano-sized concentrates of the present invention enable in an efficient manner the solubilization, transport and dilution of oil-soluble, oil non-soluble or water-soluble nutraceuticals, food supplements, food additives, plant extracts, medicaments, peptides, proteins or carbohydrates. Thus they may be used as efficient vehicles for transport of active materials into the human body."
NONE	Bio-Delivery US20030152629A1 2003-08-14	"Controlled release system that can encapsulate different flavors, sensory markers, and active ingredients, or combinations of flavors, sensory markers and various active ingredients and release multiple active ingredients in a consecutive manner, one after the other. The controlled delivery system is substantially free-flowing powder formed of solid hydrophobic nanospheres that are encapsulated in a moisture sensitive microspheres."
Qingtian New Material Research & Development Co. (China)	Food Additive CN1409966A 2003-04-16	"An antibacterial nanometre powder without decolouring for food contains nanometre zirconium phosphate particles as carrier and active antibacterial component. Its advantages are small granularity, broad spectrum, high compatibility, stability and antibacterial efficiency, and no poison."
Pengcheng Vocational Univ. (China)	Food Packaging CN1408746A 2003-04-09	"Antibiotic fresh preserving plastic film and its producing method"
Henkel KommandiGesell-schaft Auf Aktien, Düsseldorf, Germany	Food Processing, Bio-Delivery US6204231 2001-03-20	"Aqueous caustic alkali for cleaning food industry facilities, giving regenerated concentrate useful directly in animal feed, contains aqueous potassium hydroxide and optionally other alkali, especially sodium hydroxide."
NONE	Bio-delivery US6197757 2001-03-06	"Particles, especially microparticles or nanoparticles, of crosslinked monosaccharides and oligosaccharides, processes for their preparation and cosmetic, pharmaceutical or food compositions in which they are present"
Kraft Foods	Bio-delivery EP1355537A1 2003-10-29	"Production of capsules and particles for improvement of food products"

Patent Assignee	Area of Application, Patent/ Application #, Date Issued or Published	Patent Excerpt
BASF	Bio-delivery, Food Additive US5891907 1999-04-06	"Stable aqueous solubilizates are disclosed suitable for parenteral administration, of carotenoids and vitamins or vitamin derivatives, in which the carotenoid and the water-insoluble vitamins are, with the aid of a nonionic emulsifier, in the form of a micellar solution, the micelles being smaller than 100 nm"
BASF	Food Additive US5968251 1999-10-19-	"Carotenoid preparations in the form of coldwater-dispersible powders are produced by...preparing a molecular-disperse solution of a carotenoid, with or without an emulsifier and/or an edible oil, in a volatile, water-miscible, organic solvent at elevated temperature and adding therein an aqueous solution of a protective colloid, whereupon the hydrophilic solvent component is transferred into the aqueous phase, and the hydrophobic phase of the carotenoid results as nanodisperse phase..."
Rohm and Haas	Bio-delivery EP1447074A2 2004-08-18	"Polymeric nanoparticles in consumer products. Crosslinked polymeric nanoparticles having a diameter of 1-10 nm comprising skin care ingredients and **food** ingredients."
Borealis Technology (Finland)	Packaging WO04063267A1 2004-07-29	"Article comprising stretched polymer composition with nanofillers: Polymer article (e.g. film for **food packaging**), comprises polymer composition containing polyolefin matrix and nanofiller dispersed in the matrix."
Cap-Sulution Nanoscience Ag, (Germany)	Bio-delivery WO04030649A2 2004-04-15	"Microcapsules or nanocapsules containing sparingly water-soluble active agent, useful e.g. for rapid drug release on oral administration, having permeable shell containing polyelectrolyte and counter-ion."
University College Dublin, National University of Ireland, Dublin	Food Additive WO04016696A1 2004-02-26	"A method for the manufacture of patterned microparticles comprises immobilising microparticles, including nanoparticles, to be patterned on a surface of a porous membrane, causing an inorganic or organic coating material which can bind to exposed surfaces of said microparticles…The patterned microparticles produced can be used in wide range of applications in health, information and communication, and sustainable environment such as shelter, clothing, energy, **food**, transport and security."
Rhodia Chimie, Boulogne-Billancourt Cedex, France	Bio-delivery WO03095085A1 2003-11-20	"Colloidal dispersions of calcium phosphate nanoparticles and at least one protein, the size of said nanoparticles ranging between 50 and 300 nm, and the morphology of said nanoparticles being spherical…The invention can be used in the **food**, cosmetic, pharmacological industries."

Patent Assignee	Area of Application, Patent/ Application #, Date Issued or Published	Patent Excerpt
Shanxi Coal Chemistry Inst., Chinese Academy Of Sciences, China	Packaging CN1454939A 2003-11-12	"The preparation method of nano titanium dioxide granule whose surface is coated with aluminium oxide. The grain diameter of the prepared nano titanium dioxide is 10-100 nm, its surface is coated with aluminium oxide membrane. Nano titanium dioxide coated with aluminium dioxide has good dispersion property, can implement single granule dispersion, can be used as excellent UV-ray screening agent, and can be used in the fields of paint, rubber, fibre, coating material, sun protection products, printing ink and food package, etc."
Gerold, Lukowski, Jülich, Wolf-Dieter, Ulrike Lindequist, Sabine Mundt	Food Additive DE10310021A1 2003-10-23	"Micro- or nanoparticles of biomass of lipid-containing marine organisms, useful as pharmaceutical or cosmetic active agents or food additives, e.g. for preventing binding of bacteria to skin or tissue."
Guan-Gzhou Institute Of Chemistry, Chinese Academy Of Sciences	Food Additive CN1448427A 2003-10-15	"Water dispersible nanometer avicel, its prep. and colloid therefrom: The nanometer microcrystal cellulose powder is surface modified nanometer microcrystal cellulose with added hydrophilic colloid in the amount of 5-150 wt% of nanometer microcrystal cellulose and has grain size of 6.3-100 nanometers. During its preparation, hydrophilic colloid is dispersed homogeneously into water dispersed medium of surface modified nanometer microcrystal cellulose and the mixture is then dried and crushed. The nanometer microcrystal cellulose is easy to be water dispersed to form colloid, which is homogeneous and high in gluing strength and has the small size of microcrystal cellulose maintained, so that it has wide and unique application foreground in food production, medicine, papermaking, textile, new material preparation and other fields."
Zhang Liwen China	Food Additive, Bio-delivery CN1439768A 2003-09-03	"Nano feather powder and its processing method and use: A nano-class feather down powder used as the functional and health-care additive of food, feed cosmetics, medicine, or chemical fibres is prepared from the feather down of duck, goose, birds, etc through water washing, screening, shearing pulverizing, immersing in alcohol, centrifugal drying, microwave oscillating, quick cooling, low-temp pulverizing and sieving. Its advantages are no loss of active components, high specific surface area, molecular activity and affinity to human body and higher health-care effect."
Nano-Materials Technology Pte Ltd., Singapore Beijing University Of Chemical Technology	? WO03055804A1 2003-07-10	"Calcium carbonate of different shapes including spindle, petal, whisker, needle, flake, ball and fiber. The calcium carbonate has an average particle size in the range of 10 nm - 2.5 µm and can be utilized in various fields such as rubber, plastics, papermaking, coatings, building materials, inks, paintings, food, medicine, domestic chemical industry, textile and feed."
Cellresin Technologies, Llc	Packaging US20030129403A1 2003-07-10	"Barrier material with nanosize metal particles as coating of plastic diaper or for food-contact packaging materials, comprises particles of zinc or similar reacting metal or metal alloy, dispersed in matrix material"

Patent Assignee	Area of Application, Patent/ Application #, Date Issued or Published	Patent Excerpt
Bridgestone Corporation, Tokyo, Japan	Food Additive US6579929 2003-06-17	"Stabilized silica and method of making and using the same: A surface stabilized, non-agglomerated silica is provided…[it] has a size in the nanometer range. The surface stabilized, non-agglomerated silica can be used as an additive in any application that uses silica, such as reinforcing fillers for elastomeric compositions, foods, drugs, dentifrices, inks, toners, coatings and abrasives."
Solubest Ltd., Rehorot, Israel	Bio-delivery, Food Additive WO03028700A3 2003-04-10	"Water soluble nanoparticles of hydrophilic and hydrophobic active materials: This invention provides a soluble nano-sized particles formed of a core (Water-insoluble lipophilic)compound or hydrophilic compound and an amphiphilic polymer and which demonstrated improved solubility and/or stability. The lipophilic compound within the soluble nano-sized soluble ("Solu-nanoparticles") may consist of pharmaceutical compounds, food additives, cosmetics, agricultural products and veterinary products."
Central P BV, Naarden, Netherlands	Bio-delivery WO03024583A1 2003-03-27	"Novel Calixarene Based Dispersible Colloidal Systems in the Form Of Nanoparticles for medical, biological, veterinary, cosmetic and alimentary use, includes nanoparticles comprising amphiphilically modified calixarene."
Wageningen Centre For Food Sciences, Wageningen, Netherlands	Food WO03011040A1 2003-02-13	"A novel process for preparing a gelled aqueous composition, which process employs a gel-forming globular protein such as whey protein, ovalbumin or soy protein…The invention also relates to products obtainable by the above process."
University of Seville, University of Málaga, Spain	Bio-delivery, Food Additive WO02060591A1 2002-08-08	"Device and method for producing stationary multi-component liquid capillary streams and micrometric and nanometric sized capsules, the diameter of which may range from tens of nanometers to hundreds of microns and to a relatively monodispersed aerosol of electrically charged multi-component droplets generated by rupture of the streams due to capillary instabilities. The device and method can be used in fields such as materials science and food technology, wherever generation and controlled handling of structured micrometric and nanometric sized streams is an essential part of the process."
Mars, Inc.	Food Additive US5741505 1998-04-21	"...A coated edible product comprising... edible material...and a substantially continuous inorganic coating on a surface of the edible material, wherein said coating covers at least a portion of the edible material and said coating has a thickness ranging from 0.0001 to 0.5 microns."
Globoasia, L.L.C., Hanover, Md.	Food Additive (preservative) US6379712 2002-04-30	"The invention relates to nanosilver-containing antibacterial and antifungal granules ("NAGs"). The NAGs have longlasting inhibitory effect on a broad-spectrum of bacteria and fungi. The NAGs can be used in a variety of healthcare and industrial products…Examples of industrial products include, but are not limited to, food preservatives, water disinfectants, paper disinfectants, construction filling materials (to prevent mold formation)."

Patent Assignee	Area of Application, Patent/ Application #, Date Issued or Published	Patent Excerpt
Cognis Deutschland Gmbh, Düsseldorf, Germany	Food Additive US6352737 2002-03-05	"The use of nanoscale sterols and/or sterol esters with particle diameters of 10 to 300 nm as food additives and as active substances for the production of hypocholesterolemic agents. The particular fineness of the particles promotes more rapid absorption by the blood serum after oral ingestion by comparison with conventional sterols and sterol esters."
Henkel Kgaa, Düsseldorf, Germany	Food Additive DE10027948A1 2001-12-20	"Production of suspension of undecomposed meltable material used in e.g. the pharmaceuticals, cosmetics, and food industries comprises preparing emulsion from material, liquid phase and surface modifying agent, and cooling"
Coletica, Lyons, France	Bio-Delivery US6303150 2001-10-16	"Method for producing nanocapsules with crosslinked protein-based walls nanocapsules thereby obtained and cosmetic, pharmaceutical and food compositions using same"
Lu Bingkun China	Packaging CN1298902A 2001-06-13	"Process for preparing antibacterial plastics for food or beverage containers using nanoscale antibacterial powder"
Wolff Walsrode Ag, (Germany)	Packaging DE19937117A1 2001-02-08	"Film, useful for the packaging of food stuffs, contains at least one copolyamide layer comprising 10-2000 ppm dispersed nanoscale nucleating particles"
Tetra Laval Holdings & Finance S.A.	Packaging US6117541 2000-09-12	"Polyolefin material integrated with nanophase particles: Packaging laminate, used in a container for fluid foods e.g. milk or juice – comprising a layer of polyolefin interspersed with nanometer size clay particles for gas barrier properties"
NONE	Packaging US5946930 2001-02-08	"Self-cooling beverage and food container using fullerene nanotubes"

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