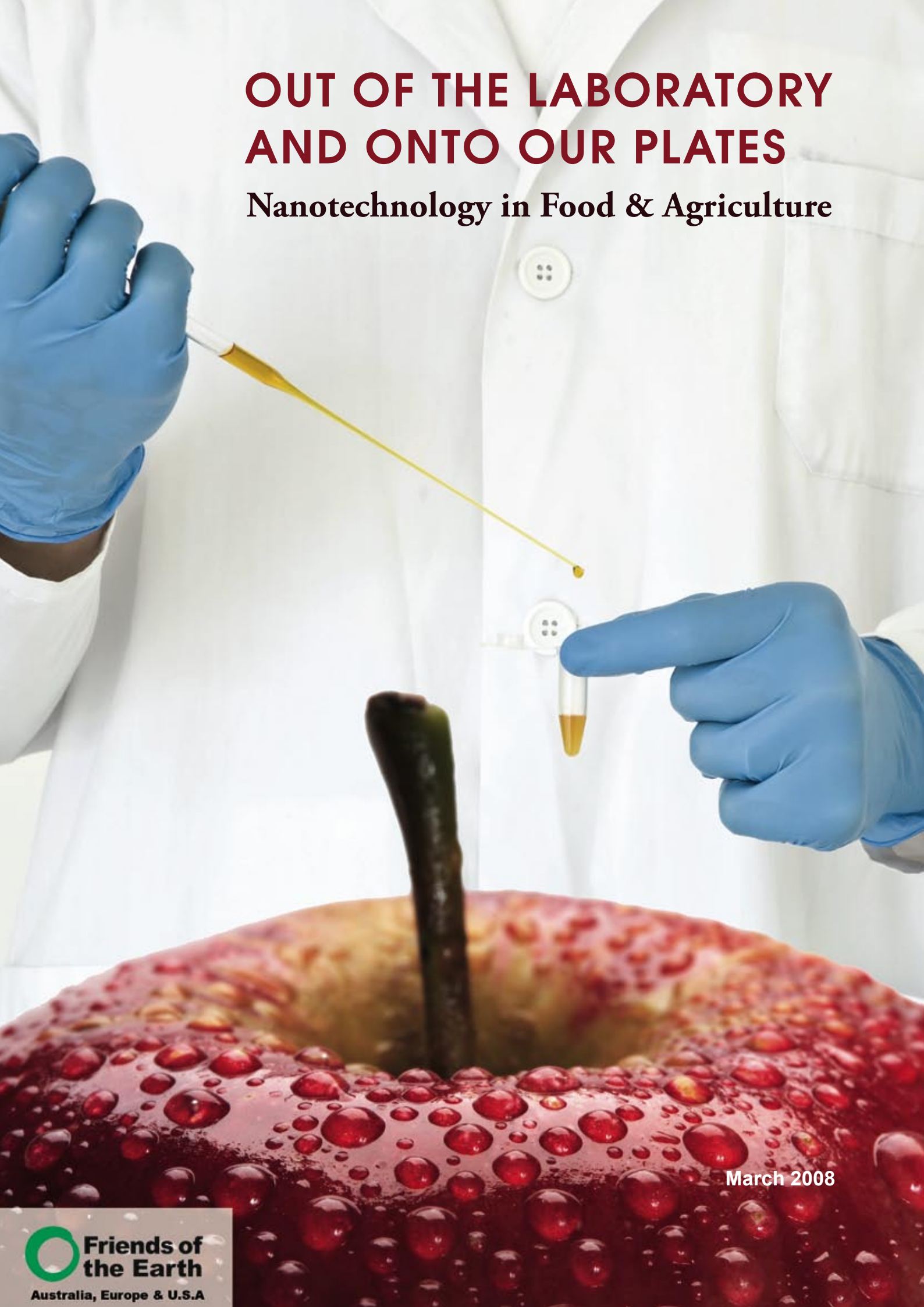
OUT OF THE LABORATORY AND ONTO OUR PLATES

Nanotechnology in Food & Agriculture



March 2008

Friends of the Earth
Australia, Europe & U.S.A

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Nanotechnology in Food & Agriculture

Friends of the Earth
Australia, Europe and U.S.A

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Nanotechnology in Food & Agriculture

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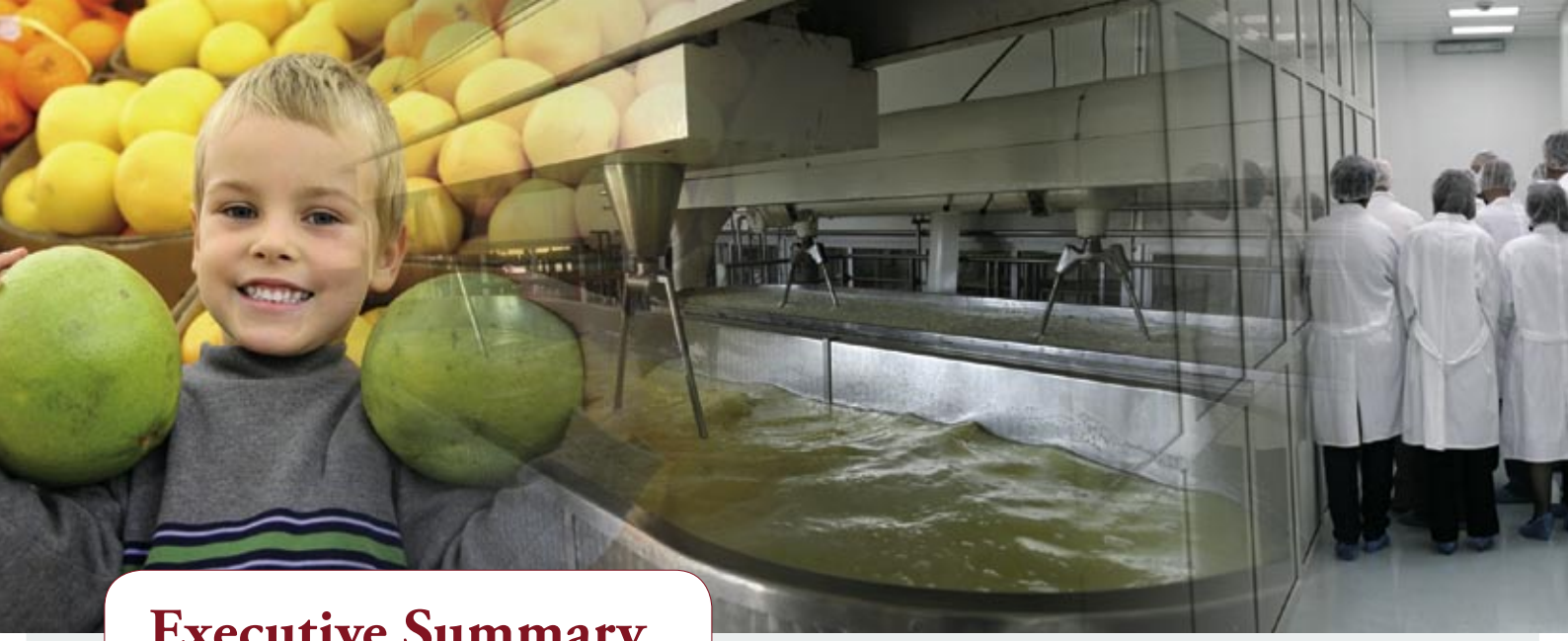


Executive Summary

In the absence of mandatory product labelling, public debate or laws to ensure their safety, products created using nanotechnology have entered the food chain. Manufactured nanoparticles, nano-emulsions and nano-capsules are now found in agricultural chemicals, processed foods, food packaging and food contact materials including food storage containers, cutlery and chopping boards. Friends of the Earth has identified 104 of these products, which are now on sale internationally. However given that many food manufacturers may be unwilling to advertise the nanomaterial content of their products, we believe this to be just a small fraction of the total number of products now available worldwide.

Nanotechnology has been provisionally defined as relating to materials, systems and processes which exist or operate at a scale of 100 nanometres (nm) or less. It involves the manipulation of materials and the creation of structures and systems at the scale of atoms and molecules, the nanoscale. The properties and effects of nanoscale particles and materials differ significantly from larger particles of the same chemical composition.

Nanoparticles can be more chemically reactive and more bioactive than larger particles. Because of their very small size, nanoparticles also have much greater access to our bodies, so they are more likely than larger particles to enter cells, tissues and organs. These novel properties offer many new opportunities for food industry applications, for example as potent nutritional additives, stronger flavourings and colourings, or antibacterial ingredients for food packaging. However these same properties may also result in greater toxicity risks for human health and the environment.

There is a rapidly expanding body of scientific studies demonstrating that some of the nanomaterials now being used in foods and agricultural products introduce new risks to human health and the environment. For example, nanoparticles of silver, titanium dioxide, zinc and zinc oxide, materials now used in nutritional supplements, food packaging and food contact materials, have been found to be highly toxic to cells in test tube studies. Preliminary environmental studies also suggest that these substances may be toxic to ecologically important species such as water fleas. Yet there is still no nanotechnology-specific regulation or safety testing required before manufactured nanomaterials can be used in food, food packaging, or agricultural products.

Early studies of public opinion show that given the ongoing scientific uncertainty about the safety of manufactured

nanomaterials in food additives, ingredients and packaging, people do not want to eat nanofoods. But because there are no laws to require labelling of manufactured nano ingredients and additives in food and packaging, there is no way for anyone to choose to eat nano-free.

Nanotechnology also poses broader challenges to the development of more sustainable food and farming systems. At a time when global sales of organic food and farming are experiencing sustained growth, nanotechnology appears likely to entrench our reliance on chemical and energy-intensive agricultural technologies. Against the backdrop of dangerous climate change, there is growing public interest in reducing the distances that food travels between producers and consumers, yet nanotechnology appears likely to promote transport of fresh and processed foods over even greater distances. The potential for nanotechnology to further concentrate corporate control of global agriculture and food systems and further erode local farmers' control of food production is also a source of concern.

Given the potentially serious health and environmental risks and social implications associated with nanofood and agriculture, Friends of the Earth Australia, Europe and United States are calling for:

• A moratorium on the further commercial release of food products, food packaging, food contact materials and agrochemicals that contain manufactured nanomaterials until nanotechnology-specific safety laws are established and the public is involved in decision making.

Nanomaterials must be regulated as new substances

• All deliberately manufactured nanomaterials must be subject to new safety assessments as new substances, even where the properties of their larger scale counterparts are well-known.

• All deliberately manufactured nanomaterials must be subject to rigorous nano-specific health and environmental impact assessment and demonstrated to be safe prior to approval for commercial use in foods, food-packaging, food contact materials or agricultural applications.

The size based definition of nanomaterials must be extended

• All particles up to 300nm in size must be considered to be 'nanomaterials' for the purposes of health and environment assessment, given the early evidence that they pose similar health risks as particles less than 100nm in size which have to date been defined as 'nano'.

Transparency in safety assessment and product labelling is essential

• All relevant data related to safety assessments, and the methodologies used to obtain them, must be placed in the public domain.

• All manufactured nano ingredients must be clearly indicated on product labels to allow members of the public to make an informed choice about product use.

Public involvement in decision making is required

• The public, including all stakeholder groups affected, must be involved in all aspects of decision making regarding nanotechnology in food and agriculture. This includes in the development of regulatory regimes, labelling systems, and prioritisation of public funding for food and agricultural research. People's right to say no to nanofoods must be recognised explicitly.

Support for sustainable food and farming is needed

• The assessment of food and agricultural nanotechnology, in the context of wider societal needs for sustainable food and farming, must be incorporated into relevant decision making processes.

A short introduction to nanotechnology

What is nanotechnology?

The term 'nanotechnology' does not describe a singular technology, but rather encompasses a range of technologies that operate at the scale of the building blocks of biological and manufactured materials – the 'nanoscale'.

Nanotechnology has been provisionally defined as relating to materials, systems and processes which operate at a scale of 100 nanometres (nm) or less. Nanomaterials have been defined as having one or more dimensions measuring 100nm or less, or having at least one dimension at this scale which affects the materials' behaviour and properties. However this definition of nanomaterials is likely to be far too narrow for the purposes of health and environmental safety assessment (see below).

One nanometre (nm) is one thousandth of a micrometre (µm), one millionth of a millimetre (mm) and one billionth of a metre (m). To put the nanoscale into context: a strand of DNA is 2.5nm wide, a protein molecule is 5nm, a red blood cell 7,000 nm and a human hair is 80,000 nm wide. If one imagines that a nanoparticle is represented by a person, a red blood cell would be 7 kilometres long!

Nanotechnology is a platform technology

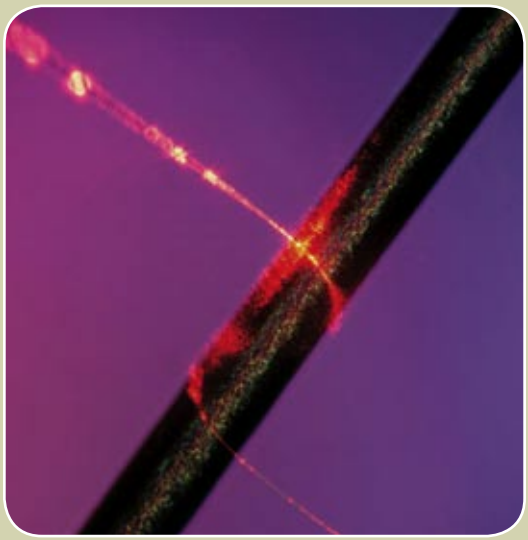
The novel properties of nanomaterials offer many new opportunities for the food and agricultural industries, for example as more potent food colourings, flavourings and nutritional additives, antibacterial ingredients for food packaging, and more potent agrochemicals and fertilisers. In many instances the same technology can enable applications across the whole agriculture and food supply chain. For example, nanoclay composites – plastics to which nanoscale clay platelets have been added – are now used widely in food and beverage packaging, as well as in agricultural pipes and plastics to allow controlled release of herbicides, and have been studied for their use in controlled release fertilizer coatings. The capacity to apply nanotechnologies across multiple sectors not only delivers greater returns on research investment, but also enables companies to expand

Size based definitions of small particles

Smaller than 100nm – a nanoparticle

Smaller than 1,000nm (a micron, or micrometer also written as 1µm) – a sub-micron microparticle

Larger than 1,000nm – a microparticle



A light-conducting silica nanowire wraps a beam of light around a strand of human hair. The nanowires are flexible and can be as slender as 50 nanometers in width, about one thousandth the width of a hair. Photo: Limin Tong/Harvard University.

commercial activities into entirely new market segments and new industries. For this reason, nanotechnology is often called a 'platform technology'.

In coming years and decades, 'next generation nanotechnology' is forecast to move beyond the use of simple particles and encapsulated ingredients to the development of more complex nanodevices, nanosystems and nanomachines (Roco 2001). The application of nanotechnology to biotechnology ('nanobiotechnology') is predicted not only to manipulate the genetic material of humans, animals and agricultural plants, but also to incorporate synthetic materials into biological structures and vice versa (Roco and Bainbridge 2002). Converging nanoscale technologies are predicted to enable the creation of entirely novel artificial organisms for use in food processing, agriculture and agrofuels, as well as other applications (ETC Group 2007). This field is known as synthetic biology.

Nanomaterials have novel properties and pose novel risks

To put it simply: small particle size equates to new particle properties, which can also introduce new risks. Nanoparticles have a very large surface area which typically results in greater chemical reactivity, biological activity and catalytic behaviour compared to larger particles of the same chemical composition (Garnett and Kallinteri 2006; Limbach et al. 2007; Nel et al. 2006). Nanomaterials also have far greater access to our body (known as bioavailability) than larger particles, resulting in greater uptake into individual cells, tissues and organs. Materials which measure less than 300nm can be taken up by individual cells (Garnett and Kallinteri 2006), while nanomaterials which measure less than 70nm can even be taken up by our cells' nuclei, where they can cause major damage (Chen and Mikecz 2005; Geiser et al. 2005; Li et al. 2003). Unfortunately, the greater chemical reactivity and bioavailability of nanomaterials may also result in greater toxicity of nanoparticles compared to the same unit of mass of larger particles of the same chemical composition (Hoet et al. 2004; Oberdörster et al. 2005a; Oberdörster et al. 2005b). Other properties of nanomaterials that influence toxicity include: chemical composition, shape, surface structure, surface charge, catalytic behaviour, extent of particle aggregation (clumping) or disaggregation, and the presence or absence of other groups of chemicals attached to the nanomaterial (Brunner et al. 2006; Magrez et al. 2006; Sayes et al. 2004; Sayes et al. 2006).

Some nanomaterials have proved toxic to human tissue and cell cultures in *in vitro* (test tube) studies, resulting in increased oxidative stress, production of proteins triggering an inflammatory response (Oberdörster et al. 2005b), DNA mutation (Geiser et al. 2005), structural damage to cell nuclei and interference with cell activity and growth (Chen and von Mikecz 2005), structural damage to mitochondria and even cell death (Li et al. 2003). Nanomaterials now in commercial use by the food industry, such as nano titanium dioxide, silver, zinc and zinc oxide have been shown to be toxic to cells and tissues in *in vitro* experiments and to test animals in *in vivo* studies (see Table 9).

Nanomaterials have such diverse properties and behaviours that it is impossible to provide a generic assessment of their health and environmental risks (Maynard 2006). The shape, charge and size of different particles can influence their kinetic (absorption, distribution, metabolism and excretion) and toxic properties (Hagens et al. 2007). For this reason even nanomaterials of the same chemical composition which have different sizes or shapes can have vastly different toxicity (Sayes et al. 2006). Until we have a much more comprehensive understanding of the biological behaviour of nanomaterials, it is impossible to predict the toxicity risks associated with any one material, and

each new nanomaterial must be subject to new health and safety assessment prior to its commercial use. Maynard (2006) notes that "it is clear from published toxicity studies that particle size alone is not a good criteria for differentiating between more or less hazardous materials and technologies". However particle size remains an obvious, if somewhat crude, criteria that could trigger more comprehensive testing and particle characterisation, prior to a nanomaterial being permitted in commercial foods and agricultural products.

The need to broaden the provisional 100nm definition of nanomaterials for health and environmental safety assessment

The International Standards Organisation (ISO) and ASTM International have not yet agreed on a size-based or other definition for nanomaterials. However many government bodies and scientific institutions have begun using the provisional definition of nanomaterials as having novel, size-dependent characteristics which are not seen in larger particles of the same material. Typically this is defined as a particle having at least one dimension existing in the size range of 0.2 - 100nm (i.e. above the atomic level up to 100nm). This size definition is somewhat arbitrary, but it has been considered that materials of less than100nm in size are most likely to exhibit novel, nano-specific properties due to their increased relative surface area and the dominance of quantum effects in this size range (U.K. RS/RAE 2004). Altered properties can include greater chemical reactivity, altered colour, strength, solubility, electrical conductivity etc. Importantly, nanoparticles also have greater access to our bodies' cells, tissues and organs than larger particles of the same material. In its 2004 report the United Kingdom's Royal Society and Royal Academy of Engineering identified unbound particles of less than100nm in size as presenting the greatest potential risk for human health (U.K. RS/RAE 2004).

However the suitability of the 100nm definition has recently been queried, especially in relation to health and environmental safety assessment. There is growing international recognition that some particles greater than 100nm exhibit similar anatomical and physiological behaviour to nanomaterials. Novel, size-dependent behaviour seen in particles which measure a few hundred nanometres includes very high reactivity, bioactivity and bioavailability, increased influence of particle surface effects and strong particle surface adhesion (Garnett and Kallinteri 2006). Significantly, preliminary studies also suggest that some particles which measure a few hundred nanometres, or even 1,000nm, can pose comparable health risks to particles now considered to be 'nano' (Wang et al. 2006; Ashwood et al. 2007).

Governments and scientists still uncertain about the best size to define nanomaterials

The size at which it makes sense to define materials as 'nano' and to subject them to nano-specific health and environmental safety assessment remains the topic of discussion within standards bodies, in government and in the scientific literature. We still know very little about why the properties of nanomaterials are different from larger particles and how factors such as size, shape, surface charge etc. interact to affect toxicity and the particles' biological behaviour. Consequently, we do not yet know enough to determine the appropriate size limit at which materials should be subject to nano-specific health and safety assessment, although there is growing agreement that 100nm is likely to be insufficient in at least some instances.

Reflecting the considerable uncertainty around what size is most appropriate to consider a material to be a nanomaterial, different government agencies, research institutions and scientists have used different sizes to define them. In its 2006

voluntary industry notification scheme, the British government defined nanomaterials as "having two or more dimensions up to 200nm" (U.K. DEFRA 2006). In a 2006 report the Chemical Selection Working Group of the U.S. Food and Drug Administration (FDA) defined nanomaterials as "particles with dimensions less than micrometer scale [i.e. less then 1,000nm] that exhibit unique properties not recognized in micron or larger sized particles" (U.S. FDA 2006). Food scientists from Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) have also defined nanomaterials as measuring up to 1,000nm (Sanguansri and Augustin 2006). In a 2007 report on nanomaterials FDA chose not to offer a size-based definition at all (U.S. FDA 2007).

Why Friends of the Earth recommends defining nanomaterials as less than 300nm for the purposes of health and environmental safety assessment

Friends of the Earth recognises that there is not a clear relationship between particle size and a particle's biological behaviour, given the poorly understood role of other factors including shape, surface properties, charge, coatings etc. However we also appreciate the need for a size-based trigger to ensure that particles that may pose novel toxicological risks are subject to appropriate new safety testing and regulation prior to being allowed in commercial foods and agricultural products. Given that particles up to a few hundred nanometres in size share so many of the physiological and anatomical behaviours of nanomaterials, including the ability to be taken up into individual cells, and that preliminary studies have indicated that particles in this size range may pose size-dependent toxicity risks, a precautionary approach is warranted. We recommend that particles up to 300nm in size are treated as nanomaterials for the purposes of health and safety assessment.

To enable comparison of the discussion and studies cited in this report with other literature, we restrict the use of the term nanoparticle to particles which have at least one dimension which measures less

than 100nm. However given the evidence of nano-specific biological behaviour and related toxicity risks associated with particles a few hundred nanometres in size, Friends of the Earth urges regulators responsible for assessing and managing the health and environmental risks of nanoparticles to require particles up to 300nm in size to be subject to nano-specific safety testing and regulation prior to being permitted for commercial use in food and agricultural products.

Manufactured vs. incidental nanoparticles

'Manufactured' nanomaterials are those which are produced deliberately. They include nanoparticles (e.g. metal oxides such as zinc oxide and titanium dioxide), as well as structures created through nanotechnology such as nanotubes, nanowires, quantum dots, dendrimers and carbon fullerenes (buckyballs), among others (see glossary).

In comparison, 'incidental' nanoparticles are nanoparticles which are not manufactured deliberately, but either occur in nature or as a byproduct of industrial processes. Sources of incidental nanoparticles, also called ultrafine particles in the study of air pollution, include forest fires and volcanoes, and high-temperature industrial processes such as combustion, welding, grinding and exhaust fumes of cars, trucks and motorcycles (U.K. HSE 2004). Although humans have historically been exposed to small numbers of these incidental nanoparticles, until the industrial revolution this exposure was quite limited.

The emerging field of nanotoxicology (the study of the risks associated with manufactured nanomaterials) is being informed by our understanding of risks associated with incidentally produced nanoparticles. For example, we know that exposure to large levels of incidental nanoparticles in urban air pollution causes increased incidence of disease and even death among vulnerable sections of the population (Yamawaki and Iwai 2006).

In this report, Friends of the Earth focuses on manufactured nanomaterials used in food and agriculture. However we recognise that the presence of incidental nanomaterials in foods, for example as a result of the wear from food processing equipment, could also pose new health risks which warrant consideration by regulators.

The need to investigate the health and environmental implications of other small particles

Preliminary evidence suggests that although these particles may be thousands of times larger than nanoparticles, small microparticles around 1-20µm in size (1,000 – 20,000nm) may also pose health risks. Microparticles do not have the same bioavailability of nanoparticles and they cannot be taken up by individual cells. They are also comparatively less chemically reactive and bioactive than nanoparticles, and bioactive than nanoparticles. However the reactivity and bioavailability of microparticles remain far greater than that of larger particles (Sanguansri and Augustin 2006). Studies using rats have demonstrated gastrointestinal uptake of particles measuring up to 20µm in size, mainly via Peyer's Patches in the small intestine (Hagens et al. 2007). Pathology studies also suggest that microparticles up to 20µm in size are taken up through the human gastro-intestinal tract, translocated through the body, and accumulate in secondary organs where they may be associated with long-term pathological damage, for example the development of granulomas and lesions (Ballestri et al. 2001; Gatti and Rivassi 2002). Granulomas and lesions can have serious long-term health effects, leading to chronic inflammation and even cancer. Beyond the need for nanotechnology-specific regulation for nanomaterials in foods and food contact materials, Friends of the Earth therefore also urges regulators to investigate the need for appropriate new safety assessments of small microparticles.

Nanotechnology enters the food chain

Nanoadditives are now found in some margerine/soft drinks/dairy products/sausages and other processed food.

How nanofood is defined

The term 'nanofood' describes food which has been cultivated, produced, processed or packaged using nanotechnology techniques or tools, or to which manufactured nanomaterials have been added (Joseph and Morrison 2006). Examples of nano-ingredients and manufactured nanomaterial additives include nanoparticles of iron or zinc, and nanocapsules containing ingredients like co-enzyme Q10 or Omega 3.

Future generations of humanity will be able to eat any food, no matter how rich. Sugar, salt, fat, cholesterol — all the things we love but have to consume in moderation now will have no restrictions on them in future. All food will be nutritious; the sole criterion for choosing meals will be taste... Jetsons-style food pills will never materialize; instead, in the future, enjoying sumptuous meals will be a guilt-free highlight of every day.

(Sawyer 1990)

Nanotechnology is moving out of the laboratory and into every sector of food production. Manufactured nanomaterials are already used in some food products, nutritional supplements, many packaging and food storage applications and some agricultural inputs (e.g. fertilisers and pesticides. In this report we use the term pesticide to mean any chemical used to control either animal or plant pests, i.e. including both pesticides and herbicides). Friends of the Earth's investigation into the use of nanotechnology across the food chain reveals that foods which

contain manufactured nanomaterial ingredients and additives are not the stuff of science fiction but are already found on supermarket shelves.

Secrecy surrounds the commercial use of nanotechnology and nanomaterials by the food industry. Food manufacturers' reluctance to discuss their use of nanotechnology and nanomaterials is made worse by the absence of labelling laws that require manufacturers to identify nanofoods. This makes it impossible to know for sure whether or not a given product contains nano-ingredients. Estimates of commercially available nanofoods vary widely; nanotechnology analysts estimate that between 150-600 nanofoods and 400-500 nano food packaging applications are already on the market (Cientifica 2006; Daniells 2007; Helmut Kaiser Consultancy Group 2007a; Helmut Kaiser Consultancy Group 2007b; Reynolds 2007).

Table 1: Examples of the current use of nanomaterials in agriculture, foods and food packaging (see Appendix A for a complete referenced list)

Type of product	Product name and manufacturer	Nano content	Purpose
Nutritional supplement	Nanoceuticals 'mycrohydrin' powder, RBC Lifesciences	Molecular cages 1-5 nm diameter made from silica-mineral hydride complex	Nano-sized mycrohydrin has increased potency and bioavailability. Exposure to moisture releases H- ions and acts as a powerful antioxidant.
Nutritional drink	Oat Chocolate Nutritional Drink Mix, Toddler Health	300nm particles of iron (SunActive Fe)	Nano-sized iron particles have increased reactivity and bioavailability.
Food contact material (cooking equipment)	Nano silver cutting board, A-Do Global	Nanoparticles of silver	Nano-sized silver particles have increased antibacterial properties.
Food contact material (crockery)	Nano silver baby mug, Baby Dream	Nanoparticles of silver	Nano-sized silver particles have increased antibacterial properties.
Food contact material (kitchenware)	Antibacterial kitchenware, Nanocaretech/NCT	Nanoparticles of silver	Nano-sized silver particles have increased antibacterial properties.
Food packaging	Adhesive for McDonald's burger containers, Ecosynthetix	50-150nm starch nano-spheres	These nanoparticles have 400 times the surface area of natural starch particles. When used as an adhesive they require less water and thus less time and energy to dry.
Food packaging	Durethan® KU 2-2601 plastic wrapping, Bayer	Nanoparticles of silica in a polymer-based nanocomposite	Nanoparticles of silica in the plastic prevent the penetration of oxygen and gas of the wrapping, extending the product's shelf life.
Food additive	Aquasol preservative, AquaNova	Nanoscale micelle (capsule) of lipophilic or water insoluble substances	Surrounding active ingredients within soluble nanocapsules increases absorption within the body (including individual cells).
Plant growth treatment	PrimoMaxx, Syngenta	100nm particle size emulsion	Using nano-sized particles increases the potency of active ingredients, potentially reducing the quantity to be applied.

Appendix A contains a list of 104 commercially available foods, nutritional supplements, food contact materials like storage containers and chopping boards, and agricultural chemicals such as pesticides, plant growth treatments and chemical fertilisers that contain manufactured nanomaterials (Table 1 provides a few examples). Given the reluctance of food manufacturers to discuss their use of nanotechnology (Shelke 2006), it appears likely that our list represents only a small fraction of commercially available products that contain nanomaterials.

Table 2: A selection of major food and agriculture companies engaged in nanotechnology research and development (ETC Group 2004; Innovest 2006; Renton 2006; Wolfe 2005).

Company
Altria (Kraft Foods)
Associated British Foods
Ajinomoto
BASF
Bayer
Cadbury Schweppes
Campbell Soup
Cargill
DuPont Food Industry Solutions
General Mills
Glaxo-SmithKline
Goodman Fielder
Group Danone
John Lust Group Plc
H.J. Heinz
Hershey Foods
La Doria
Maruha
McCain Foods
Mars, Inc.
Nestlé
Northern Foods
Nichirei
Nippon Suisan Kaisha
PepsiCo
Sara Lee
Syngenta
Unilever
United Foods

Note: For display purpose companies are listed in alphabetical order.

Many more nanofood products are in development. By 2010 it is estimated that sales of nanofoods will be worth almost US$6 billion (Cientifica 2006). Many of the world's largest food companies, including Heinz, Nestlé, Unilever and Kraft, are exploring nanotechnology for food processing and packaging. Many of the world's largest agrochemicals and seed companies also have active nanotechnology research and development programs (Table 2).

Nanotechnology has potential applications in all aspects of agriculture, food processing, food packaging and even farm and food monitoring:

- Methods to enable foods such as soft drinks, ice cream, chocolate or chips to be marketed as 'health' foods by reducing fat, carbohydrate or calorie content or by increasing protein, fibre or vitamin content.
- Production of stronger flavourings, colourings, and nutritional additives, and processing aids to increase the pace of manufacturing and to lower costs of ingredients and processing.
- Development of foods capable of changing their colour, flavour or nutritional properties according to a person's dietary needs, allergies or taste preferences (high on the research agenda of food giants including Kraft and Nestlé).
- Packaging to increase food shelf life by detecting spoilage, bacteria, or the loss of food nutrient, and to release antimicrobials, flavours, colours or nutritional supplements in response.
- Re-formulation of on-farm inputs to produce more potent fertilisers, plant growth treatments and pesticides that respond to specific conditions or targets.

Nanotechnology and food processing

Friends of the Earth's investigation reveals that foods which contain nanoscale ingredients and additives are already found on supermarket shelves. Given the emerging body of scientific evidence demonstrating the toxicity risks of nanomaterials, Friends of the Earth believes the sale of effectively and unregulated nanofoods is of serious concern.

Nanofood now: no longer just a vision

The vision of nanofoods described by nanofood technologists includes liquids that can change colour, taste and texture at the press of a microwave button, and products customised to respond to an individual's health and nutritional requirements. Yet while such applications can best be described as 'next generation' nanofoods, more prosaic products are far closer to commercialisation. Nestlé and Unilever are reported to be developing a nano-emulsion based ice cream with a lower fat content that retains a fatty texture and flavour (Renton 2006). More immediately, nano-nutritional additives are already being used to boost the vitamin and mineral content of some processed foods and to speed up the manufacturing of processed meats.

Nanoparticles and particles up to 300nm in size are added to many foods as processing aids

Nano-encapsulated active ingredients including vitamins and fatty acids are now sold commercially for use in processing and preservation of beverages, meats, cheese and other foods (Aquanova undated). Nanoparticles and particles a few hundred nanometres in size are

Nano in your sausage - "NovaSol the solution for meat curing and colour stability"

Industrial sausage and cured meat production requires the addition of numerous additives to speed up the production process, to stabilize colour and 'improve' taste. German company Aquanova has developed a nanotechnology-based carrier system using 30nm micelles to encapsulate active ingredients such as Vitamins C and E and fatty acids which can be used as preservatives and aids (Aquanova undated). Aquanova markets its micelles as "NovaSol" and claims that the nanoscale carrier system increases the potency and bioavailability of active ingredients. The German industry magazine "Fleischwirtschaft" claims that NovaSol offers considerable advantages for meat processors: faster processing, cheaper ingredients, higher colour stability, and ready to use liquid form (Fleischwirtschaft 2006). These nanoformulations of these additives have been available to German manufacturers since 2006. They may be used in an assortment of cured meats and sausages currently available to European consumers. The failure to identify nano-ingredients on product labels prevents their tracking. However it is conceivable that consumers world wide have been exposed to these nanomaterials through exports.

added intentionally to many foods to improve flow properties (e.g. how well it pours), colour and stability during processing, or to increase shelf life. For instance, alumino-silicates are commonly used as anti-caking agents in granular or powdered processed foods, while anatase titanium dioxide is a common food whitener and brightener additive, used in confectionery, some cheeses and sauces (Ashwood et al. 2007; Powell et al. 2000). In bulk form (conventional, larger particle size), these food additives are usually biologically inert and are considered by regulators in the European Union and elsewhere to be safe for human consumption (EFSA 2004). However, these regulators make no distinction between particle size when assessing the safety of food additives, despite the growing evidence that many nano-scale additives show heightened toxicity risks. For instance, 200nm particles of titanium dioxide have been found to be immunologically active and could promote inflammation (Ashwood et al. 2007). Scientists have suggested that particles a few hundred nanometres in size that are used as food additives may be a factor in the rising incidence of auto-immune diseases like irritable bowel syndrome and Crohn's disease (Ashwood et al. 2007; Schneider 2007; see discussion in Chapter 6).

Nanoparticles and particles up to 300nm in size are also used as nutritional additives

Nutritional additives are another growing source of nanoparticles in foods. The Institute of Medicine of the U.S National Academy of Sciences defines "functional foods", also known as nutraceuticals (a combination of the words nutrition and pharmaceutical), as foods that "provide a health benefit beyond the traditional nutrients [food] contains". The global functional food market is growing rapidly, reaching US$73.5 billion in 2005 (Just-Food.com undated). Nano-encapsulation involves enclosing an active ingredient in a nanoscale capsule (Shelke 2005).

Dairy products, cereals, breads and beverages are now fortified with vitamins, minerals such as iron, magnesium or zinc, probiotics, bioactive peptides, antioxidants, plant sterols and soy. Some of these active ingredients are now being added to foods as nanoparticles or particles a few hundred nanometres in size.

Active ingredients include vitamins, preservatives and enzymes. These have until recently been added to foods in microscale capsules, but are now also being produced in capsules thousands of times smaller in an effort to increase their potency. For example many of the commonly used Omega 3 food additives are micrometres in size, such as the 140-180µm micro-encapsulated tuna fish oils used by Nu-Mega Driphorm® to fortify Australia's Tip Top bread line (Nu-Mega 2007). However, increasingly companies such as Aquanova and Zymes are offering Omega 3 in 30-40nm nano-capsules - an incredible 4,000 times smaller than the Nu-Mega range (Halliday 2007a).

Aquanova's Novasol range of nano-encapsulated bioactive ingredients also includes vitamins, co-enzyme Q10, isoflavones, flavonoids, carotenoids, phyto-extracts, essential oils, preserving agents, food colouring substances and other bioactive substances. Its products are found in a wide range of food additives and in beverage additives such as Solu™ E 200 BG marketed by BASF, which is a Vitamin E nano-solution especially formulated for clear beverages like sports beverages, flavoured and enhanced waters (BASF 2005).

The effectiveness of nutraceutical ingredients depends on preserving and enhancing their bioavailability. Nano-sizing or nano-encapsulating active

ingredients delivers greater bioavailability, improved solubility and increased potency compared to these substances in larger or micro-encapsulated form (Mozafari et al. 2006). This is touted as delivering consumer benefits. The greater potency of nanoparticle additives may well reduce the quantities of additives required, and so benefit food processors. However the greater potential for cellular uptake of nanomaterials, coupled with their greater chemical reactivity, could also introduce new health risks.

Modern food processing methods produce nanoparticles

The emerging discussion of potential health risks associated with nanomaterials in foods has largely focused on manufactured nanomaterial food or food packaging additives and has ignored nanoparticles created during processing. However nanoparticles are also present in many foods because of the technology used to process the foods, rather than because they are food additives or ingredients. Although food processing technologies that produce nanoparticles are not new, the rapidly expanding consumption of highly processed foods is most certainly increasing our exposure to nanoparticles in foods.

Processing techniques which produce nanoparticles, particles up to a few hundred nanometres in size, and nano-scale emulsions are used in the manufacture of salad dressings, chocolate syrups, sweeteners, flavoured oils, and many other processed foods (Sanguansri and Augustin 2006). The formation of nanoparticles and nanoscale emulsions can result from food processing techniques such as high pressure valve homogenisation, dry ball milling, dry jet milling and ultrasound emulsification. Although many food manufacturers may remain entirely unaware that their foods contain nanoparticles, it is likely that these processing techniques are used precisely because the textural changes and flow properties they produce are attractive to manufacturers.

Recent research has also found in food nanoparticles which can best be described as contaminants. Nanopathology researcher Dr Antonietta Gatti has found that many food products contain insoluble, inorganic nanoparticles and microparticles that have no nutritional value, and which appear to have contaminated foods unintentionally, for example as a result of the wear of food processing machines or through environmental pollution (Gatti undated; Personal communication with Dr A.Gatti 19 September 2007). Gatti and colleagues tested breads and biscuits and found that about 40% contained inorganic nanoparticle and microparticle contamination (Gatti et al. submitted for publication).

While this report focuses on the issues associated with the intentional addition of nanomaterials to foods, food packaging and agricultural products, we recognise that the health implications of food processing techniques that produce nanoparticles and nanoscale emulsions also warrant the attention of food regulators. The potential for such foods to pose new health risks must be investigated in order to determine whether or not related new food safety standards are required. Just as a better understanding of the health risks of incidental nanoparticles in air pollution have resulted in efforts to reduce air pollution, improved understanding of the health risks associated with incidental nanoparticle contaminants in foods may also warrant efforts to reduce incidental nanoparticles' contamination of processed foods.

Nanotechnology used for food packaging and food contact materials

Extending the shelf-life of packaged foods

One of the earliest commercial applications of nanotechnology within the food sector is in packaging (Roach 2006). Between 400 and 500 nano-packaging products are estimated to be in commercial use now, while nanotechnology is predicted to be used in the manufacture of 25% of all food packaging within the next decade (Helmut Kaiser Consultancy Group 2007a; Reynolds 2007).

A key purpose of nano packaging is to deliver longer shelf life by improving the barrier functions of food packaging to reduce gas and moisture exchange and UV light exposure (AzoNano 2007; Bayer undated; Lagarón et al. 2005; Sorrentino et al. 2007). For example, DuPont has announced the release of a nano titanium dioxide plastic additive 'DuPont Light Stabilizer 210' which could reduce UV damage of foods in transparent packaging (ElAmin 2007a). In 2003, over 90% of nano packaging (by revenue) was based on nano-composites, in which nanomaterials are used to improve the barrier functions of plastic wrapping for foods, and plastic bottles for beer, soft drinks and juice (PIRA International cited in Louvier 2006; see Appendix A for products). Nano packaging can also be designed to release antimicrobials, antioxidants, enzymes, flavours and nutraceuticals to extend shelf-life (Cha and Chinnan 2004; LaCoste et al. 2005).

Edible nano coatings

Most of us are familiar with the waxy coatings often used on apples. Now nanotechnology is enabling the development of nanoscale edible coatings as thin as 5nm wide, which are invisible to the human eye. Edible nano coatings could be used on meats, cheese, fruit and vegetables, confectionery, bakery goods and fast food. They could provide a barrier to moisture and gas exchange, act as a vehicle to deliver colours, flavours, antioxidants, enzymes and anti-browning agents, and could also increase the shelf life of manufactured foods, even after the packaging is opened (Renton 2006; Weiss et al. 2006).

United States company Sono-Tek Corp. announced in early 2007 that it has developed an edible antibacterial nano coating which can be applied directly to bakery goods; it is currently testing the process with its clients (ElAmin 2007b).

Table 3: Examples of chemical release nano packaging under development

Company/ Institution	Nano content	Purpose
CSP Technologies	Polymer capable of releasing ingredients into the food or beverage in response to external stimuli	Control over humidity, oxygen, bacteria, odour and even the flavour of the food itself (LeGood and Clarke 2006).
Kraft	Nano-sensor based 'electronic tongue' able to 'taste' chemicals to the level of parts per trillion and then guide chemical release	Control the release of smell, taste and nutraceuticals into food products in response to the preferences of individual consumers (Wolfe 2005).

Chemical release nano packaging

Chemical release nano packaging enables food packaging to interact with the food it contains. The exchange can proceed in both directions. Packaging can release nanoscale antimicrobials, antioxidants, flavours, fragrances or nutraceuticals into the food or beverage to extend its shelf life or to improve its taste or smell (del Nobile et al. 2004; LaCoste et al. 2005; Lopez-Rubio et al. 2006; Nachay 2007). In many instances chemical release packaging also incorporates surveillance elements, that is, the release of nano-chemicals will occur in response to a particular trigger event (Gander 2007). Conversely, nano packaging using carbon nanotubes is being developed with the ability to 'pump' out oxygen or carbon dioxide that would otherwise result in food or beverage deterioration (FoodQualitynews.com 2005). Nano packaging that can absorb undesirable flavours is also in development.

Nano-based antimicrobial packaging and food contact materials

Distinct from trigger-dependent chemical release packaging, designed to release biocides in response to the growth of a microbial population, humidity or other changing conditions, other packaging and food contact materials incorporate antimicrobial nanomaterials, that are designed not to be released, so that the packaging itself acts as an antimicrobial. These products commonly use nanoparticles of silver although some use nano zinc oxide or nano chlorine dioxide (AzoNano 2007; LeGood and Clarke 2006; Table 4). Nano magnesium oxide, nano copper oxide, nano titanium dioxide and carbon nanotubes are also predicted for future use in antimicrobial food packaging (ElAmin 2007c; Nanologue 2006).

Table 4: Nano-based antibacterial food packaging and food contact materials (PEN 2007) Note: List based on the Project on Emerging Nanotechnologies' Consumer Products Inventory 27th February 2008.

Company/ Institution	Application
SongSing Nano Technology Co., Ltd	Food cling wrap treated with nano zinc oxide
Sharper Image	Food plastic storage bags treated with nano silver
BlueMoonGoods, A-DO Global, Quan Zhou Hu Zheng Nano Technology Co., Ltd and Sharper Image	Food storage containers treated with nano silver
Daewoo, Samsung and LG	Refrigerators treated with nano silver
Baby Dream® Co., Ltd	Baby cup treated with nano silver
A-DO Global	Chopping board treated with nano silver
SongSing Nano Technology Co	Tea pot treated with nano silver
Nano Care Technology Ltd	Kitchenware treated with nano silver

Nano-sensor and track and trace packaging

Packaging equipped with nano sensors is designed to track either the internal or the external conditions of food products, pellets and containers throughout the supply chain. For example, such packaging can monitor temperature or humidity over time and then provide relevant information on these conditions, for example by changing colour (Food Production Daily 2006a; Gander 2007; El Amin 2006a, Table 5). Companies as diverse as Nestlé, British Airways, MonoPrix Supermarkets, 3M and many others are already using packaging equipped with chemical sensors, and nanotechnology is offering new and more sophisticated tools to extend these capabilities and to reduce costs (LeGood and Clarke 2006).

Nanotechnology is also enabling sensor packaging to incorporate cheap radio frequency identification (RFID) tags (Nachay 2007; Pehanich 2006). Unlike earlier RFID tags, nano-enabled RFID tags are much smaller, can be flexible and are printed on thin labels. This increases the tags' versatility (for example by enabling the use of labels which are effectively invisible) and thus enables much cheaper production.

Other varieties of nano-based track and trace packaging technologies are also in development. For instance, United States company Oxonica Inc has developed nano barcodes to be used for individual items or pellets, which must be read with a modified microscope. These have been developed primarily for anti-counterfeiting purposes (Roberts 2007). An ingestible nano-based track and trace technology is promised by pSiNutria, a spin out of nanobiotechnology company pSivida. Potential pSiNutria products include: "products to detect pathogens in food, for food tracing, for food preservation, [and] temperature measurements in food storage" (pSivida 2006).

Nano biodegradable packaging

The use of nanomaterials to strengthen bioplastics (plant-based plastics) may enable bioplastics to be used instead of fossil-fuel based plastics for food packaging and carry bags (see Table 6; ElAmin 2007e; Nanowerk 2007; Sorrentino et al. 2007; Technical University of Denmark 2007). Potential environmental benefits and risks of nano biodegradable packaging are discussed in later sections.

Table 5: Nano-sensor packaging under development

Company/ Institution	Nano content	Purpose
Georgia Tech in the United States	Multi-walled carbon nanotube-based biosensor	Detects micro-organisms, toxic proteins, or spoilage of foods and some beverages (Nachay 2007).
University of Southampton UK & Deutsches Kunststoff-Institut, Germany	"Opal" film, incorporating 50nm carbon black nanoparticles	Changes colour in response to food spoilage (El Amin 2007d).
University of Strathclyde, Scotland	UV-light activated, nano titanium-dioxide based, oxygen-sensing ink	Tamper proofing (El Amin 2006a).
Australian company MiniFAB	Nanotechnology-based biosensors	Detect biological contamination (Invest Australia 2007).

Table 6: Development of nano-composite bioplastics

Company/Institution	Nano content	Purpose
Plantic Technologies, Australia	Nano-composite biopolymers, filler unspecified	Production of biodegradable plastics. Supplied to 80% of the Australian chocolate tray market, including Cadbury Australia (Invest Australia 2007).
Rohm and Haas, USA	Nano-composite biopolymers using Paraloid BPM-500	Used to strengthen PLA, a biodegradable plastic resin made from corn, while maintaining the plastic's transparency (El Amin 2007e).
"Sustainpack": 35 research institutes, universities and corporate partners from 13 European countries	Nano-composite biopolymers using nano clay	To strengthen fibre-based, biodegradable packaging, and to make the packaging water repellent (Nanowerk 2007).
Technical University of Denmark and others	Nano-composite biopolymers using nano clay and other minerals	The use of nanoclays and other minerals to strengthen bioplastics (Technical University of Denmark 2007).
Australia's Commonwealth Scientific and Industrial Research Organization	Nano-composite biopolymers filler unspecified	Nano-composites which are combustible, compostable, renewable and carbon-dioxide neutral (Invest Australia 2007).

Non-stick nano lining for mayonnaise and tomato sauce bottles

Promising an end to the need to tap or shake mayonnaise or ketchup bottles to remove the last of their contents, several German research institutes, industry partners and the Munich University of Technology have joined forces to develop non-stick nanofood packaging (Scenta 2007). The researchers have applied thin films which measure less than 20nm to the inside surface of food packaging. They have already developed their first samples, and hope to release the new packaging commercially in the next 2 – 3 years. The researchers promote their product as an environmentally friendly solution to reduce leftover traces of condiments in bottles. However there are concerns that manufactured nanomaterials are released into the environment from waste streams or during recycling. This may present a new range of serious ecological risks. It is therefore possible that such packaging may introduce more pollution problems than it solves.

Nanotechnology used in agriculture

Nanotechnology is introducing a new array of potentially more toxic pesticides, plant growth regulators and chemical fertilisers than those in current use at a time when we should be increasing our support for more sustainable food systems. By providing new tools for gene manipulation, nanotechnology is also likely to expand the genetic engineering of crops. Nano-based interactive farm surveillance and management systems remain a long way off commercialisation. If they are achieved, they may deliver far greater efficiencies. However in their further automation of farm management, such systems may also result in larger scale agribusiness employing ever fewer workers.

Nano agrochemicals are already in commercial use

Some of the first nano agrochemicals in development are nano-reformulations of existing pesticides, fungicides, plant, soil and seed treatments (ETC Group 2004, Green and Beestman 2007, Joseph and Morrison 2006). Agrochemical companies are reducing the particle size of existing chemical emulsions to the nanoscale, or are encapsulating active ingredients in nanocapsules designed to break open in certain conditions, for example in response to sunlight, heat or the alkaline conditions in an insect's stomach. Similar to the nanocapsules and nanoemulsions being developed for the food and packaging sectors, the smaller size of nanoparticles and emulsions used in agrochemicals is intended to make them more potent.

Joseph and Morrison (2006) observe that "many companies make formulations which contain nanoparticles within the 100-250 nm size range that are able to dissolve in water more effectively than existing ones (thus increasing their activity). Other companies employ suspensions of nanoscale particles (nanoemulsions), which can be either water or oil-based and contain uniform suspensions of pesticidal or herbicidal nanoparticles in the range of 200-400 nm".

The U.S. EPA has acknowledged that it has been contacted by several manufacturers interested in releasing nanoscale pesticides (U.S. EPA 2007). However, almost no major agrochemical companies have admitted to manufacturing products with particles measuring 100nm or less. An exception is Syngenta, the world's largest agrochemical company, which has been selling its nano-formulated "Primo MAXX" plant growth regulator for several years. Primo MAXX is marketed as a "micro-emulsion" concentrate (Syngenta undated). When contacted by Friends of the Earth, a spokesperson from Syngenta Australia initially confirmed that other fungicides and seed treatments in Syngenta's MAXX range of "micro-emulsion" concentrates also contained particles 100nm in size. The spokesperson subsequently retracted this statement

Table 7: Nano agrochemicals under development

Type of product	Product name & manufacturer	Nano content	Purpose
"Super" combined fertiliser and pesticide (Pakistan-US Science and Technology Cooperative Program 2006).	Pakistan-US Science and Technology Cooperative Program	Nanoclay capsule contains growth stimulants and biocontrol agents	Because it can be designed for slow release of active ingredients, treatment requires only one application over the life of the crop
Herbicide (Raj 2006).	Tamil Nadu Agricultural University (India) and Technologico de Monterry (Mexico)	Nano-formulated	Designed to attack the seed coating of weeds, destroy soil seed banks and prevent weed germination
Pesticides, including herbicides (Invest Australia 2007).	Australian Commonwealth Scientific and Industrial Research Organization	Nano-encapsulated active ingredients	Very small size of nanocapsules increases their potency and may enable targeted release of active ingredients

and told us that none of Syngenta's other products contain nanoparticles. Such confusion could be avoided with mandatory labelling of nano-ingredients and formulations. Tables 7 provides information on nano agrochemicals which are now on sale or in development.

Nano-genetic manipulation of agricultural crops and animals

For decades, molecular biologists have sought to genetically engineer microbes, plants and animals, but have been faced with many technical limitations and hurdles (Zhang et al. 2006). Nanobiotechnology now appears to offer a new suite of tools to manipulate the genes of plants or animals by using nanoparticles, nanofibres and nanocapsules, rather than using viral vectors, to carry foreign DNA and chemicals into cells (Bharali et al. 2005; He et al. 2003; Radu et al. 2004; Roy et al. 2005; Torney et al. 2007; Vassaux et al. 2006). These nanomaterials can transport a much larger number of genes as well as the chemicals that trigger gene expression. Theoretically, the use of nanotechnology also offers greater control over the release of DNA at the target site.

Nanobiotechnology is already enabling scientists to rearrange the DNA of agricultural crops. In 2004, the ETC Group reported that researchers at Chiang Mai University in Thailand had been able to alter rice colour from purple to green. They reported that ultimately the Thai researchers hoped to use their technique to develop Jasmine rice varieties that can be grown all year long, with shorter stems and improved grain colour (ETC Group 2004). There have also been reports that cellular 'injection' with carbon nanofibres containing foreign DNA has been used to genetically alter golden rice (AzoNano 2003).

Synthetic biology seeks to create entirely new organisms

'Synthetic biology' is the name given to a new area of work that combines genetic engineering with nanotechnology, informatics and engineering. The United

Kingdom's Royal Society has described synthetic biology as "an emerging area of research that can broadly be described as the design and construction of novel artificial biological pathways, organisms or devices, or the redesign of existing natural biological systems" (U.K. RS 2007). The Royal Society explains that: "The application of engineering principles to the design and construction of complex biological systems is likely to provide a step change from the tweaking of existing genomes usually described as genetic engineering".

It is likely to be some time before artificial organisms capable of self-replication are developed, although critical breakthroughs in the quest to develop synthetic life are being achieved. One of the first steps in the creation of an artificial organism occurred recently, when synthetic biology researchers successfully emptied one bacteria of its entire genetic makeup, and replaced it with that of another bacteria, literally transforming one species into another for the first time outside a virus (Lartigue et al. 2007).

Synthetic biology has potential applications throughout agricultural and food production systems. The ETC Group reports that Amyris Biotechnologies is developing synthetic microbes to produce nutraceuticals, vitamins and flavours for use in food processing (Amyris Biotechnologies 2006; ETC Group 2007). Codon Devices is also developing synthetic biology applications for agriculture, including efforts to improve the efficiency and control of genetic engineering of plants. For a detailed introduction to the area of synthetic biology see ETC Group (2007).

Nano-sensors for on-farm monitoring and surveillance

Nanotechnology and nanobiotechnology sensors are being designed for a range of agricultural applications. An Australian research facility has developed 'nanoarrays' which could have applications in monitoring crop growth, in animal breeding and in disease diagnostics. Its developers believe that it will enable manufacture of a hand held device which can sample cow's milk and indicate within an hour whether or not the bacteria which cause Bovine Mastitis are present (Clifford 2007). Another Australian group has developed a new hand-held monitoring device which can detect sheep lice on a shearer's blade. The system uses colorimetric detection based on gold nanoparticle clusters (Nanotechnology Victoria undated). Other potential applications for nanosensors include improving crop or animal genetics.

The quest to develop wireless nano surveillance systems to enable remote farm surveillance, and perhaps ultimately automated farm management, remains at an early stage of development. Over time proponents hope that nanotechnology and nanobiotechnology monitoring systems will enable the development of tiny, self-powered surveillance systems which can be distributed across a farm and effectively monitor on-farm conditions, for example soil moisture, temperature, pH, nitrogen availability, the presence of weeds, and disease or vigour of crops or animals (Joseph and Morrison 2006; Opara 2004; U.S.DoA 2003). Bath and Turberfield (2007) have recently reviewed development of what they call DNA nanomachines "in which individual molecules act, singly and in concert, as specialized machines", capable of responding to external stimuli. They note that DNA based sensors which respond to temperature and pH have already been developed. Interactive nanotechnology surveillance systems are also predicted that could respond to conditions observed, for example by releasing nano-fertilisers in response to identified nitrogen stress. However, despite the strong interest in nano-based automated surveillance and farm management systems, it is likely to be some time before such systems are technically and practically viable.

Nanofoods and nano agrochemicals pose new health risks

The incorporation of manufactured nanomaterials into foods and beverages, nutritional supplements, food packaging and edible food coatings, fertilisers, pesticides and comprehensive seed treatments presents a whole new array of risks for the public, workers in the food industry and farmers.

Manufactured nanomaterials may pose serious health risks

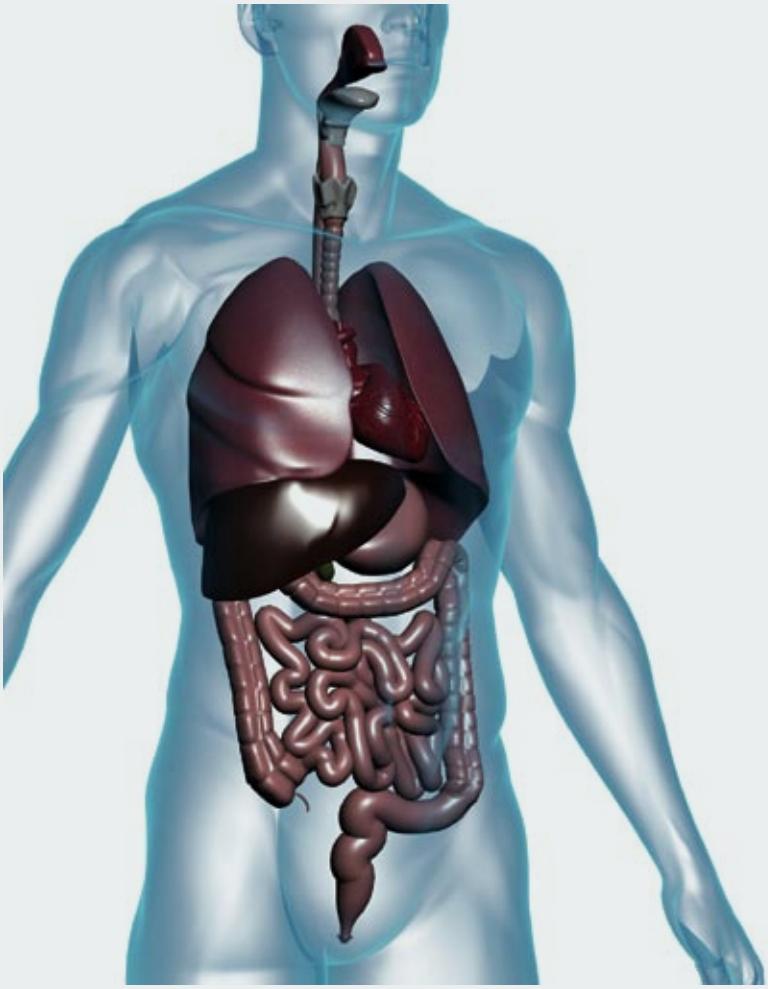
Our bodies' defensive mechanisms are not as effective at removing nanoparticles from our lungs, gastro-intestinal tract and organs, as they are with larger particles (Oberdörster et al. 2005a). Nanoparticles are also more adhesive than larger particles to surfaces within our bodies (Chen et al. 2006a). As a result of these factors and their very small size, nanoparticles are much more likely to be taken up into our cells and tissues than are larger particles.

Numerous *in vivo* experiments using rats and mice have demonstrated gastro-intestinal uptake of nanoparticles (Chen et al. 2006b; Desai et al. 1996; Hillyer and Albrecht 2001; Wang et al. 2007a; Wang et al. 2007b) and small microparticles (Hazzard et al. 1996; McMinn et al. 1996; Wang et al. 2006). Pathological examination of human tissues also suggests ingestion and translocation of microparticles up to 20µm in size (Ballestri et al. 2001; Gatti and Rivassi 2002)

A growing body of evidence demonstrates that some manufactured nanoparticles will be more toxic per unit of mass than larger particles of the same chemical composition (Brunner et al. 2006; Chen et al. 2006b; Long et al. 2006; Magrez et al. 2006). For example titanium dioxide is considered to be biologically inert in bulk form and is widely used as a food additive. However *in vitro* experiments show that as a nanoparticle or particle up to a few hundred nanometres in size, titanium dioxide damages DNA, disrupts the function of cells, interferes with the defence activities of immune cells and, by adsorbing fragments of bacteria and 'smuggling' them across the gastro-intestinal tract, can provoke inflammation (Ashwood et al 2007; Donaldson et al. 1996; Dunford et al. 1997; Long et al. 2006; Lucarelli et al. 2004; Wang et al. 2007b). A single high oral dose of titanium dioxide nanoparticles caused significant lesions in the kidneys and livers of female mice (Wang et al. 2007b). Table 8 provides a key summary of the existing scientific evidence of the toxicity of just some of the nanomaterials now used by the food industry.

The potential for ingested non-degradable nanoparticles to cause long-term pathological effects in addition to short-term toxicity is of great concern. A small number of clinical studies suggest that non-degradable nanoparticles and small microparticles which do not provoke an acute toxic response can accumulate in our bodies and over time result in the development of 'nanopathologies', for example granulomas, lesions (areas of damaged cells or tissue), cancer or blood clots (Ballestri et al. 2001; Gatti 2004; Gatti and Rivassi 2002; Gatti et al. 2004).

To our knowledge no long term experimental studies have been conducted to investigate the potential for manufactured nanomaterials to show chronic toxicity. However even long-term (2 year) animal experiments are not able to adequately identify the potential for nanomaterials to cause long-term health problems within a human's life span. It



Why nanoparticles pose new risks

- Nanoparticles are more chemically reactive than larger particles
- Nanoparticles have greater access to our bodies than larger particles
- Greater bioavailability and greater bioactivity may introduce new toxicity risks
- Nanoparticles can compromise our immune system response
- Nanoparticles may have longer term pathological effects

Nanotoxicity remains very poorly understood. We don't know:

- What levels of nano-exposure we are currently facing
- What levels of exposure could harm our health or if there is any safe level of exposure

is sobering to note that although there is scientific consensus that inhalation exposure to asbestos can result in lung cancer, animal experiments investigating this link remained inconclusive because the development of asbestos-induced disease takes longer than the lifetime of laboratory test animals (Magrez et al. 2006). This suggests strongly that the precautionary principle should be used when developing regulations to ensure that long-term exposure to manufactured nanomaterials does not result in harm to health.

Occupational health risks must be addressed as a matter of urgency

As with the production of all nanoproducts, workers who handle, manufacture, package or transport foods and agricultural inputs that contain manufactured nanomaterials are likely to face higher levels of nanomaterial exposure than the public and on a more routine basis. This is of great concern because scientists still do not know what levels of nanomaterial exposure may harm workers' health, and whether or not any level of occupational exposure to nanomaterials may be safe. Furthermore, reliable systems and equipment to prevent occupational exposure do not yet exist, and we have yet to identify a general basis for measuring and characterising nanomaterial exposure that does occur (Maynard and Kuempel 2005; U.K. HSE 2004).

Studies have shown that nanomaterials gain ready access to the blood stream following inhalation, which may be the primary route of occupational exposure to nanomaterials (Oberdörster et al. 2005b). At least some nanomaterials can penetrate the skin (Ryman-Rasmussen et al. 2006), especially if the skin is flexed (Rouse et al. 2007; Tinkle et al. 2003), or exposed to surfactants (Monteiro-Riviere et al. 2006) as is likely in many workplaces. Nanoparticles and even small

microparticles can be taken up through broken or damaged skin (Oberdörster et al. 2005a).

Nanoparticles and the link to Crohn's disease and immune system dysfunction

It is well known that people with asthma are especially susceptible to air pollution. In effect, asthma sufferers act as the 'canary in the mine', alerting those around them that air pollution levels are getting dangerously high. Scientists have very recently suggested that the growing prevalence of immune system dysfunctions and inflammations of the gastro intestinal tract such as Crohn's disease (a damaging and chronic inflammation of the gastrointestinal tract which can lead to cancer) may be a similar warning signal in relation to nanoparticles and particles a few hundred nanometres in size in our food (Ashwood et al. 2007; Gatti 2004; Lomer et al. 2001; Lucarelli et al. 2004; Schneider 2007).

Toxicity risks of nanofood additives

Very few studies have investigated the toxicity of nanoparticle nutritional additives. Some preliminary studies looking at 300nm nanoparticles of iron fed to mice have found that although the bioavailability of iron was increased greatly, there was no toxicity problem (Rohner et al. 2007; Wegmüller et al. 2004). However another preliminary experiment has shown that mice fed a high dose of nanoparticles and even small microparticles of zinc can suffer severe organ damage and blood thickening (Wang et al. 2006).

The failure of governments to require comprehensive safety testing of Toxicity risks in nano additives is concerning, given that 300nm iron and zinc particles are now marketed for fortification of foods and beverages (eg SunActive® products marketed by Taiyo International). There are also a number of companies selling 'generic' nano-additives, such as nano zinc oxide, nano silica and other nano-encapsulated active ingredients (see Appendix A).

The potential for potent bioavailable nano-nutritional additives to deliver excessive doses of some vitamins or minerals is also concerning. For example online industry magazine Food Processing.com reports that a United States company is now promoting its nano-formulated Vitamin E delivers "10 times the adult recommended daily allowance for vitamin E can be delivered to consumers ... without change in taste or appearance of clear, fortified waters and other functional beverages" (Shelke 2007). Yet scientists recognise that substances which are not toxic in themselves can have a toxic effect if consumed in excessive quantities. For example, excessive consumption of Vitamin A can cause adverse skeletal effects and bone fractures in the limbs (Downs 2003). Excessive consumption of Vitamin B6 can cause a nerve disorder that can lead to pain, numbness, and weakness in the limbs; excessive consumption of folic acid can cause crippling neurologic damage (U.S. IOM 1998). If nano-nutritional additives and supplements provide an excessive dose of some vitamins and nutrients, these may also interfere with the absorption of other nutrients. Dr Qasim Chaudhry who leads the nanotechnology research team at the United Kingdom's Central Science Laboratory warns that nanoparticle and nano-encapsulated food ingredients "may have unanticipated effects, far greater absorption than intended or altered uptake of other nutrients, but little, if anything, is known currently" (Parry 2006).

There is also the possibility that nanoscale ingredients or contaminants may themselves pose toxicity problems that are difficult for food regulators to identify. UK consultant Neville Craddock, a leading expert in food safety testing,

Table 8: Experimental evidence of the toxicity of selected nanomaterials now in commercial use by the food industry

Nanomaterial and current applications	Size and physical description	Experimental evidence of toxicity
Titanium dioxide Small microparticle form widely used as food additive; nanoparticle form used as antimicrobial and U.V. protector in food packaging and storage containers and sold as food additive	20nm	Destroyed DNA (*in vitro*; Donaldson et al. 1996)
	30nm mix of rutile and anatase forms of titanium dioxide (see glossary)	Produced free radicals in brain immune cells (*in vitro*; Long et al. 2006)
	Nanoparticle, size unknown, rutile and anatase forms	DNA damage to human skin cells when exposed to UV light (*in vitro*; Dunford et al. 1997)
	Four sizes 3-20nm, mix of rutile and anatase form	High concentrations interfered with the function of skin and lung cells. Anatase particles 100 times more toxic than rutile particles (*in vitro*; Sayes et al. 2006)
	25nm, 80nm, 155nm	25nm and 80nm particles caused liver and kidney damage in female mice. TiO_2 accumulated in liver, spleen, kidneys and lung tissues (*in vivo*; Wang et al. 2007b)
Silver Used as antimicrobial in food packaging, storage containers, chopping boards and refrigerators, also sold as health supplement	15nm	Highly toxic to mouse germ-line stem cells (*in vitro*; Braydich-Stolle et al. 2005)
	15nm, 100nm	Highly toxic to rat liver cells (*in vitro*; Hussain et al. 2005)
	15nm, ionic form	Toxic to rat brain cells (*in vitro*; Hussain et al. 2006)
Zinc and zinc oxide Sold as nutritional additives and used as antimicrobial in food packaging	20nm, 120nm zinc oxide powder	120nm particles caused dose–effect damage in mice liver, heart and spleen. 20nm particles damaged liver, spleen and pancreas (*in vivo*; Wang et al. 2007a)
	19nm zinc oxide	Toxic to human and rat cells even at very low concentrations (*in vitro*; Brunner et al. 2006)
	58±16 nm, 1.08±0.25µm zinc powder	Test mice showed severe symptoms of lethargy, vomiting and diarrhoea. Nanoparticle dose produced more severe response, killed 2 mice in first week, and caused greater kidney damage and aneamia. Greater liver damage in microparticle treatment (*in vivo*; Wang et al. 2006)
Silicon dioxide Particles a few hundred nm in size used as food additives, nano form touted for use in food packaging	50nm, 70nm, 0.2µm, 0.5 µm, 1µm, 5 µm	50nm and 70nm particles taken up into cell nucleus where they caused aberrant protein formation and inhibited cell growth. Caused the onset of a pathology similar to neurodegenerative disorders (*in vitro*; Chen and von Mickecz 2005)

has warned that safety regulators will find it difficult to detect and assess the safety of nanoscale food ingredients or contaminants: "The analysis of a [nano]particle-sized item in a food product would not be an every-day test" (Rowe 2006). This suggests that risk management schemes to ensure the safety of nanofoods face potentially insurmountable practical obstacles. This casts doubt on the perception that appropriate regulations can ensure the safety of nanofoods.

Public health issues assiciated with nanofortification

Beyond the need to ensure the safety of nanofood additives, it is also useful to question whether or not fortifying food with nano nutrients is actually desirable from a public health perspective. There is a growing number of manufacturers prepared to claim that their nano-fortified beverages or foods will meet a large part, or even the entirety, of an individual's dietary needs. For example Toddler Health's range of fortified chocolate and vanilla 'nutritional drinks', which include 300nm particles of SunActive® iron, is marketed as "an all-natural balanced nutritional drink for children from 13 months to 5 years. One serving of Toddler Health helps little ones meet their daily requirements for vitamins, minerals and protein" (Toddler Health undated). Yet no matter how fortified, nanofoods cannot substitute for the nutritional value of a diet based on a variety of fresh, minimally processed foods. There is a real possibility that the promotion of nano-fortified foods could be one factor in people eating less fruit and vegetables, with associated negative public health outcomes.

Nanofood packaging represents new routes of nanoexposure

The use of manufactured nanomaterials in food packaging and edible coatings will undoubtedly increase the likelihood of the public ingesting nanomaterials. Future chemical-release packaging technologies are being designed to release nanocapsules of flavours, odours or nutritional additives into foods and beverages over time. Such packaging offers benefits to processors, such as reduced processing costs and longer shelf life of foods and beverages. However consumer benefits such as stronger tastes or flavours appear to be outweighed by the potential new health risks associated with ingestion of nanomaterials. Edible nano coatings, being developed for confectionery, bakery products and fresh fruit and vegetables, will also result in increased ingestion of nanomaterials, with potential new health risks.

The use of nanomaterials in food contact materials including packaging, cling wrap, storage containers and chopping boards could also potentially increase the probability of nanomaterial ingestion. It appears possible that nanomaterials could migrate from various food packaging into foods. Polymers and chemical additives in conventional food packaging are known to migrate from the packaging into food products (Franz 2005; Das et al. 2007). Conversely, flavours and nutrients in foods and beverages are also known to migrate into plastic packaging. The Institute of Food Science and Technology has stated its concern that manufactured nanomaterials are already being used in food packaging, despite migration rates, and thus exposure risks, remaining unknown (IFST 2006). The United Kingdom's Central Science Laboratory and Danish scientists at the National Food Institute are currently investigating the potential for nanomaterials migration from food packaging into foods (U.K. FSA 2006; ElAmin 2007f). Preliminary results of a study carried out in the UK indicate that nanomaterial migration from the two polymer nanocomposites tested (nanoclay-in multilayered PET bottles, and nanosilver-polypropylene composite) may be minimal (Chaudhry 2008). However. until these studies are completed, there remains an absence of any published

data quantifying rates of migration of manufactured nanomaterials from packaging into foods (Nanlogue.net 2005).

Challenges facing antibacterial and nano-sensor packaging

Anti-bacterial nanofood packaging and nano-sensor technologies have been promoted as delivering greater food safety by detecting or eliminating bacterial and toxin contamination of food. However it is possible that nanomaterials will migrate from antibacterial food packaging into foods, presenting new health risks. This appears inevitable where nano-films or packaging are designed to release antibacterials onto the food surface in response to detected growth of bacteria, fungi or mould.

De Jong et al. (2005) have warned that although promising, nanotechnology based toxin indicators in nano-sensor packaging also face significant practical difficulties. Because toxins in foods are not homogenously distributed throughout food, to be 100% effective a sensor must not only be extremely sensitive to very small

What makes nano silver a more powerful antibacterial than larger silver particles?

In ionic form silver is both a powerful antibacterial agent and toxic to cells in culture. Because nanoparticles of silver have a greater surface area than larger particles of silver, nano silver is more chemically reactive and more readily ionised than silver in larger particle form. Nano silver therefore has greater antibacterial and toxic effects compared to larger silver particles partly because it is more readily converted to silver ions. However there is also preliminary evidence that nano silver can exert effective antibacterial action at a considerably lower concentration than that of silver ions (Lok et al. 2006).This suggests that the antibacterial properties and toxicity of nano silver are not explained only by its chemical composition and the production of ions alone.

Physical characteristics of nanomaterials, such as their size, shape and surface properties, can exert a toxic effect that goes beyond that associated with their chemical composition (Brunner et al. 2006). For instance, Hussain et al. (2005) demonstrated that nanoparticles of silver produce reactive oxygen species (ROS) and this can result in oxidative stress-mediated toxicity. Production of ROS, highly reactive molecules which include free radicals, can interfere with cellular metabolism, cause inflammation and damage proteins, membranes and DNA. ROS production is a key mechanism for nanomaterials toxicity (Nel et al. 2006).

The powerful antibacterial and toxic effects of nano silver may also be of concern given that the burgeoning use of nano silver in food contact materials and other disinfectants is likely to result in both humans and environmental systems facing greater overall exposure to silver.

Powerful antibacterials such as nano silver may interfere with beneficial bacteria in our bodies and the environment, and ultimately result in the development of more virulent harmful bacteria (see also Melhus 2007; Senjen 2007; Throback et al. 2007).

amounts of a toxin, but also be able to sample the whole of the food product or beverage.

Canadian-based civil society organisation The ETC Group (2004) has suggested that while useful in food monitoring, nano-sensor packaging and nano track and trace barcodes will not address the root problems of the industrial agriculture and food system that result in contaminated foods. They suggest that "faster meat (dis)assembly lines, increased mechanisation, a shrinking labour force of low-wage workers, fewer inspectors, the lack of corporate and government accountability and the great distances between food producers, processors and consumers" are ultimately responsible for the rising incidence of food contamination.

While any illness as a result of food contamination is unacceptable, it is important to remember that for every person who suffers illness as a result of food poisoning, there are 50 who suffer ill health as a result of poor diets and inadequate consumption of fruit and vegetables (Lang and Rayner 2001). If processed, nano-packaged food is marketed successfully as safer than eating fresh, unpackaged foods, and consumption of fresh foods declines further, it is possible that the net outcome will actually be poorer health.

Health risks associated with nano agrochemicals

Exposure to conventional pesticides has been linked to greater incidence of cancer and serious reproductive health problems among agricultural workers and their families (Davidson and Knapp 2007; Hanazato 2001; Relyea and Hoverman 2006). Nano-formulations of existing agrochemicals are designed to be more reactive and more bioactive than conventional agrochemicals. There is the real possibility that although smaller quantities of chemicals may be used, nano agrochemicals may introduce even more serious environment and health risks than the conventional chemicals that they replace.

Nanofoods and nano agriculture pose new environmental risks

The production, use and disposal of foods, food packaging and agricultural products containing manufactured nanomaterials will inevitably result in the release of these nanomaterials into the environment. This may be the result of waste streams associated with manufacturing, wear during the product's use, or following end of life product disposal or recycling. Other nanomaterials will be released into the environment intentionally, for example as pesticides or plant growth treatments.

Although commercial use of nanomaterials by the agriculture and food sectors is increasing, the ecological risks associated with nanomaterials remain very poorly understood. Some aquatic organisms appear to concentrate manufactured nanomaterials, but their uptake into plants has not been studied, and it is unknown whether or not nanomaterials will accumulate along the food chain (Boxhall et al. 2007; Tran et al. 2005). Early studies demonstrating the potential for nanomaterials now in commercial use to be environmentally harmful underscore the urgent need for further research (Moore 2006). The environmental risks associated with crops which have been genetically engineered using nanomaterials and synthetic biology organisms being developed for agriculture are even more poorly understood.

Nanomaterials now in commercial use pose serious ecological risks

Despite the limited number of studies examining the ecological effects of nanomaterials, there is already evidence suggesting that nanomaterials in commercial use by the agriculture and food industry may cause environmental harm. This is especially true for antibacterial nanomaterials such as silver, zinc oxide and titanium dioxide, which are increasingly being added to food packaging and food contact materials including cling wrap, chopping boards, cutlery and food storage containers. Nano titanium dioxide, one of the most widely used nanomaterials, caused organ pathologies, biochemical disturbances, and respiratory distress in rainbow trout (Federici et al. 2007). Nano titanium dioxide is also toxic to algae and to water fleas, especially after exposure to UV light (Hund-Rinke and Simon 2006; Lovern and Klaper 2006). Other preliminary studies have also found that nano zinc is toxic to algae and to water fleas (Luo 2007) and that nano zinc oxide is toxic to bacteria and to water fleas (Heinlaan et al. 2007). These findings are concerning, especially as water fleas are used by regulators as an ecological indicatcor species.

The effects of nanomaterials on bacteria, microbes and fungi in natural systems remain very poorly understood. It is possible that the increased presence in waste streams of highly potent antibacterial nanomaterials could disrupt the functioning of beneficial bacterial in the wider environment, for example those performing nitrification and denitrification in freshwater and the marine environment (Throback et al. 2007). Nano-antimicrobial agents could also disrupt the functioning of nitrogen fixing bacteria associated with plants (Oberdörster et al. 2005a). Any significant disruption of nitrification, denitrification or nitrogen fixing processes could have negative impacts for the functioning of entire ecosystems. There is also a risk that widespread use of antimicrobials will result in greater resistance among harmful bacterial populations (Melhus 2007).

Although not currently in commercial use by the food industry, carbon nanotubes have been touted for future use as antibacterials in food packaging and food manufacturing (ElAmin 2007c) and

in packaging films designed to extend food's shelf life (FoodQualitynews.com 2005). The environmental risks of carbon nanotubes remain poorly researched, however preliminary studies demonstrate that byproducts associated with their manufacture can cause increased mortality and delayed development of the small estuarine invertebrate *Amphiascus tenuiremis* (Templeton et al. 2006) and delayed hatching of zebra fish (*Danio rerio*) embryos (Cheng et al. 2007).

Nano agrochemicals may introduce more problems than the chemicals they replace

Conventional agricultural chemicals used in pesticides, chemical fertilisers, seed and plant growth treatments have been implicated in polluting soils and waterways, have caused substantial disruption to these ecosystems and have led to biodiversity loss (Beane Freeman et al. 2005; Petrelli et al. 2000; van Balen et al. 2006).

Proponents claim that the greater potency of nano-formulated pesticides, and the greater capacity to target their application or release to specific conditions, will deliver environmental savings through reduced applications and reduced run off. However the same characteristics which make nano-pesticides more effective than their bulk counterparts - increased toxicity, more bioavailability to target pests and greater longevity in the field - also present new risks to humans and the environment. Because nano agrochemicals are being formulated for their increased potency, it is possible that they will introduce even greater ecological problems than the chemicals they replace. Nano formulated agrochemicals may result in more persistent residues and create new kinds of contamination in soils and waterways.

The United Kingdom's Royal Society and Royal Academy of Engineering have called for the environmental release of nanoparticles to be "avoided as far as possible", and for their intentional release to "be prohibited until appropriate research has been undertaken and it can be demonstrated that the potential benefits outweigh the potential risks" (U.K. RS/RAE 2004, Section 5.7: paragraph 63). This recommendation should be applied in respect of all nano agrochemicals.

The claim that nano agrochemicals will reduce the overall use of pesticides should be received critically given similar, unfulfilled, promises made by many of the same companies in relation to GE crops.

Nanobiotechnology and synthetic biology pose even more uncertain ecological risks

The ecological risks posed by crops genetically engineered using nanoparticles rather than other vectors are likely to be very similar to those associated with existing GE crops. The significance of the use of nanoparticles may simply lie in their overcoming some of the technical barriers previously faced by genetic engineers (Zhang et al. 2006), thereby enabling a new generation of GE crops to be released commercially. If this occurs, it could result in a new wave of erosion of genetic diversity of food crops as existing strains and species are displaced. It would also present a new source of the same ecological risks identified with contemporary GE crops. These include: genetic contamination of wild relatives and other crops resulting in increased weediness or development of herbicide/ insect/ virus resistance, a negative impact on animal populations through reduced food availability or toxicity to non-target species; the use of insect or virus resistant crops encouraging the development of more virulent and difficult to control viruses. Ecosystem level disruption could result from any or all of these (Ervin and Welsh 2003).

Given that synthetic biology organisms will be artificially created, potential environmental and biosafety risks are impossible to predict. Synthetic biology organisms could disrupt, displace or infect other species, alter the environment in

which they were introduced to the extent that ecosystem function is compromised, and/ or establish within a system such that they become impossible to eliminate (ETC Group 2007; Tucker and Zilinskas 2006). Many synthetic biologists, working with fairly simple genetic circuits, report preventing rapid mutation of the circuits as being a key challenge to their work. The potential for synthetic biology organisms, released into the environment, to mutate in unpredictable ways is therefore of great concern.

The wide scale and worldwide genetic contamination of both GE free crops and GE free food processing highlight the difficulties of contamination in an industry that involves self-replicating (living) organisms and millions of people (Friends of the Earth International 2007). Although no one has yet succeeded in manufacturing a self-replicating synthetic organism, given the growing number of researchers active in the field, and the hundreds of millions of dollars invested in research, there are compelling reasons to establish strict regulation of synthetic biology before it becomes a reality.

Nanotechnology used in agriculture and food production has broader environmental implications

Nanotechnology could entrench our reliance on chemical and fossil fuel intensive industrial agriculture at a time when there should be greater efforts to move away from chemical-intensive agriculture. The use of nanotechnology in agriculture will compete with and undermine agricultural alternatives such as organic farming which have been demonstrated to deliver a wide range of other environmental benefits Long-term studies how that organic farming results in reduced use of water and fossil fuel energy, higher soil organic matter and nitrogen, reduced soil erosion and greater agricultural and ecological diversity (Hisano and Altoé 2002; Pimental et al. 2005). Nanotechnology also appears likely to intensify existing trends towards ever larger scale farming operations, and an even more narrow focus on producing specialised crops (ETC Group 2004; Scrinis and Lyons 2007). This could lead to further losses of agricultural and ecological diversity.

The potential for nano-strengthened bioplastics to reduce our reliance on plastic food packaging has been touted as a key environmental benefit. Packaging accounts for about 40% of the entire plastic production worldwide and roughly half of this is used for food packaging (Technical University of Denmark 2007). If safe and effective nanobioplastics can be developed, that do not result in greater overall use of plastics, these could deliver environmental savings. However the potential for nano fillers to present new environmental risks once the bioplastic degrades remains poorly understood.

Unfortunately, nano-sensor and chemical release nano-packaging appear likely to expand our overall use of packaging by increasing the food industry's use of packaging for individual food items, including fruit and vegetables.

To date there is no life cycle analysis of the energy required to produce, package and transport nanofoods compared to conventional production. However it appears likely that the expansion of nanotechnology in food processing and packaging could result in a higher overall ecological footprint. Nano food packaging, which has a primary goal of extending the shelf-life of packaged food, is likely to encourage manufacturers to transport food over ever greater distances, and thus contribute to the growth of food transport-related greenhouse gas emissions. If nanotechnology results in people eating nano-fortified processed foods at the expense of fruit and vegetables, this could also expand the energy demands associated with food production.

Time to choose sustainable food and farming

Producing enough safe, healthy food to meet the needs of all global citizens, and doing so in an ecologically sustainable and socially just manner, will be a growing challenge in the decades ahead. Proponents of nanotechnology predict that it will deliver more environmentally benign agricultural systems which are also vastly more productive - the solution both to environmental degradation associated with conventional agriculture, as well as to widespread hunger. However Friends of the Earth is concerned that while nanotechnology may deliver efficiencies in some areas, on balance it may introduce more health and environmental problems than it solves, while doing nothing to redress the root causes of existing inequities in global food distribution.

Nanotechnology is unlikely to deliver environmentally sustainable food systems

Nanotechnology in agriculture stands in contrast to growing public support for more environmentally sustainable food production. Against the back drop of climate change, there is a mounting recognition that meeting a greater proportion of our food needs on a regional basis, reducing the greenhouse gas emissions associated with food production and transport, and using less fossil-fuel intensive agricultural inputs makes environmental sense. Yet, nanotechnology appears likely to result in new pressures to globalise each sector of the agriculture and food system and to transport agricultural chemicals, seeds and farm inputs, unprocessed agricultural commodities and processed foods over even further distances at each stage in the production chain.

Nano agrochemicals designed for controlled self-release in response to changing environmental conditions and nano-sensor based farm management systems, aim to enable larger scales of production of more uniform crops. In this way, nanotechnology entrenches and expands the industrial scale model of monoculture agriculture which has resulted in rapid losses of agricultural and

biological diversity over the past century.

Nanotechnology in agriculture appears likely to entrench our dependence on a chemical-intensive system at a time when there is increasing public support for organic farming that reduces the use of chemicals (Feder 2006). Because nano-pesticides are designed to be more potent weed and pest killers, they may also prove more toxic to non-target wildlife than conventional agrochemicals. If these nano agrochemicals are biopersistent, they could simply introduce a new generation of hazardous pollution into soils and waterways.

Worldwide food systems are in trouble

The world produces more than enough food to meet the dietary needs of our population of 6.6 billion, but the distribution of this food is extremely inequitable (FAO 2006). While over 300 million people are now clinically obese (WHO 2007) more than 850 million people experience extreme hunger (FAO 2007a).

Over 2.5 billion people world-wide rely on agriculture to make a living (Oxfam Australia undated). However control of the global food system, valued at US$4 trillion, is held by a dwindling number of multinational companies (U.S. DoA ERS 2005). Food distribution and retail sales are concentrated in the hands of a few big companies, who exert a great influence over product supply, and who play a key role in determining which crops farmers grow, where and at what price (Reardon et al. 2003; WHO Europe 2007).

This disparity between who produces agricultural products and who owns and profits from them is one of the major factors in the growing inequity in access to food. It has also resulted in the paradox where many of the people that experience extreme hunger include people who are engaged in successful farming.

Nanotechnology could make existing inequities worse

By underpinning the next wave of technological transformation of the global agriculture and food industry, nanotechnology appears likely to further expand the market share of major agrochemical companies, food processors and food retailers (Scrinis and Lyons 2007). Nano track and trace technologies will enable global processors, retailers and suppliers to operate even more efficiently over larger geographic areas, giving them a strong competitive advantage over smaller operators. Nano food packaging will extend food shelf life, enabling it to be transported over even further distances while reducing the incidence of food spoilage, significantly reducing the costs of global suppliers and retailers. Potent nano agrochemicals are being developed by the major agrochemical companies and appear likely to further concentrate their market share in what is already a highly concentrated sector (ETC Group 2005).

Furthermore, nano-encapsulated pesticides, fertilisers and plant growth treatments designed to release their active ingredients in response to environmental triggers could enable even larger areas of cropland to be farmed by even fewer people. Nanotechnology enabled remote farm surveillance and automated farm management systems could dramatically accelerate existing trends towards large-scale, high-technology agricultural production, requiring almost no on-farm labour (ETC Group 2004; Scrinis and Lyons 2007).

Some observers see the potentially greater efficiencies associated with automated nanomanagement systems as delivering social benefits (Opara 2004). However as automation would reduce dramatically the need for farmers and farm labourers, this could also result in the further decline of rural communities (Foladori and Invernizzi 2007; Scrinis and Lyons 2007). Nano agricultural applications that reduce labour

requirements, but increase capital costs could also make it even more difficult for small farm owners to remain economically viable. Whereas the cost of agricultural inputs, including technological inputs, has increased in recent decades, commodity prices have fallen and farmers' incomes have stagnated or declined; small farmers around the world have struggled to remain viable (Hisano and Altoé 2002; La Via Campesina and Federasi Serikat Petani Indonesia 2006; Philpott 2006). By deepening existing trends towards a globalised agriculture and food industry controlled by small numbers of large operators, nanotechnology could further undermine the ability of local populations to control local food production, a right known as food sovereignty (Nyéléni - Forum for Food Sovereignty 2007).

Nanotechnology could further erode our cultural knowledge of food and farming

Whereas nanofoods are increasingly marketed as delivering consumer benefits, in addition to the new health and environmental risks they introduce, they could also have negative social consequences by eroding our understanding of how to eat well and agricultural knowledge which has developed over thousands of years.

Nano food processing and nanonutritional additives are likely to erode our cultural understanding of the nutritional value of food. For example many of us eat citrus fruit or berries which are naturally high in vitamin C, when we feel the onset of a cold. However nano processing and nano nutritional additives could enable nano-fortified confectionery to be marketed as having the same health properties as fresh fruit. With the increasing use of nanotechnology to alter the nutritional properties of processed foods, we could soon be left with no capacity to understand the health values of foods, other than their marketing claims. Similarly, nano packaging that incorporates sensors which indicate whether food is still 'fresh' or edible could displace knowledge passed down through generations on how to identify safe, fresh food. Traditionally we have sourced vegetables by their colour and texture, and fish by the clarity of its eyes. But the expansion of nano-sensor packaging could mean that we buy these packaged products on the basis of the colour indicated by the nano-sensor instead.

If farm nano-surveillance and automated management systems are developed as predicted, our ability to farm could come to depend on technological packages sold by a small number of companies. Nano farming systems could commodify the knowledge and skills associated with food production gained over thousands of years and embed it into proprietary nanotechnologies on which we could become completely reliant (Scrinis and Lyons 2007).

Nanotechnology introduces new privacy concerns

Nano-sensor and track and trace packaging also introduce new privacy concerns. They are designed to increase the ability to monitor food products and their condition through each link in the supply chain (LeGood and Clarke 2006). This capacity is useful for a number of commercial, security and public health reasons. But the potential tracking of foods after their point of sale also raises privacy and ethical concerns, especially relating to what sort of information will be collected and how this information will be controlled. Information gathered about the consumer (for example purchasing habits or their location of residence) could be used by companies who hope to gain a commercial advantage through targeted marketing or product promotion, or on-sold to others. There is also the potential that nano-sensors could be used to gather more sensitive information about individuals, for example genetic makeup, health or disease profiles.

Synthetic biology poses broader social and ethical challenges

To date research into synthetic biology research has been carried out without any meaningful effort to consider the broader social and ethical implications of creating artificial life, or to involve the public in assessment of these. Given public concerns about technological manipulation of living organisms in relation to GE crops, it appears likely that the public would also be concerned about organisms manipulated or created using synthetic biology. It is therefore essential that the ethical challenges concerning the creation of artificial life are addressed early on, alongside public involvement in decision making about governance issues and research funding. This must address concerns relating to the extension of intellectual property rights to living organisms, and the potential for synthetic biology to further concentrate corporate control of food production.

Real food and real farming offers real alternatives to nano agriculture

Friends of the Earth Australia, Europe and United States suggest we should not take big risks with nanofood in an attempt to overcome widespread poor eating habits and diet-related disease. Instead, we should support healthier eating habits based on eating more fresh fruit and vegetables, including minimally processed, organic food (real food). Similarly, we suggest that nano agrochemicals, nano-manipulated seeds and nanosurveillance systems are not the solution to the huge environmental problems facing global agriculture. Rather, we should support smaller scale, ecologically sustainable farming practice that also makes positive social contributions to local communities (real farming).

Real food

Real food embodies the principles that we believe are necessary for healthy, environmentally and socially sustainable food: produced without harmful chemicals, minimally processed, affordable for all members of the community, produced under fair labour conditions, and where possible eaten close to where it was grown to support local farmers and to minimise the climate cost of food processing and transport.

Real farming

Real farming embodies the principles that we believe are necessary for environmentally and socially sustainable agriculture: safe for the wider environment and human health, providing a fair income and fair conditions to farmers and food workers, respectful of the right of local producers to food sovereignty, and relying on minimal external inputs (e.g. chemical fertilisers or pesticides).

Fresh, minimally processed, organic food delivers real nutritional benefits

Rather than looking to manufactured nanomaterials to boost the nutritional value of foods like chocolate bars, ice cream or soft drinks to overcome widespread nutritional deficiencies in industrialised countries, we should be making every effort to ensure that people eat a varied diet of fresh foods that includes adequate fruit and vegetables.

The health benefits of eating minimally processed, organic foods make intuitive sense. There is now also increasing empirical evidence of the high nutritional value of organic, minimally processed foods. A four year, £12 million study involving 33 European academic institutions led by Newcastle

University has confirmed that, compared to conventionally grown produce, organic produce has higher nutritional values. The study found that organic produce contained greater quantities of substances thought to boost health and combat disease. Organic vegetables had as much as 40% higher antioxidant content, while organic milk contained up to 90% greater antioxidant levels compared to conventional milk (Times Online U.K. 2007).

There is also a growing recognition that fresh foods which have been minimally processed have the highest health value. The intactness or wholeness of certain foods may affect the availability of nutrients and beneficial compounds they contain, and can be an important factor influencing our insulin and glycaemic responses. For example the metabolic and hormonal effects are different for comparatively intact soybean products like tofu or drinks, compared to those made from soy protein isolates (Wahlqvist and Lee 2006).

In its Proposed Second WHO European Action Plan for Food and Nutrition Policy 2007–2012, the World Health Organization's Regional Committee for Europe has recognised that diets which are high in fruit and vegetables and low in industrially processed foods deliver important health benefits (WHO Europe 2007).

Benefits of small-medium scale organic farming

Recent decades have revealed the high environmental costs associated with industrial scale chemical-intensive agriculture, including biodiversity loss, toxic pollution of soils and waterways, salinity, erosion and declining soil fertility. The FAO(2007b) has observed that there is now "uncompromising evidence of diminishing returns on grains despite the rapid increases of chemical pesticide and fertilizer applications, resulting in lower confidence that these high input technologies will provide for equitable household and national food security in the next decades". Friends of the Earth suggests that nano-enabled agriculture appears likely to entrench the problematic aspects of conventional agriculture. In contrast, as part of a new healthier paradigm of food and farming, small-medium scale, locally controlled organic production has a vital role to play. The rapid growth of sales of organic and fair traded food attests to the burgeoning public interest in agriculture that is both environmentally sound and socially just. Global sales of organic food and beverages reached almost US $40 billion in 2006 and are the fastest growing food sector (Organic Monitor 2006). Commercial organic production is now practiced in 120 countries (FAO 2007b).

Organic farming is delivering significant environmental and socio-economic benefits, while on a global scale supporting similar or increased yields compared to chemical-intensive industrial agriculture. A recent study compared yields between organic and conventional agriculture in 293 cases world wide and found that organic yields were comparable to conventional agriculture in the Global North and greater than those of conventional agriculture in the Global South (Badgley et al. 2007). A 22 year trial in the United States found that organic farms produced comparable yields, but required 30% less fossil fuel energy and water inputs than conventional farms, and resulted in higher soil organic matter and nitrogen levels, higher biodiversity, greater drought resilience and reduced soil erosion (Pimental et al. 2005). Regional agro-ecological initiatives in Brazil have delivered yield increases of up to 50%, improved incomes for farmers, restored local agricultural biodiversity and reinvigorated local economies (Hisano and Altoé 2002). While the number of farm workers in conventional agriculture is in decline, organic farms have created an additional 150,000 jobs in Germany (Bizzari 2007).

Nano-specific regulation required to ensure food safety

A growing number of civil society organisations world-wide have called for precautionary management of nanotechnology. This has included the release of "Principles for the Oversight of Nanotechnologies and Nanomaterials" (ICTA 2007). At its release in July 2007 this document was endorsed by 40 civil society organisation signatories from around the world, including Friends of the Earth Australia, Europe and United States. Nanofood scientists have also called for new regulations to ensure that all nanofood, nano food packaging and nano food contact materials are subject to nanotechnology-specific safety testing prior to being included in commercial food products (IFST 2006; Lagaron et al. 2007; Sorrentino et al. 2007). In its 2006 report, the European Union's Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) recognised the many systemic failures of existing regulatory systems to manage the risks associated with nanotoxicity (E.U. SCENIHR 2006). Yet recent reviews of regulatory measures in the United Kingdom, the United States, Australia and Japan found that none of these countries require manufacturers to conduct nanotechnology-specific safety assessments of nanofoods before they are released on to the market (Bowman and Hodge 2006; Bowman and Hodge 2007).

Regulatory systems in the United States, Europe, Australia, Japan and other countries treat all particles the same; that is, they do not recognise that nanoparticles of familiar substances may have novel properties and novel risks (Bowman and Hodge 2007). Although we know that many nanoparticles now in commercial use pose greater toxicity risks than the same materials in larger particle form, if a food ingredient has been approved in bulk form, it remains legal to sell it in nano form. There is no requirement for new safety testing, food labelling to inform consumers, new occupational exposure standards or mitigation measures to protect workers or to ensure environmental safety. Incredibly, there is not even a requirement that the manufacturer notify the relevant regulator, that they are using nanomaterials in the manufacture of their products. Despite a perception in some quarters that those engaged in synthetic biology research are regulated adequately by GE regulations, this is not the case.

There is an urgent need for regulatory systems capable of managing the many new risks associated with nanofoods and the use of nanotechnology in agriculture. Alongside managing nanotoxicity risks, governments must also respond to nanotechnology's broader social, economic, civil liberties and ethical challenges. To ensure democratic control of these new technologies in the important area of food and agriculture, public involvement in nanotechnology decision making is essential.

Senior scientists call for precautionary management of nanotoxicity risks

In 2004 the United Kingdom's Royal Society – the world's oldest scientific institution – in conjunction with the Royal Academy of Engineering made very explicit recommendations for the precautionary management of nanotoxicity risks (U.K. RS/RAE 2004):

- "We recommend that chemicals in the form of nanoparticles or nanotubes be treated as new substances …in the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)…

(Section 8.3.2: paragraphs 18 & 19)"

• "We recommend that ingredients in the form of nanoparticles undergo a full safety assessment by the relevant scientific advisory body before they are permitted for use in products… (Section 8.3.3: paragraph 24 & 23)"

• "We recommend that the ingredients lists of consumer products should identify the fact that manufactured nanoparticulate material has been added (Section 8.3.3: paragraph 26)"

• "Until more is known about environmental impacts of nanoparticles and nanotubes, we recommend that the release of manufactured nanoparticles and nanotubes into the environment be avoided as far as possible (Section 5.7: paragraph 63)"

• "Specifically, in relation to two main sources of current and potential releases of free nanoparticles and nanotubes to the environment, we recommend:

(i) that factories and research laboratories treat manufactured nanoparticles and nanotubes as if they were hazardous, and seek to reduce or remove them from waste streams. (Section 5.4: paragraph 41)

(ii) that the use of free (that is, not fixed in a matrix) manufactured nanoparticles in environmental applications such as remediation be prohibited until appropriate research has been undertaken and it can be demonstrated that the potential benefits outweigh the potential risks. (Section 5.4: paragraph 44)"

European Regulation

The European Union regulates food and food packaging at a European Union level, and once agreed the directives and regulations are implemented on a national basis (see Appendix B for an overview of the applicable laws). REACH (Registration, Evaluation and Authorisation of Chemicals), the EU's new chemical regulation explicitly excludes food and most food packaging, although some chemicals involved in creating packaging may come under this legislation (ElAmin 2006b). Pesticides are regulated as either plant protection products or biocidal products and need to be assessed and authorised before use. As many pesticides are a source of surface and ground water pollution, they are also subject to water legislation. None of the existing EU regulations applicable to agriculture, food or food packaging currently consider or mention nanoscale products or materials.

In July 2007, the European Parliament's Committee on the Environment, Public Health and Food Safety recognised that existing food safety standards are inadequate to manage the new risks associated with nanofoods. It recommended that because of the different toxicity profile of nanomaterials, they should be assessed as new chemicals: "the permitted limits for an additive in nanoparticle form should not be the same as when it is in traditional [bulk] form" (Halliday 2007b). This would require the introduction of new, nanotechnology-specific safety standards and testing requirements. Perhaps to this end, the European Food Safety Authority (EFSA) has been asked by the EU to provide an initial scientific opinion on the potential risks arising from the use of nanotechnology in food (EAS 2007). The deadline for this report is 31 March 2008.

Current EU food regulations require all foods to be safe

The general safety article of the EU Food Law Regulation 178/2002 requires all food for consumption to be safe. As an overarching safety article, this should apply to all nanofoods and food packaging containing nanomaterials. However, as noted above, no European regulations recognise the critical issue of particle size, so if a substance has already been approved in bulk form, there is no regulatory trigger to require new safety assessment before a particle is used in

Five reasons why existing laws are inadequate to assess the risks posed by nanofoods, nano food packaging and nano agrochemicals

Reason 1: Toxicity risks of nanofoods and nano agrochemicals remain very poorly understood. The current scientific evidence of the risks associated with nanomaterials is sufficient to warrant a precautionary approach to their management. However significant knowledge gaps remain, presenting a barrier to the development of effective regulation to manage nanofoods and nano agrochemicals.

Reason 2: Nanomaterials are not assessed as new chemicals. Existing regulations do not treat nanomaterials as new chemicals. If a chemical has been approved in larger particle form, the new use of the substance in nanoparticle form does not trigger any requirement for new or additional safety testing. This has been recognised by the United Kingdom's Royal Society and Royal Academy of Engineering as a critical regulatory gap. They recommended that all nanomaterials be assessed as new chemicals (U.K. RS/RAE 2004).

Reason 3: Current methods for measuring exposure are not suitable for nano. Existing regulations are based on the mass of the material as a predictor for expected exposure rates. This approach is completely inappropriate for nanomaterials as the toxicity can be far greater per unit of mass (Reijnders 2006). Scientists have suggested that nanoparticle surface area or the number of nanoparticles is a more valid metric for measurement of nano exposure (Nel et al. 2006; SCENIHR 2006).

Reason 4: Current safety testing is not suitable for nano. Even if a nanomaterial triggered new safety testing, current test guidelines are inadequate for nanomaterials as they do not assess key properties that influence nanotoxicity. These include: shape, surface, catalytic properties, structure, surface charge, aggregation, solubility and the presence or absence of 'functional groups' of other chemicals (Magrez et al. 2006; Nel et al. 2006). Nanomaterials must also face full life-cycle assessment, which existing regulation does not require.

Reason 5: Many safety assessments use confidential industry studies. Past assessments of nanomaterials safety by the European Scientific Committee on Cosmetics and Non-food Products and the United States Food and Drug Administration have relied on proprietary company studies (Innovest 2006). There is often no requirement for the safety of nanomaterials to be assessed by independent nanotoxicologists or for the results and methodology of this safety testing to be made public.

nano form in food ingredients, additives or packaging. This means that in practice many nanomaterials could be used as additives in foods and food packaging without legally requiring new safety assessment.

EU novel foods regulation needs to cover nanofoods

The EU novel foods regulation 258/ requires mandatory pre-market approval of all new ingredients and products (introduced after May 1997), including product safety assessments carried out by the EFSA. The regulation requires assessments on the composition, nutritional value, metabolism, intended use and the level of microbiological and chemical contaminants. Studies on the toxicology, allergenicity and details of the manufacturing process may also be considered. However, once again, as the regulation makes no distinction in relation to particle size, nanoparticles will not require new safety assessments if the substance has already been approved in bulk form.

EU Regulation 258/97 is currently under revision and this may provide an opportunity to change the legislation to cover nanofoods properly. In a review of this legislation the U.K. Food Standards Agency (FSA) stated that the regulation appears to be adequate for most products. However as the FSA acknowledged, nano forms of substances that have a history of use are exempt and would escape additional safety requirements.

EU Food Additive Use Directive needs to be expanded to include nano-sized additives

The EU Food Additive Use Directive lists all permitted food additives, the maximum level of their use and the foods in which they can be used (EU directive 89/107). All additives on this list have been assessed for safety by the Scientific Committees which advise the European Commission, via the EFSA. Currently the minimum particle size is only prescribed in the case of microcrystalline cellulose (E460) and minimum molecular weight distribution in the case of carrageenan (E407, a chemical extracted from red algae that is added to commercial ice creams as an emulsifying agent). Size is not specified in relation to any of the other permitted additives on the above list, and nanomaterials are not recognised to be new substances. In its 2006 review the UK FSA reported that there are no immediate plans to redress this regulatory gap (U.K. FSA 2006).

EU food packaging regulation is under review, but will it cover nano ingredients?

EU Food Packaging Regulation (EC 1935/2004) covers all materials that come into contact with food such as a packaging, bottles (plastic and glass), cutlery, domestic appliances and even adhesives and inks for printing labels. Similarly to the regulation on novel foods, it requires the establishment of a positive list of authorised food contact materials, and an assessment of their potential toxicity or safety. However its weakness is that once again, the failure to identify nanomaterials as new substances means that nanomaterials of substances which are already authorised in bulk form for use in food contact materials will not be subject to new safety assessments.

This regulation also requires that authorised food contact materials must be traceable. The Institute of Food Science and Technology (IFST), the leading European independent professional qualifying body for food scientists and technologists, have argued that "traceability should include a specific reference to the presence of nanoparticles and should, ultimately, enable the relevant safety dossiers for these materials to be accessed" (IFST 2006).

Interestingly the special case of active packaging is covered in some detail in this framework, requiring that active

packing ingredients must comply with EU 89/107 – the food additive directive. EU food packaging regulation currently sets exposure standards and regulations regarding the migration of chemicals and other ingredients from food packaging and other food contact materials into foods. However once again, there are no nanotechnology-specific exposure standards or requirements for new safety testing of nano packaging, for example to determine whether or not nanomaterials will exhibit a higher migration rate from packaging into foods.

In the instance of edible coatings based on manufactured nanomaterials, nanomaterials ingestion is inevitable, which may present health risks (see health section). Nanomaterials used in edible coatings should be evaluated as novel foods, requiring strict nano-specific safety testing, even if the bulk material has previously been approved as safe.

EU labelling laws need to cover nanomaterials and ingredients

EU food labelling laws require the names of some ingredients to be listed on product labels, and in some specified cases their physical condition or treatment they have undergone. To ensure the capacity for informed consumer choice, the label should indicate if nanomaterials have been used in the food or in the food packaging. The IFST suggest that, in the case of food additives, this could be done by modifying the E-number system with a subscript "n" (IFST 2006). However there is currently no legal requirement for the composition of food contact materials to be declared. Friends of the Earth recommends regulatory amendments to ensure that consumers can establish if nanoparticles have been added to food packaging or food contact materials.

EU pesticide and biocide regulation needs to cover nano-formulations

Products covered by the EU Pesticides and the EU Biocides Directive (Directive 91/414, Council Directive 79/117, Regulation 396/2005 and Directive 98/8/EC and Directive 76/769/EEC) need to be assessed and authorised before use. As many pesticides are a source of surface and ground water pollution, they are also subject to the EU Water Framework Directive. However none of this legislation currently considers nanoscale products, or recognises nanomaterials to be new substances. Friends of the Earth strongly recommends that all new pesticides and biocides and any new nano-formulations of existing products require additional safety assessment before their authorisation for commercial use.

US regulatory environment: no data, no problem?

In the United States, nanofoods and most food packaging is regulated by the United States Food and Drug Administration (FDA), while agrochemicals are regulated by the Environmental Protection Agency (EPA). Neither EPA nor FDA have recognised nanomaterials to be new chemicals or have required any new oversight of them.

As in the EU, Australia and elsewhere, US legislation fails to recognise that nanoparticles present new and often greater toxicity risks than larger particles of the same chemical composition. Nanoparticles of substances that have been previously approved in larger particle form do not trigger requirements for new safety testing, and can legally be used commercially without notifying the relevant regulator.

In a blow to the precautionary principle, transparency and the right of consumers to choose nano-free, the FDA has also refused to label nanofoods and other products (Randall Lutter, USFDA deputy commissioner for policy, cited in: Bridges 2007).

US food and agrochemicals regulation rests on the principle that an absence of evidence of chemical or product harm, even if very little research has been conducted into its safety, means that the

product is considered safe. This has been called the 'no safety data, no problem' approach. This approach places a burden on the community to demonstrate that a nano product is harmful, before regulators will control its release, for example by requiring manufacturers to conduct new safety testing. This reversal of the burden of proof not only undermines the precautionary principle, it also acts as a disincentive for companies to engage in comprehensive product safety testing.

A further and very serious weakness is that US regulators often focus on the marketing claims of product manufacturers, rather than the actual content of foods, packaging, pesticides etc. Despite the authority of regulators to regulate products' content, if a manufacturer chooses not to make marketing claims about its product's nano content, there is a real possibility that a product could be treated as nano-free.

US food and food packaging regulation leaves many nano products unregulated

Food additives and new dietary ingredients in food supplements require 'premarket authorization' from the FDA. For this authorisation to be granted the FDA requires companies to provide their own safety testing data, from which the FDA also specifies the conditions for its use. However manufacturers of food additives can legally market a product if the chemicals have already been approved for commercial use (US Food and Drug Administration 2007). If they have already been approved for use in larger particle form, nanoparticles do not legally require any additional authorisation or trigger new safety testing, despite the fact that many may introduce new toxicity risks. Additionally, food ingredients that are classified as 'generally recognized as safe' (GRAS) do not require any premarket authorization from the FDA. The GRAS system also fails to distinguish between substances in larger particle or nanoparticle form.

If manufacturers determine that there is no migration of nanomaterials from food packaging to food products, their food packaging is not regulated as a food additive. As "no migration" can legally include a small amount of migration, this is a serious regulatory gap (Monsanto v. Kennedy 1979). Even small amounts of nanomaterial contaminants in foods could pose serious toxicity risks.

The EPA appears reluctant to use its powers to regulate nano agrochemicals

The EPA has legal powers to compel nano agrochemicals manufacturers to provide toxicity data and to demonstrate product safety – that is, to place the burden of proof on the manufacturers (Davies 2007). However the EPA is yet to decide whether or not nano agrochemicals warrant new safety testing. To date it has not required manufacturers introducing nano-formulations of existing pesticides to submit their products to nanotechnology specific safety testing.

In early 2007 the EPA announced its intention to regulate as biocides (i.e. chemicals used to kill microorganisms) all nano products, including food packaging and other food contact materials, which contain nano silver and whose manufacturers make claims of antimicrobial action (Acello 2007). However in September 2007 the EPA disappointed many observers when it said it would only regulate the silver ions released from washing machines, and was taking no action to manage the risks posed by the growing number of other consumer products which contain silver nanoparticles (EPA 2007).

Australian regulation also leaves many nano products effectively unregulated

In Australia nanofood additives and ingredients are regulated by Food Standards Australia and New Zealand (FSANZ), under the Food Standards Code, while agrochemicals and veterinary products are the responsibility of the Australian Pesticides and Veterinary Medicine Authority (APVMA).

As with the EU and US systems, Australian regulations are primarily focused on "new" chemicals. To date, Australian legislation fails to recognise that nanoparticles present new and often greater toxicity risks than larger particles of the same chemical composition (Bowman and Hodge 2006).

There is some evidence of confusion among Australian regulators regarding nanoproducts. Syngenta has sold its nano-formulated plant growth regulator Primo MAXX in Australia for several years. However, as recently as October 2007 the APVMA said that they had not received applications for nanopesticides, and also claimed that "any such applications are a fair way off" (Salleh 2007). Although new formulations of pesticides are routinely assessed by the regulator, there is still no nanotechnology specific safety testing.

A public statement on regulatory aspects of nanotechnology in food applications by FSANZ suggests that similar to the US FDA, FSANZ has yet to be convinced that the risks associated with nanofoods warrant regulatory oversight: "While no evidence of any adverse effects is currently available, Food Standards Australia New Zealand (FSANZ) maintains a watching brief on the use of nanotechnology by the food industry. Safety questions may arise as we learn more about the practical applications of nanotechnology in foods and these will be considered on a case by case basis" (Gruber and Belperio undated).

Australian regulators appear to be struggling to stay abreast of the rapid expansion of nanotechnology into agriculture and food systems. However their apparent support for the 'no data, no problem' approach being taken by the US is a real concern. Given the growing evidence of serious toxicity risks associated with nanomaterials already in use by the agriculture and food industry, nanotechnology-specific regulations for the food sector are urgently required.

The right to say no to nanofoods

The industry is ignoring early public concern about nanofoods

Public awareness about nanotechnology remains very low. However, early surveys show that once given information about nanotechnology, people do not want to eat nanofoods or foods wrapped in packaging that contains manufactured nanomaterials.

Public engagement initiatives and experimental studies suggest that once provided with information about nanotechnology, the public is concerned about many of the same issues identified in relation to GE food: a lack of transparency, a lack of choice about exposure, risks to health and the environment, unfair distribution of risks and benefits, a lack of socially useful applications and a lack of public participation in decision making (Gavelin et al. 2007; Macoubrie 2006).

Public concerns about nanotechnology are greatest when nanotechnology is applied to food. Participants in a 2006 consumer conference in Germany, organised by the German Federal Institute for Risk Assessment (BfR), expressed the most serious reservations about nanotechnology when it was applied to

foods (German FIRA 2006). A year later the BfR conducted a survey of 1,000 people and found that a majority of people not only do not personally want to eat nanofoods, but also think that nanotechnology should not be used in food applications at all. 60% of survey respondents were against the use of nano additives to prevent spices from becoming lumpy; 84% rejected the idea of using nanoparticles to make foods look appealing for longer (Halliday 2007c). A study conducted in the German speaking part of Switzerland also found that people did not want to eat nanofoods or foods wrapped in nano packaging (Siegrist et al. 2007). Similarly, a United States survey of 1,014 adults found that only 7% of respondents were currently prepared to purchase foods produced using nanotechnology. 29% would not purchase food produced using nanotechnology, while 62% wanted more information about health risks and benefits before they would consider buying nanofoods (Peter D. Hart Research Associates 2007).

Yet despite early studies indicating serious public reservations about nanotechnology in food and agriculture, and a key wish for transparency to enable people to make informed food choices, the food industry is pushing ahead with the commercialisation of nanofoods, while refusing to disclose which foods products and food contact materials now contain nanomaterials. For example although BASF sells its nano synthetic lycopene to the world's major food and beverage companies, it has refused to identify the companies to which it sells the nano lycopene or the products in which it is used (Shelke 2006).

The need for greater industry transparency in its use of nanotechnology

In addition to preventing people from making informed choices about whether or not they want to eat nanofoods, the food and agriculture industry's refusal to speak publicly about its use of nanotechnology has compromised the ability of even government regulators to determine whether or not nanomaterials are already in commercial use. Whereas nanotechnology industry analysts suggest that as many as 600 nanofood products may now be commercially available (Daniells 2007), conversations with US, Australian and German food regulators reveal that they have extremely limited information about whether foods, food packaging and agricultural products now contain manufactured nanomaterials, let alone which nanomaterials are used in which products. This clearly undermines the capacity of those charged with ensuring the safety of our foods to know whether or not existing safety standards are meeting the new challenges associated with nanofoods.

People's right to make informed food choices and to say 'no' to nanofoods

Mandatory labelling of all nanofoods is required to enable people to make an informed choice about whether or not to eat them. However beyond the need for labelling to enable informed purchasing choices, the public must be given the opportunity to be involved in decision making about the use of nanotechnology in the food and agriculture sector Given the significant implications of nanotechnology for our relationship with food and agriculture, and for food producing communities worldwide, we call for public involvement in all aspects of decision making, including the right to say no to nanofoods.

Recommendations for sustainable food and farming

A moratorium on food nanotechnology

Friends of the Earth calls for a moratorium on the commercial release of food products, food packaging, food contact materials and agrochemicals that contain manufactured nanomaterials until nanotechnology-specific regulation is introduced to protect the public, workers and the environment from their risks, and until the public is involved in decision making.

In line with recommendations from the United Kingdom's Royal Society and Royal Academy of Engineering's 2004 report on nanotechnology, intentional release of nanomaterials into the environment should be prohibited until this can be proven to be safe. This prohibition should include on-farm use of nano agrochemicals and all synthetic biology applications.

What government must do:

1. Establish comprehensive and precautionary legislation to manage the risks associated with nanotechnology

We call for the establishment of regulatory regimes requiring comprehensive assessment of all manufactured nanomaterials in food, food packaging, food contact materials and agricultural products.

Nanomaterials regulated as new substances

- All nanomaterials must be subject to new safety assessments as new substances, even where the properties of larger scale counterparts are well-known.
- Particles up to 300nm in size must be considered to be 'nanomaterials' for the purposes of health and environment assessment given early evidence that they pose many similar health risks to particles less than 100nm in size.

Assessment

- All manufactured nanomaterials must be subject to nano-specific health and environmental impact assessment and must be demonstrated to be safe prior to approval for commercial use in foods, food contact materials or agricultural applications.
- Assessments must be based on the precautionary principle and the onus must be on manufacturers to comprehensively demonstrate the safety of their product. No data, no market.
- Safety assessment must be based on the nano content of products, not marketing claims.
- Safety assessment must include the product's entire life cycle.
- Social and cultural implications of nanotechnology's expansion into the agriculture and food systems must be addressed alongside concerns over safety.

Transparency

- All relevant data related to safety assessments, and the methodologies used to obtain them, must be placed in the public domain.
- All manufactured nano ingredients must be clearly indicated on product labels to allow members of the public to make an informed choice about product use.

Public involvement in decision making

- The public, including all stakeholder groups affected, must be involved in all aspects of decision making regarding the use of nanotechnology in the food and

agriculture sector. The right to say no to nanofoods needs to be assured.

• A wide range of participatory processes must be initiated to enable early stage input from the general public and civil society into new technology assessment, determination of research priorities, and agreement on priorities and principles for public policy and legislation.

• Resources must be provided to enable participants to take part in these processes in a meaningful way.

Urgent inquiry into the broader risks associated with small particles in foods

Furthermore, we call for national governments to support an independent inquiry into:

• The health implications of the rising incidence of incidentally produced nanoparticles in processed foods and whether a policy response is required from governments.

• The health implications of particles <20µm in size, and whether a policy response is required from governments to ensure that particles in this size range do not present unacceptable health risks.

2. Support sustainable food and farming to improve public and environmental health

Governments must:

• Develop policies for sustainable small scale farming, appropriate to geographic and cultural context, and ensure they are properly implemented and funded.

• Public research funding and public agricultural subsidies must not marginalize ecologically compatible farming models.

• Food and farming technologies must be assessed in relation to environmental, social and cultural implications.

• Holistic food policies must be developed that encourage healthier eating habits, rather than consumption of low nutritional value, highly processed foods. Initiatives could include limiting advertisement of junk foods during childrens' television shows, or shifting financial incentives to encourage greater consumption of fresh foods.

What industry must do

Food producers and retailers must respect people's right to safe foods, and to make informed food purchasing choices. Food producers and retailers must stop selling nanofood, nano food packaging, nano food contact materials and nano agrochemicals until:

• The public is involved in decision making.

• Nanotechnology-specific regulation is introduced to protect the public, workers and the environment from potential new risks associated with nanotoxicity.

Assessment

• Manufacturers must work with regulators to ensure that their products have undergone appropriate safety testing, and must provide the relevant data regarding the health and environmental safety of their product. No data, no market.

Transparency

• All relevant data related to safety assessments, and the methodologies used to obtain them, must be placed in the public domain.

• All food and agricultural products which include manufactured nanomaterials must be clearly labelled to allow members of the public and farmers to make an informed choice.

What concerned individuals and organisations can do

1. Hold government and industry to account over nanofoods

• Write to your local councillor and members of state, federal and regional parliaments, requesting their support for a moratorium on the use of nanotechnology

for the food sector. Demand that governments regulate and label food, food packaging and agricultural products that contain manufactured nanomaterials, before allowing any further commercial sales.

• Ensure that food and agricultural manufacturers take seriously public concerns about nanofoods. Contact the manufacturers of foods you eat often and ask them about what steps they are taking to keep unsafe, untested nanomaterials out of the food they sell.

• Insist that governments and industry take seriously the risks of occupational exposure to nanomaterials for food and agricultural workers. If you are concerned about nano-exposure in your work place, talk with your colleagues or your union representative about opportunities for collective action to secure a safe work place.

• Contact civil society organisations you think may be interested in taking action to ensure precautionary management of the use of nanotechnology in food and agriculture applications. Find out what environment, public health, farmers and civil liberties organisations in your neighbourhood are doing to work towards alternative food systems that deliver positive environmental and social outcomes.

2. Choose food that is healthy for you and the environment, and pays a fair wage to food producers

There are many simple steps we can all take to make food choices that are good for our health, good for the environment, and that support fair conditions for farmers.

• Make environmentally friendly food and farming choices – look out for the organic label at your supermarket or store.

• Buy fair trade products whenever possible - fair trade products ensure that working conditions are reasonable and that a fair wage is paid to farmers in the Global South.

• Support local food producers and small scale retailers and buy directly from local farmers, butchers and bakers. You could even consider joining a food co-operative or bulk buying scheme.

• Avoid eating highly processed foods and eat more fresh food instead. Processed foods not only have higher environmental costs of production and have lower nutritional value, they are also a big source of incidentally produced nanoparticles in foods.

• Avoid highly packaged foods – packaging is energy intensive and produces lots of waste and is often unnecessary. Let your local food outlets and the manufacturers of your favourite foods know that you want to see less food packaging. You could even consider leaving your food packaging in the store.

• Support the right of communities to control local food trade, including deciding how food is grown, who can sell it and what can be imported.

Visit our websites to learn more about nanotechnology or to support our work towards safe foods:

Friends of the Earth Australia
http://nano.foe.org.au

Friends of the Earth Europe
http://www.foeeurope.org/activities/nanotechnology/index.htm

Friends of the Earth United States
http://www.foe.org/camps/comm/nanotech/

Glossary

Ampiphilic
Amphilic describes a molecule combining hydrophilic (water loving) and lipophilic (fat loving) properties.

Anatase form of titanium dioxide
Found as small, isolated and sharply developed titanium dioxide crystals.

Antioxidant
A molecule which slows or prevents destructive oxidation (the interaction of substances with oxygen in a process that can lead to their breakdown). Oxidative stress can damage cells.

Biocide
A biocide is a pesticide used in non-agricultural applications, mainly as an anti-microbial agent.

Biopolymer
Any polymer (a long repeating chain of atoms) found in nature. Examples include starch, proteins and DNA.

Bioavailability
Bioavailability measures the extent to which a substance can reach the systemic blood circulation and its availability at the site of action.

Dendrimer
Dendrimers are three-dimensional, synthetic macromolecules with branching parts, usually formed using a fabrication process at the nanoscale.

Carbon fullerene ('buckyball')
A fullerene is a pure carbon molecule composed of at least 60 atoms of carbon which has a shape similar to a hollow soccer ball or a geodesic dome.

Crohn's disease
A damaging and chronic inflammation of the gastrointestinal tract, which can lead to cancer.

Emulsion
A suspension of small globules of one liquid within a second liquid. The two liquids stay separate.

Encapsulation
A process in which particles or droplets as active ingredients are coated to create capsules.

Fair trade
Fair trade is an organised social movement which promotes fair standards for international labour, environmentalism and social policy in the production of food and goods. The movement focuses in particular on exports from the Global South to the Global North.

Granuloma
A small mass or nodule of chronically inflamed tissue that is usually associated with an infective process or injured tissue, for example as seen in Crohn's disease, tuberculosis, sarcoidosis etc.

Intracellular organelles
A differentiated structure, or small organ, within a cell, that performs a specific function.

In vitro
Experiment performed in a test tube or culture.

In vivo
Experiment performed in a living organism.

Lesions
Abnormal tissue found on or in an organism, usually damaged by disease or trauma.

Liposome
Oily, microscopic capsules designed to package and deliver biological cargo, such as drugs, to cells in the body.

Macrophage
A large immune cell that envelopes invading pathogens and other foreign material.

Micelle
An aggregate of molecules, where in an aqueous solution the hydrophilic (water loving) head regions form a protective barrier around the oil containing hydrophobic (water hating) tail regions in the micelle centre.

Mitochondria
Organs within cells which provide the cell with energy.

Mucosa
The moist layer that lines the mouth and gastrointestinal tract.

Nano-composite
Materials that are created by mixing nanomaterial fillers into a base material.

Nano-bio-sensor
Nano-sensor that incorporates a biologically active interface, eg DNA, proteins etc.

Nano-sensor
Nanoscale chemical, biological or physical sensory points or system used to detect and convey information about a given environment, eg temperature, pH, location, or the presence of diseased tissue.

Nanotubes
A carbon molecule that resembles a cylinder.

Nanowires
A nanowire is an extremely thin wire with a diameter on the order of a few nanometers (nm) or less.

Non-degradable particles
Particles that our bodies are not able to decompose into materials which can be used or removed. Also called persistent particles.

Oxidative stress
An imbalance between the production of reactive oxygen and a biological system's ability to readily detoxify the reactive intermediates or easily repair the resulting damage.

Pesticide
A pesticide is any chemical used for control of plant or animal pests. Pesticides include insecticides, herbicides, fungicides, nematocides and rodenticides.

PET
Polyethylene terephthalate. A thermoplastic material used to manufacture plastic soft drink containers and rigid containers.

Polymer
A substance made of many repeating chemical units or molecules. The term polymer is often used in connection with plastic, rubber, or elastomer.

Quantum dots
A quantum dot is a particle of matter so small that the addition or removal of an electron changes its properties in some useful way eg it might glow under UV light

Reactive oxygen species (ROS)
Very small molecules which are highly reactive due to the presence of unpaired valence shell electrons, includes oxygen ions, free radicals and peroxides. ROS form as a natural byproduct of the normal metabolism of oxygen and have important roles in cell signalling. However, during times of environmental stress ROS levels can increase dramatically and result in significant damage to cell structures (oxidative stress).

Rutile form of titanium dioxide
The most common form of titanium dioxide, has a tetragonal unit cell.

Submucosa
In the gastrointestinal tract, the submucosa is the layer of loose connective tissue that supports the mucosa and joins it to the bulk of underlying smooth muscle.

Synthetic lycopene
Lycopene is a bright red natural colour and powerful antioxidant found in tomatoes and other red fruit. Synthetic lycopene is derived artificially and is increasingly produced at the nanoscale.

Appendix A: List of agriculture and food products identified by Friends of the Earth that contain manufactured nanomaterials

Table 1: Nanomaterials in agricultural products

Product name	Manufacturer	Nano content	Claim	Web address or reference
Primo MAXX plant growth regulator	Syngenta	100nm particle size emulsion ("micro-emulsion concentrate")	The extremely small particle size allows Primo MAXX to mix completely with water and not settle out in a spray tank	http://www.syngentapp.com/prodrender/index.asp?nav=CHEMISTRY&ProdID=747
Geohumus Soil Wetting Agent	Geohumus	Biocompatible high-performance polymer	Soil enhancer with water storage capacity based on nanotechnology	http://www.geohumus.com/download/geohumus_flyer_eng.pdf
Irrigation emmitter/ plastic pipe	Geoflow	Nanoclay platelets (PolyOne's Nanoblend MB)		http://www.ptonline.com/articles/200602fa2.html

Table 2: Nanomaterials in food packaging

Product name	Manufacturer	Nano content	Claim	Web address or reference
Durethan® KU 2-2601	Bayer	Silica in a polymer-based nanocomposite	Nanoparticles of silica in the plastic prevent the penetration of oxygen and gas of the wrapping, extending the product's shelf life.	http://www.research.bayer.com/edition_15/15_polyamides.pdfx
Hite Brewery beers: three-layer, 1.6L beer bottle	Honeywell	Honeywell's Aegis OX nylon-based nano composite	• Oxygen and Carbon Dioxide Barrier • Clarity • Recyclability • Ease of Preform • Processability • Flavor/Odor/Aroma Barrier • Structural Integrity • Delamination Resistance • Aegis® barrier nylon resins can be found in a multitude of applications globally.	http://www.packaging-gateway.com/features/feature79/ http://www51.honeywell.com/sm/aegis/
Miller Beers: **• Lite** **• Genuine Draft** **• Ice House**	Nanocor	Imperm nylon/nano-composite barrier technology produced by Nanocor	Imperm is a plastic imbued with clay nano-particles that make bottles less likely to shatter and increases shelf life to up to six-month	http://www.nanocor.com/applications.asp http://www.forbes.com/investmentnewsletters/2005/08/09/nanotechnology-kraft-hershey-cz_jw_0810soapbox_inl.html?partner=rss
Nano Plastic Wrap	SongSing nanotechnology	Nano zinc light catalyst	Antibacterial, anti-uv, temperature resistant, fire proof	http://www.ssnano.net/ehtml/detail1.php?productid=73
Cadbury Schweppes: **• Cadbury® Dairy Milk™ Milk Tray™** **• Cadbury® Eden chocolate boxes** **• Shelf-ready packaging for the Cadbury® Fun Filled Freddo**	Plantic Technologies	Thermoformed Plantic® R1 trays (nano-composite biopolymer)	• Biodegradable after use • Compostable to European standards EN13432 • Made from renewable and sustainable resources (non-GM corn starch) • water dispersible, won't pollute local groundwater systems or waterways • In use since 2002.	http://www.plantic.com.au/docs/Plantic_Cadbury_CS.pdf
Marks & Spencer Swiss Chocolate Assortment	Plantic Technologies	Plantic Plastics	• Biodegradable after use • Compostable to European standards EN13432 • Made from renewable and sustainable resources (non-GM corn starch) • Certified safe for disposal in soil (by AIB-VINCOTTE)	http://www.plantic.com.au/docs/Plantic_MS_CS.pdf
Constantia multifilm N-Coat	Constantia multifilm	Nano-composite polymer	A clear laminate with outstanding gas barrier properties, developed primarily for the nuts, dry foods, and snack markets	http://www.constantia-multifilm.com/
DuPont™ Light Stabilizer 210	DuPont	Nano titanium dioxide	U.V.-protected plastic food packaging	http://www2.dupont.com/Titanium_Technologies/en_US/products/dls_210/dls_210_landing.html
Adhesive for McDonald's burger containers	Ecosynthetix	50-150nm starch nano-spheres	The adhesive requires less water and less time and energy to dry.	http://www.physorg.com/news71748835.html

Table 3: Nanomaterials in kitchen equipment/cooking

Product category	Product name	Manufacturer	Nano content	Claim	Web address or reference
Cleaning agent	**Baby bottle cleaning brush**	Kheo Sung World Inc	Nano silver		http://www.i-sangshin.com/
Cleaning agent	**Generic additive**	I&E	Nano silver	Also recommended for use in cooking equipment, crockery, food storage	http://nanoine.com/product/e_product01_1.php
Cleaning agent	**Ionic Zone Nano TiO2 PCO Liquid**	Ionic Zone	Nano titanium dioxide	A safe, highly tested, new product from Japan that also makes surfaces self-cleaning and resistant to odor, second hand smoke, etc.	http://www.air-purifiers-superstore.com/TiO2_catalyst_self_cleaning_liquid.html
Cleaning agent	**Nano Clean Spray**	ECOsmart AustralAsia P/L	Nano titanium dioxide	Once contact is made, the microbe is oxidized and dies instantly.	http://www.ecosmarte.com.au/nano/index.htm
Cleaning agent	**Nano silver colloid**	Nanogist, Co Ltd	Nano silver colloid		http://nanover.en.ecplaza.net/
Cleaning agent	**Nano silver dish wash**	Nanogist, Co Ltd	Nano silver	Exhibits excellent antimicrobial efficacy to a wide spectrum of microorganisms.	http://nanover.en.ecplaza.net/
Cleaning agent	**Nano silver disinfectant spray**	Nanogist, Co Ltd	Nano silver	NANOSILVER Disinfectant Spray can help protect your family by helping prevent the spread of harmful bacteria and controlling mould and mildew.	http://nanover.en.ecplaza.net/
Cleaning agent	**Nano silver hand sanitizer**	Nanogist, Co Ltd	Nano silver		http://nanover.en.ecplaza.net/
Cleaning agent	**Nano Silver Spray**	SongSing nanotechnology	Nano silver	Sterilization, deoderization	http://www.ssnano.net/ehtml/detail1.php?productid=75
Cleaning agent	**Nano silver wet wipes**	Nanogist, Co Ltd	Nano silver	Kills and removes wide spectrum of microorganisms	http://nanover.en.ecplaza.net/
Cleaning agent	**Nano silver wet wipes**	Nano Silver Wholesale Ltd.	Nano silver		http://www.nanosilverwholesale.com
Cleaning agent	**Nano-in Natural environmental cleaning agent**	Nano-Infiity Nanotech	Micelle product	Patents: U.S.No5, 244580, U.S.No5, 2441, 323, Invention No.56086, 57199, 65557, and 65654 Food class non-ionic surfactant, natural coconut oil and 100% orange oil.	http://www.nano-infinity.com.tw/product03.htm
Cleaning agent	**Washing up gloves**	Kheo Sung World Inc	Nano silver		http://www.misian.com/eng/sub/product_01.html
Cooking equipment	**GreenPan™ with ThermolonTM non-stick frypan**	HSN	Ceramic nano coating	Ceramic based, nano nonstick GreenPan™ Thermolon™	http://kitchen-dining.hsn.com/greenpan-w-thermalon-technology-6pc-cookware-set_m-10031074_xp.aspx
Cooking equipment	**Marble Durastone non-stick frypans and woks**	Joycook	Nano silver	Interior Nano Silver 5 Ply Coating - Marble Durastone	http://kitchenlines.com/product_info.php?products_id=37&osCsid=d0f8a8c4e4c737d5b9fdec11b1b9d475
Cooking equipment	**Nano silver cutting board**	A-Do Global	Nano silver	99.9% anti bacterial	http://www.adox.info/?doc=shop/item.php&it_id=000123
Cooking equipment	**Nano silver cutting board**	Nano Silver Wholesale Ltd.	Nano silver		http://www.nanosilverwholesale.com
Cooking equipment	**Nano Silver Teapot**	SongSing nanotechnology	Nano silver	Antibacterial	http://www.ssnano.net/ehtml/detail1.php?productid=74
Cooking equipment	**Non-stick self-assembling nanofilms for glass bakeware**	Nanofilm LTD	10nm film	Non-stick, long-lasting, contaminant releasing, non-staining, applied during OEM manufacture	http://www.nanofilmtechnology.com/products_name/reactive-glass.htm
Cooking equipment	**Oilfresh 1000**	Oilfresh Corp	nanoceramic catalytic pellets	Frying oil refining catalytic device designed to prolong freshness of oil while in use for deep frying significantly longer	http://www.oilfresh.com/of1000.html

Product category	Product name	Manufacturer	Nano content	Claim	Web address or reference
Crockery and cutlery	**Antibacterial Kitchenware**	NCT (Nano Care Technology)	Nano silver	Nano-silver based patented technology to be applied on the surface of products, providing antibacterial substance and hardness enhancement	http://www.nanocaretech.com/En_ArticleShow.asp?ArticleID=13
Crockery and cutlery	**Antibacterial Tableware**	NCT (Nano Care Technology)	Nano silver	Nano-silver based patented technology to be applied on the surface of products, providing antibacterial substance and hardness enhancement	http://www.nanocaretech.com/En_ArticleShow.asp?ArticleID=14
Crockery and cutlery	**Silver Nano Baby Milk Drink Bottle**	Baby Dream	Nano silver		http://babydream.en.ec21.com
Crockery and cutlery	**Silver Nano Baby Mug**	Baby Dream	Nano silver		http://babydream.en.ec21.com
Food cleaning agent	**Nano-in Natural Environmental Cleaning Agent**	Nano-Infinity Nanotech Co. Ltd	"Nano micelle product"	Nano micelle product containing natural glycerin	http://www.nano-infinity.com.tw/product03.htm
Food Storage	**Toppits Fix-Brat Alufolie**	Melitta	"Carbon in glass matrix"		http://www.melitta.info/cms/presse/pressedb/presse_artikel.php?table=1&kategorie=&search_string=&pm_ptid=1
Food Storage	**Food Container NS**	A-Do Global	Nano Silver	99.9% anti bacterial nano technology	http://www.adox.info/?doc=shop/list.php&ca_id=110
Food Storage	**Fresh Box Silver Nanoparticle Food Storage Container**	BlueMoonGoods	Nano Silver	Foods stay fresher longer in the BEST silver nano food container sold	http://www.bluemoongoods.com/silver_nanoparticle_food_containers.htm
Food Storage	**Nano Silver Food Storage Containers**	JR Nanotech Plc	Nano Silver		http://www.jrnanotech.com/consumer_goods.html
Food Storage	**Nano Silver Food Storage Containers**	Nano Silver Products	Nano Silver		http://www.nanosilverproducts.com/mm5/merchant.mvc?Screen=PROD&Store_Code=NSP&Product_Code=FSC12&Category_Code=
Food Storage	**Nano Silver Food Storage Containers**	Nano Silver Wholesale Ltd.	Nano Silver	They are newly developed antimicrobial food containers which are made by nano technology.	http://www.nanosilverwholesale.com/nano_silver_products.html
Food Storage	**Nano ZnO Plastic Wrap**	SongSing nanotechnology	Nano zinc oxide		http://www.ssnano.net/ehtml/detail1.php?productid=79
Food Storage	**Silver nano antibacterial bag**	WorldOne	Nano Silver	Silver Nano Antibacterial bags act as a safe and naturally anti-germ, anti-mold and anti-fungus agent.	http://www.worldoneusa.com/atibag.html
Refrigerator	**LG Refrigerator that incorporates Bioshield™**	LG Electronics	Nano silver, nano carbon	Bio silver and Bio shield, with nano-size silver particles, coat the interior of the refrigerator (Bio silver) and the gasket (Bio shield) of the refrigerator, thus perfectly preventing the intrusion of bacteria from outside	http://www.tokolg.com/promotion2.asp
Refrigerator	**Refrigerator**	Daewoo Industries	Nano Silver	Superior deodorant and antibiotic power, we have applied it to major parts of refrigerator in order to restrain the growth and increase of a wide variety of bacteria and eliminate odor	http://www.daewoo-electronics.de/eu/products/cool_ref_glos.asp
Refrigerator	**Refrigerator**	Hitachi	Nano titanium filter		www.hitachi.com.au
Refrigerator	**Samsung Refrigerator RS2621SW**	Samsung	Nano silver		http://www.samsung.com/Products/Refrigerators/SidebySide/RS2621SWXAA.asp

Table 4: Nanomaterials in foods and beverages

Product category	Product name	Manufacturer	Nano content	Claim	Web address or reference
Beverage	**Nano Tea**	Shenzen Become Industry & Trading Co	nanoparticles (160nm)	Patent No.: 01100033.3 - The three-step preparation method and its application for nanotea, Patent No.: 02100314.9/ 00244295.7 multi-layers swinging nano-ball milling procedures	http://www.369.com.cn/En/nanotea.htm
Beverage	**Nano Slim™**	Nano Slim	"Nano-DiffuseTM Technology"	Orosolic acid (derived from the *Lagerstroemia* speciosa plant)	http://www.nanoslim.com/nanoslim_information.shtml
Beverage	**Nanoceuticals Slim Shake Chocolate**	RBC Lifesciences	"NanoclustersTM"		http://www.rbclifesciences.com/Meal_Replacement_Shakes.aspx
Beverage	**Nanoceuticals Slim Shake Vanilla**	RBC Lifesciences	"NanoclustersTM"		http://www.rbclifesciences.com/Meal_Replacement_Shakes.aspx
Beverage	**Fortified fruit juice**	High Vive.com	300nm iron (SunActive Fe)		http://www.highvive.com/sunactiveiron.htm
Beverage	**"Daily Vitamin Boost" Fortified fruit juice**	Jamba Juice Hawaii	300nm iron (SunActive Fe)	22 essential vitamins and minerals and 100% or more of your daily needs of 18 of them!	http://jambajuicehawaii.com/vita-boost.asp
Beverage	**Oat Chocolate Nutritional Drink Mix**	Toddler Health	300nm iron (SunActive Fe)	"Toddler Health is an all-natural balanced nutritional drink for children from 13 months to 5 years. One serving of Toddler Health helps little ones meet their daily requirements for vitamins, minerals and protein"	http://www.toddlerhealth.net/OatChocolate.php
Beverage	**Oat Vanilla Nutritional Drink Mix**	Toddler Health	300nm iron (SunActive Fe)	"Toddler Health is an all-natural balanced nutritional drink for children from 13 months to 5 years. One serving of Toddler Health helps little ones meet their daily requirements for vitamins, minerals and protein"	http://www.toddlerhealth.net/OatVanillia.php
Food	**Canola Active Oil**	Shemen	Nano-sized self assembled structured liquids = micelles		http://www.shemen.co.il note: website only in hebrew.

Table 5: Nanomaterials in food additives

Product category	Product name	Manufacturer	Nano content	Claim	Web address or reference
Generic food additive	**AdNano**	Evonik (Degussa)	Nano Zinc Oxide (food grade)		www.advancednanomaterials.com
Generic food additive	**Aerosil, Sipernat**	Evonik (Degussa)	Silica (food grade)	Free flow aid for powdered ingredients in the food industry	www.areosil.com
Generic food additive	**AquaNova NovaSol**	Aquanova	Product micelle (capsule) of lipophilic or water insoluble substances	"An optimum carrier system of hydrophobic substances for a higher and faster intestinal and dermal resorption and penetration of active ingredients."	http://www.aquanova.de/product-micelle.htm
Generic food additive	**Bioral™ Omega-3 nano-cochleates**	BioDelivery Sciences International	Nano-cochleates as small as 50nm	Effective means for the addition of Omega-3 fatty acids for use in … cakes, muffins, pasta noodles, soups, and cookies… cereals, chips, and candy bars.	http://www.biodeliverysciences.com/bioralnutrients.html
Generic food additive	**NanoCoQ10®**	Pharmanex	Nano coQ10	Nano technology to deliver highly bioavailable coenzyme Q10 ...making them up to 10 times more bioavailable than other forms of CoQ10	http://www.pharmanex.com/intercom/productDetail.do?prodId=01003662&mktId=2031
Generic food additive	**Nano-self assembled structured liquids (NSSL)**	Nutralease	Nano micelles for encapsulation of nutraceuticals	Improved bioavailability means nutraceuticals are released into membrane between the digestive system and the blood	http://www.nutralease.com/technology.asp
Generic food additive	**Solu™ E 200**	BASF	Vitamin E nano-solution using NovaSol	Solubilsates of fat-soluble vitamins	http://www.human-nutrition.basf.com/downloads/SoluTM20E2020020flyer.pdf
Generic food additive	**Synthetic lycopene**	BASF	LycoVit 10% (< 200nm synthetic lycopene)	Manufacturer	http://www.human-nutrition.basf.com

Table 6: Nanomaterials in food/ health supplements

Product name	Manufacturer	Nano content	Web address or reference
Aufbau for Kids	Vitosofan	Nano zeolith plus vitamins	https://www.vitafosan.de/index.php?cPath=95&XTCsid=a61c8a23721d30b90bcd7917794de7f9
Bio-Sim	Nano Health Solutions	Nano silica	http://www.fulvic.org/html/nano_bio-sim.html
C.L.E.A.N Products (1-5)	SportMedix	Nanotechnological-based supplements	https://www.sportmedix.com/index.php?lang=english&page=products&sh_c=view_item&iid=8
Colloidal Silver Cream	Skybright Natural Health	Nano silver	http://www.skybright.co.nz
Colloidal Silver Liquid	Skybright Natural Health	Nano silver	http://www.skybright.co.nz
Crystal Clear Nano Silver	Nano Health Solutions	Nano silver	http://www.fulvic.org/html/nano_silver.html
LifePak Nano	Pharmanex	CR-6 LipoNutrients	http://www.pharmanex.com/corp/product/lifepak/lifepaknano.shtml
lifepak® nano, a multivitamin nutritional supplement	Pharmanex	Nano multivitamin	http://www.pharmanex.com/corp/pharmanews/pressreleases/11-30-05.shtml
Lypo-Spheric™ Vitamin C	Powell Productions	100-150nm "Smart" Liposomal Nano-Spheres™	http://healthspotlight.com/liposomal-encapsulation.html
Maat Shop Crystal Clear NanoSilver	Ma'at Shop	Nano silver	http://spiritofmaat.com/maatshop/n2_biosim.htm
Maat Shop Nano-2+	Ma'at Shop	Nano silver	http://spiritofmaat.com/maatshop/n2_biosim.htm
Maat-Shop Nano2Bio-Sim	Ma'at Shop	Nano diatomaceous earth	http://spiritofmaat.com/maatshop/n2_biosim.htm
Men Power	Vitosofan	Nano zeolith plus selenium and zinc	http://www.Vitasofan.de
Mesocopper	Purist Colloids	Nano copper	http://www.purestcolloids.com
MesoGold	Purist Colloids	Nano gold	http://www.purestcolloids.com
MesoIridium	Purist Colloids	Nano iridium	http://www.purestcolloids.com
MesoPalladium	Purist Colloids	Nano palladium	http://www.purestcolloids.com
MesoSilver	Purist Colloids	Nano silver	http://www.purestcolloids.com
MesoTitanium	Purist Colloids	Nano titanium	http://www.purestcolloids.com
MesoZinc	Purist Colloids	Nano zinc	http://www.purestcolloids.com
Nano Calcium/ Magnesium	Mag-I-Cal.com	Nanoparticles (<500nm)	http://www.mag-i-cal.com/calciummagnesium.htm
Nano Humic and Fulvic Acid	Nano Health Solutions	Nano humic and fulvic acid	http://www.fulvic.org/html/nano_humic___fulvic__acid.html
Nano Know how	Vitosofan	Nano zeolith	http://www.Vitasofan.de
Nano Silver dispersion	Nano Silver Technology	Nano silver	http://www.nanobiosilver.com/index.html
Nano-2+	Nano Health Solutions	Unspecified - nanoscale minerals, amino acids and enzymes	http://www.fulvic.org/html/nano2_.html
Nanoceuticals Artichoke Nano Cluster	RBC Lifesciences	"Nanoclusters™"	http://www.rbclifesciences.com/Products.aspx?ItemID=118
Nanoceuticals Hydracel	RBC Lifesciences	Unspecified - nanoscale minerals, amino acids and enzymes	http://www.rbclifesciences.com/Nanotechnology_Revolution.aspx
Nanoceuticals Mycrohydrin Powder	RBC Lifesciences	Mycrohydrin	http://www.rbclifesciences.com/Nanotechnology_Revolution.aspx
Nanoceuticals Silver 22	RBC Lifesciences	Nano silver	http://www.rbclifesciences.com/Products.aspx?ItemID=123
Nanoceuticals Spirulina Nanoclusters	RBC Lifesciences	"Nanoclusters™"	http://www.rbclifesciences.com/Nanotechnology_Revolution.aspx
NanoSil -10	Greenwood Consumer Products	Nano silver	http://www.nanosil10.com/index.html

Table 6: Nanomaterials in food/ health supplements (continued)

Product name	Manufacturer	Nano content	Web address or reference
NanoTrim	NanoNutra™ Labs	Molecular weight loss solution formulated with nano	http://www.nanonutra.com/nanotrim.html
Natural-immunogenics co	Sovereign Silver	Colloidal silver hydrosol	http://www.natural-immunogenics.com/silver_why_sovereign.php
Nutri-NanoTM CoQ-10 3.1x Softgels	Solgar	Using NovaSol	http://www.naturalgoodnessmarket.com/list2.cfm?cat=60 or http://www.solgar.com/Products/Specialty-Supplements/Coenzyme-Q-10.aspx
Ortho-Iron	Advanced Orthomolecular Research	300nm iron (SunActive Fe)	http://www.aor.ca/int/products/ortho_iron.php
Silvix3	NaturalCare	Nano silver	http://www.enaturalcare.com/prod_silv.html
Spray for Life Vitamin Supplements	Health Plus International	Nano-droplets of various vitamins	http://www.healthplusintl.com/products.html
Toxi-Drain	Vitosofan	Nano zeolith plus herbs	http://www.Vitasofan.de

Appendix B: Summary of EU regulations applicable to the use of nanotechnology in the food sector

EU Regulation/ Directive	What does it cover	What are the gaps	Website
EU 258/97 EU novel foods regulation 258/97	• Foods & novel food ingredients not consumed before the 15th of May 1997	• Does not cover material that has an established history of food use • Does not cover particle size	http://europa.eu/scadplus/leg/en/lvb/l21119.htm
EU 178/2002 The general safety article of the EU Food Law Regulation	• Food traceability • Food safety	• Too loose	http://ec.europa.eu/food/food/foodlaw/traceability/index_en.htm
EC 97/618 Framework for scientific assessment of novel foods	• Scientific assessment procedures for Regulation (EC) No 258/97	• Doctrine of substantial equivalence a concern	http://eur-lex.europa.eu/smartapi/cgi/sga_doc?smartapi!celexapi!prod!CELEXnumdoc&lg=EN&numdoc=31997H0618&model=guichett
Directive 89/107 EU Food Additive Use Directive	• Food additive	• List of permitted additives does not specifically cover particle size	http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/consleg/1989/L/01989L0107-20031120-en.pdf
EU 94/36 Regulation on colours for use in foodstuff	• Colours for use in food stuff	• List of permitted colours does not specifically cover particle size	http://eur-lex.europa.eu/smartapi/cgi/sga_doc?smartapi!celexdoc!prod!CELEXnumdoc&numdoc=31994L0036&model=lex&lg=en
EU 1935/2004 EU Food Packaging Regulation	• Must comply with food labelling laws • Must not be misleading • Active ingredients must comply with 89/107	• Does not cover particle size	http://eur-lex.europa.eu/LexUriServ/site/en/oj/2004/l_338/l_33820041113en00040017.pdf
Directive 91/414 Directive 79/117 EC Regulation No 396/200	• Pesticide regulations covering plant based products	• Needs to cover nano-formulations	http://ec.europa.eu/food/plant/protection/index_en.htm
Directive 98/8/EC, Directive 76/769/EEC.	• Regulations covering biocidal products	• Needs to cover nano-formulations	http://ec.europa.eu/environment/biocides/index.htm

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