NANOMATERIALS

UNDERSIZED, UNREGULATED & ALREADY HERE

CW corporate watch report 2007

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Corporate Watch

Corporate Watch is an independent not-for-profit research and alternative media group, founded in 1996. It aims to investigate the social and environmental impact of transnational corporations and the mechanisms by which corporations accumulate and maintain power. Corporate Watch runs an alternative news service as well as research projects on supermarkets, privatised services, corporate technologies, nuclear power, corporate power, and the public relations industry.

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printed on 100% post consumer recycled paper by Oxford Green Print
www.oxfordgreenprint.com

layout & graphic design by jean paldan @ rareformnewmedia.com

INTRODUCTION

Ever Heard of Nanotechnology?
Chances are you are already rubbing it into your skin, wearing it and maybe even eating it. Far from being science fiction, nanotechnology is a commercial reality and already in the shops. From car polish to bandages, washing machines to waterproofs and makeup to bicycles, over 100 products based on engineered nanomaterials are on sale in the UK.

Is it Safe?
Not necessarily. The rush to commercialise nanomaterial products has outpaced research into their safety. There is a growing body of evidence to suggest that nanomaterials pose a unique and at present poorly understood range of toxicity problems. How nanomaterials will impact on human health and the environment is far from understood. Beyond issues of toxicity there are also concerns about the wider social and economic impacts of nanomaterials.

Is it Regulated?
Not really. Just as nanomaterial commercialisation has overtaken research into safety, it has also left the regulators lagging behind. Nanomaterials currently exist in a regulatory vacuum with no laws in the UK, or anywhere else in the world, to deal with the specific set of problems they raise. Despite this, over 100 products are already on the market, unlabelled and effectively unregulated.

This briefing gives an overview of the first generation of commercial nanotechnology products available in the UK.

The briefing explains:

- what nanotechnology and nanomaterials are;
- how and why nanomaterials are made;
- which companies are developing and manufacturing them.

We have identified a range of consumer products in which nanomaterials are already being sold, including:

- sunscreens
- cosmetics
- clothing
- construction materials
- sports equipment
- health care products
- food packaging

The briefing also outlines some of the toxicity dangers and potential social and environmental issues associated with nanomaterials, and reviews the state of nanomaterial regulation in the UK.

WHAT IS NANOTECHNOLOGY?

Nanotechnology is the manipulation of matter at a size so small that it is measured in nanometres (one billionth of a metre), the scale of atoms and molecules.

When talking about nanotechnology its useful to contrast it with another recent technology, 'biotechnology'. The 'bio' part of biotechnology refers to what the technology is dealing with, i.e. bios or life, where as with nanotechnology the 'nano' refers not to a thing, but to the scale at which the technology takes place.

Definitions:

Atom (For more information see *http://en.wikipedia.org/wiki/Atom*)
An atom is a microscopic structure found in all ordinary matter around us.
Atoms are the fundamental building blocks of chemistry, and are conserved in chemical reactions. An atom is the smallest particle differentiable as a particular chemical element. 94 elements occur naturally on Earth. Another 23 synthetic elements can be created in nuclear reactors. All 117 elements are recorded in the periodic table, for example carbon, oxygen, gold and lead.

Molecule (For more information see *http://en.wikipedia.org/wiki/Molecule*)
Atoms are able to bond together into molecules and other types of chemical compounds. Molecules are made up of multiple atoms. A molecule of water is a combination of 2 hydrogen and one oxygen atoms. A molecule is the smallest particle of a pure chemical substance that still retains its chemical composition and properties. It may consist of atoms of the same chemical element, as with oxygen gas (O_2), or of different elements, as with water (H_2O). Examples of molecules are titanium dioxide and iron oxide.

Nanotechnology (For more information see *http://en.wikipedia.org/wiki/Nanotechnology*)
Nanotechnologies involve the design, characterisation, production and application of structures, materials, devices and systems by controlling shape and size at sizes below 100 nanometres

The Nanoscale
It is difficult to grasp quite how small the nanoscale is. To give some points of reference one nanometre (nm) is one billionth of a metre, one millionth of a millimetre, a human hair is 80,000nm thick, a red blood cell is 5,000nm in diameter a DNA molecule is 2.5nm wide and it takes 10 hydrogen atoms arranged side by side to measure 1nm wide.

The nanoscale is not new. It has always existed, though until recently it has been out of the sight, and reach, of human beings. Unaided, the human eye can't see anything much smaller than one tenth of a millimetre wide. Over the last few hundred years optical microscopes have been developed that allow humans to see objects down to the scale of microns (1,000nm - things such as bacteria and viruses). The invention and development of scanning probe microscopes over the last 20 years has allowed humans to first of all see, and then to manipulate matter at the nanoscale.

What is so exciting about the nanoscale?

The nanoscale is special in two ways:

1.Everything is the Same

When viewed at the nanoscale the whole world starts to look the same. Everything on this planet, both living and non-living, is made up of atoms and molecules, and at the nanoscale that is all you see. The paper this briefing is printed on, or the computer screen you are reading it from, the trees you can see from the window, and the glass in the window, your cat and even you yourself, everything is made up of atoms and molecules arranged in different combinations and structures. At the nanoscale it becomes possible to rearrange atoms and molecules to make new structures.

2. Things Behave Differently

The other important feature of the nanoscale is that substances start to behave very differently when they are made very small. Below about 100nm the rules that govern the behaviour of the elements of our known world start to give way to the rules of quantum physics, and everything changes. To take the example of gold: at the everyday macro scale gold is a familiar shiny orangey/yellow colour. The same is true of a particle of gold 100nm wide, but a particle of gold 30nm across is bright red. Slightly bigger than that it is purple and smaller still it is brownish in colour.

Not only colour changes at the nanoscale. Other properties including strength, chemical reactivity, conductivity and electronic properties also change as size decreases. These new nanoscale characteristics have industrial applications.

WHAT ARE NANOMATERIALS?

The first commercial applications of nanotechnology are already with us. One of the first areas of research to be transformed by it has been materials science - the study, design and manufacture of new materials. In particular research and industrial activity has focused on the design and manufacture of nanomaterials, materials measuring less than 100nm in any one dimension.

Natural Nanomaterials
As with the nanoscale, there is nothing new about nanomaterials per se. Natural processes including wind-whipped sea-spray and natural sources of extreme temperature like volcanoes, lightning strikes and forest fires all create small quantities of natural nanoparticles.

Accidental Nanomaterials
Ever since humans first started deliberately using fire they have also been inadvertently making nanoparticles. The accidental manufacture of nanoparticles increased enormously with the onset of the industrial revolution and even more so with the widespread use of the internal combustion engine. In fact, it was the study of air pollution in the form of ultra-fine, or nanoscale, particles from vehicle exhaust fumes that first started ringing alarm bells about the potential for toxicity problems with engineered nanoparticles.

Deliberate Nanomaterials
Chemical companies have long been deliberately making substances with a very small particle size that would now fall under the definition of nanomaterials. However, when these chemicals were first made no-one could actually see precisely what they were making and the resultant particles were of varying shapes and sizes. Examples of deliberate nanoparticles include: carbon black (a kind of soot) whose particle size typically falls between 400 and 10nm and which is used in tyres, rubber, plastics, pigments and printer toners; and silica fume (a byproduct of making silicon metal and alloys) which is used as an additive to cement, foods, plastics and pharmaceuticals. With the advent of the scanning probe microscope the size and shape of deliberately made nanomaterials such as carbon black and fumed silica can be more closely controlled.

Engineered Nanomaterials
It wasn't until the invention of the scanning probe microscope in the early 1980s that the lights were effectively turned on at the nanoscale. This has enabled both the imaging and the precise control of the size, shape and surface characteristics of materials at the nanoscale, and with it the manufacture of engineered nanomaterials.

Why are They Made?
Nanoscale engineering has vastly expanded the conventional range of possibilities offered by the elements of the periodic table. Engineered nanomaterials open up a whole new world of possible applications and product opportunities across all sectors of the economy: smaller and faster computers; drugs that permeate the body more effectively and can target specific cells; more reactive catalysts (used to speed up chemical reactions); more powerful explosives; more precise sensors; stronger lighter materials.

EXAMPLES OF ENGINEERED NANOMATERIALS[1]

Nanoparticles

Nanoparticles can currently be made from a wide range of materials. These include single elements such as iron, silver and carbon; simple molecules such as titanium dioxide and zinc oxide; through to complex molecules such as pharmaceuticals. A number of different methods are used to make nanoparticles, including high temperature processes, chemical reactions and attrition (milling or grinding). Nanoparticles are made in a range of shapes and sizes.

Current commercial applications for nanoparticles include; use in sunscreens/ and ultra-violet (UV) filters (titanium dioxide (TiO_2) and zinc oxide (ZO); explosives (aluminium); pigments (iron oxide) and anti-microbial finishes (zinc oxide/silver). At their simplest, nanoparticles are just nanoscale particles of a single substance. More complex nanoparticles may have been engineered to be a certain shape or be a combination of two or more substances, for example one material coated in another, such as silicon coated or 'doped' titanium dioxide for sunscreens.

Fullerenes

Fullerene is a generic term used to describe carbon nanoparticles that take the form of hollow spheres or tubes. Fullerenes are similar in structure to graphite. Whereas graphite is composed of flat sheets of carbon atoms arranged in hexagons, fullerenes contain different arrangements of carbon atoms, which enable three dimensional structures to be formed. The smallest and most common fullerene, C_{60}, is a football shaped sphere of sixty carbon atoms arranged in hexagons and pentagons, also known as the Buckminster fullerene or buckyball. Fullerenes are manufactured using high temperature processes.

Nanotubes

The name 'Nanotube' describes a particular form of fullerene, again most commonly made of carbon. Nanotubes are similar in structure to C_{60} but are elongated to form a tubular structure 1 to 2 nm in diameter and up to millimetres in length. At their simplest, nanotubes are a single layer of carbon atoms arranged in a cylinder (single-wall carbon nanotubes). They can also consist of multiple concentric tubes (multi-wall carbon nanotubes) with diameters up to 20 nm, and length greater than 1 mm.

Carbon nanotubes have a number of interesting properties. They are very strong (100 times stronger than steel), very light (one sixth the weight of steel) and they have unique electrical properties (10 times more conductive than copper). A wide range of applications are currently being developed for carbon nanotubes including additives to plastics and other composites (to increase strength and conductivity), flat panel displays and energy storage (batteries and fuel cells).

Quantum dots

Quantum dots are nanoscale crystals (ranging from 1000 to 10,000 atoms in size) of semi-conductors, metals or metal oxides. They have novel electronic, optical, magnetic and cat-alytic properties. Most research has focused on semiconductor quantum dots whose colour can be fine tuned by altering their particle size through careful control of their growth. Quantum Dots have potential medical applications as drug carriers or imaging agents. They are also being developed as nanoscale security tags.

Nanocapsules

Although beyond the definition of simple nanoparticles, nanocapsules (also known as nanoscale liposomes or sometimes "nanosomes") are another nanoscale invention that is already being incorporated into products on the market. Nanocapsules are small droplets of liquid, often slightly bigger than nanoscale, enclosed in a nano-thickness shell. Nanocapsules are essentially a delivery mechanism designed to get an active ingredient to a specific loca-tion and then to release their contents only under certain conditions. Currently they are used in cosmetics to deliver nutrients deeper into the skin, in some pesticide formulations and as ingredients in some foods and drinks. They are also being developed for use in pharmaceuticals.

WHO MAKES ENGINEERED NANOMATERIALS?

At present no one type of company typifies the emerging global nanomaterials industry. Crudely the industry can be divided into three types of company:

1. The old giants of the chemical industry for whom nanomaterials are just one of a large number of diverse business areas.
2. Smaller but already established speciality chemical companies of various sizes, already geared to making bulk quantities of specialist chemicals, for whom nanomaterials have been an obvious area to move into.
3. A new generation of smaller nano-specific companies often created to commercialise academic research.

TABLE 1. Some examples of major global manufacturers of engineered nanomaterials:

NAME	TYPE	COUNTRY	PRODUCTS
Bayer	Big Chemical	Germany	Bulk production of Baytube carbon nanotubes
BASF	Big Chemical	Germany	Bulk production of various nanomaterials (uses include food additives and sunscreen)
Degussa	Big Chemical	Germany	Bulk production of a range of ultrafine and nanomaterials
ICI/Uniquema	Big Chemical	UK	Bulk production of nanomaterials (including nanoparticle titanium dioxide for sunscreens)
Mitsubishi Chemical/	Big Chemical	Japan	Bulk production of carbon nanotubes
Advanced Nanomaterials	Nano Specialist	Australia	Bulk production of a range of nanomaterials (uses include sunscreens, catalysts, cosmetics and coatings)
Nanogist	Nano Specialist	South Korea	Bulk production of nanomaterials (anti microbial silver nanoparticles)
QinetiQ Nanomaterials	Nano Specialist	UK	Bulk production of a range of nanomaterials
NanoPhase	Nano Specialist	US	Bulk production of a range of nanomaterials
Hyperion Catalysis	Nano Specialist	US	Nanotubes for incorporation into plastics

NAME	TYPE	COUNTRY	PRODUCTS
Carbon Nanotechnologies Inc	Nano Specialist	US	Bulk production of carbon nanotubes
Umicore	Speciality Chemical	Belgium	Bulk production of nanomaterials (including nanoparticle titanium dioxide for sunscreens)
Elementis	Speciality Chemical	UK	Bulk production of nanomaterials (including nanopartical zinc oxide for sunscreens)

There are several steps that span the process from the design of a nanomaterial at a lab bench to finished product in a supermarket. As a result a nanomaterial product may involve a number of different companies in its manufacture. For example, UK nanomaterials company Oxonica design and market their products leaving manufacture to be done under license by other companies. Their main products are a fuel additive (Envirox as used by Stagecoach buses) and a sunscreen ingredient (Optisol as used by Boots in their Soltan range).

TABLE 2. Lab bench to finished product:

PRODUCT	**Optisol** titanium dioxide based sunscreen	**Envirox** cerium oxide based fuel additive
DESIGN & PROTOTYPING	Oxonica (UK)	Oxonica (UK)
BULK PRODUCTION	Umicore [2](Belguim)	Advanced Nanotechnologies (Australia)[3]
INTEGRATION OF NANOMATERIAL INTO FINAL PRODUCT	uncertain	Advanced Nanotechnologies (Australia)
MARKETING	Oxonica/Croda	Oxonica/ Rozone Limited
END USER	Boots 'Soltan' sunscreen	Stagecoach

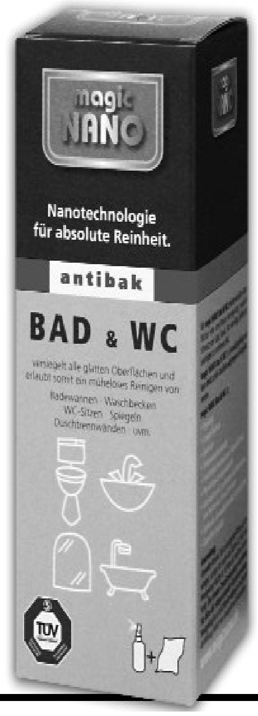
WHO USES NANOMATERIALS?

Engineered nanomaterials are manufactured in the UK (see appendix 1 for details of some UK nanomaterial manufacturers) and are imported both as raw materials and in finished products.
Nanomaterials are used by a wider range of industries and have many potential end uses from explosives to pharmaceuticals; from make-up to bicycles. The following investigation has been deliberately limited to focus on consumer products containing engineered nanomaterials currently available to the public in the UK.

Which Products Contain Engineered Nanomaterials?
Several factors make it hard to accurately assess the number of products containing engineered nanomaterials currently being sold in the UK.
At present there is no requirement for products containing nanomaterials to be labelled. Therefore it is only possible to identify products that proactively use their nanomaterial ingredients as a promotional feature, or when the inclusion of a known nanomaterial in a new product has been actively publicised. The identification of nanomaterial products is further complicated by 'nanohype' the deliberate use of nanotechnology related terms to market products that are at best only tangentially connected to nanotechnology, for example the Apple iPod nano.

Magic Nano: Not so magic and not so nano?

At the end of March 2006 a cleaning spray, "Magic Nano" sold by German company Kleinmann GmbH, became the first 'nano' product to ever be withdrawn from the shelves because of health fears. Shortly after the product's launch 79 people in Germany were taken ill after accidentally inhaling the spray. The product claimed to protect surfaces by coating them in silicon nanoparticles[4] . As no problems were encountered with non-aerosol versions of the product suspicion focused on the propellant used in the spray for causing the breathing problems rather than any nano ingredients[5] . It is now unclear if the product ever contained nanoparticles in the first place. An analysis of Magic Nano conducted by a German chemical industry body claims to have failed to find any nanoparticles in the product[6] . Magic Nano is the highest profile case to date of the misleading use of the 'nano' prefix to sell a product. The confusion over Magic Nano has strengthened calls for the mandatory labeling of products containing engineered nanomaterials[7].



Whilst it is relatively easy to identify nanoscale raw materials in manufacturer's publicity, it is much harder to find out which consumer products those raw materials are ultimately incorporated into. Commercial confidentiality and fear of a consumer backlash has made some companies unwilling to discuss their use of nanomaterials. Several of the larger cosmetics and clothing companies particularly, when contacted by Corporate Watch, were very evasive about their use of nanomaterials.

ENGINEERED NANOMATERIALS IN UK CONSUMER PRODUCTS

Table 3 (centre spread) was compiled through web searches, directly contacting companies, and by checking products listed in existing nanoproduct inventories[8] for current availability in the UK. Many of the 87 entries are for product lines (which span multiple products) making at least one hundred different nanomaterial products currently available in the UK. This figure is likely to be a vast underestimate and the contents of table 3 should be taken as an indication of the range of nanomaterial products currently available in the UK rather than an comprehensive list.

A recent global inventory of "Nanotechnology Consumer Products" compiled by the Woodrow Wilson Institute lists over 300 products. A survey by the Environmental Working Group lists 256 cosmetic products with nanoscale or micronised ingredients in US cosmetics products alone.

OTHER NANOTECHNOLOGY PRODUCT INVENTORIES:

Woodrow Wilson Institute:
Project on Emerging Nanotechnologies, Inventory of Nanotechnology Consumer Products available on line at
http://www.nanotechproject.org/44

Environmental Working Group:
'256 personal care products with nanoscale or micronized ingredients' available online at
http://ewg.org/issues/cosmetics/20061010/table2.php

Friends of the Earth Australia:
'Nanomaterials, sunscreens and cosmetics: Small ingredients, big risks' available online at
http://nano.foe.org.au/node/100

Sunscreens

The use of nanoparticle titanium dioxide and zinc oxide as ultra violet (UV) filters in sunscreens has become increasingly common. Micronised (ie bigger than nanoscale) particles of titanium dioxide and zinc oxide have long been used in sunscreens. Their ability to reflect the entire spectrum of light, including the harmful ultraviolet range, is what has traditionally given sunscreens their opaque white look. Improved manufacturing techniques have made it possible to finely control the size of titanium dioxide and zinc oxide particles. By making particles whose size is consistently smaller than the wavelength of the visible spectrum of light it has become possible to make titanium dioxide and zinc oxide particles that are transparent to the eye yet still retain their UV reflecting properties.

Research by Corporate Watch suggests that the use of nanoparticle titanium dioxide and zinc oxide in sunscreens has become widespread in the UK. During the course of our research few[9] of the sunscreen companies contacted denied using nanoparticle titanium dioxide or zinc oxide in their sunscreen formulations.

The transparent but UV reflective properties of nanoparticle titanium dioxide and zinc oxide are also used in a number of other cosmetics, such as foundation creams and moisturisers[10] .

Cosmetics

The use of nanomaterials in cosmetics is increasing. Companies including: L'Oreal, Johnson & Johnson and Estee Lauder use nanocapsules, often called "Nanosomes", to deliver active ingredients deeper into the skin.

Nanoparticles are used for a wide range of purposes in cosmetics including as colourings,[11] for example iron oxide in lipstick[12] and in artificial tanning products. A particularly worrying trend, given concerns about their safety (see box on Buckyballs and Brain Cells), is the use of C_{60} fullerenes as an antioxidant in cosmetic products, for example Zelens day and night cream.

For a more detailed examination of nanomaterials in cosmetics and sunscreens see FoE Australia's report 'Nanomaterials, Sunscreens and Cosmetics: Small ingredients, big risks' available online at http://nano.foe.org.au/node/100

Clothing

A number of nanomaterial based fabrics have been developed with improved stain resistance and moisture-wicking properties. The use of nanomaterials in clothing is dominated by US company Nano-Tex. Their fabrics, based on an unspecified nanomaterial, are used by a number of UK high street brands including GAP, Next and Marks & Spencer.
Other manufacturers of nanoparticle fabrics include Schoeller ("Nanosphere" silicon nanoparticles), as used by Howies and others, and Sympatex ("Reflexion" aluminium nanoparticles).

Construction Materials, Coatings and Paints

Pilkington make Activ, a self-cleaning glass coated with a 15 nanometre thick layer of Titanium dioxide which, when exposed to sunlight, burns dirt off the surface of the glass so that it washes off with rainwater. German tile company Agrob Buchtal use a similar technology in its Hydrotect interior and exterior tiles. Other nanomaterial coatings sold elsewhere in Europe include self-cleaning and protective finishes for bathrooms, kitchens and roof tiles. German company Bioni recently started to sell a range of mold-resistant interior and exterior paints which incorporate silver nanoparticles.

GREEN NANO?

Green nanomaterials? It's not only the usual suspects that are using nanomaterials. A number of companies that promote themselves as being 'environmentally friendly' or 'organic' have started to use engineered nanomaterials in their products. Cosmetics companies from the Body Shop to Neal's Yard to Green People[13] all use either titanium dioxide or zinc oxide nanoparticles in their sunscreens. 'Ethical' clothing company Howies use Schoeller's 'Nanosphere' silicon nanoparticle finish on some of their outdoor clothing[14]. Given the unresolved human health and environmental concerns about engineered nanomaterials, can their use, and (in the case of Howies) active promotion, be considered environmentally responsible?

Sports Equipment

Engineered nanomaterials are used in several different types of sporting equipment. This includes 'nanoclays' used to make tennis and golf balls more airtight, thus retaining their bounce longer, and carbon and titanium fullerenes/nanotubes used to strengthen tennis rackets, hockey sticks, snowboards and bicycle components.

Healthcare, Personal Hygeine and Cleaning Products

The most common use of nanomaterials in this sector uses the antibacterial properties of nano-particle silver. The most prominent product in this area is Smith and Nephew's Acticoat range of wound dressings. UK/Korean company JR Nanotech sell silver nanoparticle coated, 'sole fresh' odour resistant socks. The company also has plans to extend their range of products to sanitary towels.
Although not yet available in the UK, Henkel has recently launched 'Theramed S.O.S. Sensitive', a toothpaste containing calcium phosphate nanoparticles[15].

Transport for London is planning to use a spray-on nanoparticle silver/ titanium dioxide coating on furnishings on all London Underground trains as an anti-flu measure[16].

Domestic Appliances
Several manufacturers of domestic appliances including, Samsung, LG and Daewoo use the antibacterial properties of nanoparticle silver in their washing machines, vacuum cleaners, refrigerators and air conditioning units. See box on "Nano regulation elsewhere" for more information on US moves to regulate nanosilver washing machines.

Transport

Fuel Additives
As mentioned above Oxonica make Envirox a nanoparticle cerium oxide based fuel additive used by the entire Stagecoach UK bus fleet. Oxonica claim that Envirox cuts exhaust particulate emissions and reduces fuel consumption.

Coatings and Finishes
Mercedes Benz use ceramic nanoparticles in the ClearCoat finish on the paintwork of many of its luxury cars. Several 'off the shelf' car polishes including Turtle Wax contain silicon or zinc oxide nanoparticles.

Suspension
The Audi TT uses magnetic nanoparticles in shock absorbers in its suspension system.

Composites
Potentially the largest, but hardest to track, use of nanomaterials in transport is in vehicle body parts and components. While it has been possible to find references to the use of nanomaterials in this area it has proved hard to link it to currently available vehicles in the UK. US company Hyperion Catalysis has been adding multi-walled carbon nanotubes or Fibrils to plastics since the 1980s. These plastics, with increased strength and conductivity, have, according the nanotechnology industry press, been used to make mirror casings for Ford cars, and by third party manufacturers, and to make static dissipating fuel-lines[17]. Both Toyota and General Motors have in the past publicised their use of 'nano-composites' in vehicle components[18].

Food Packaging
Another use of manufactured nanomaterials that is hard to link to currently available products is in food packaging. Uses for nanomaterials in this area include packaging with reduced permeability to oxygen, and carbon dioxide, and UV filters. It is relatively easy to identify nano raw materials, and food packaging products based on them (for example Durethan membrane made by Lanxess[19] and Aegis drinks bottles made by Honeywell[20]), but much harder to identify their end use on supermarket shelves. Although it has not been possible to define the extent of their use in the UK it is considered likely that nanomaterials are used in UK food packaging. We have only been able to identify one nanomaterial food packaging product currently available in the UK; a range of antibacterial nano-silver food containers sold by JR Nanotech.

Food
A major potential area of use for nanomaterials that does not feature in table 3 is food and drink. The Woodrow Wilson Institute product inventory lists a handful of food and dietry supplement products containing engineered nanomaterials. This includes nutritionally enhanced cooking oils, chocolate drinks and vitamin supplements. None of these specific products appear to be currently available in the UK.

As with several of the product areas discussed above, due to a lack of labelling of nano ingredients, and, specifically with the food companies, due to industry fears of a rerun of the public rejection of GM foods, it is difficult to accurately assess the extent to which engineered nanomaterials are actually used in food products in the UK. While examples of engineered nanoscale food ingredients (such as BASF's nanoparticle synthetic lycopene, used as a food colouring) are identifiable as raw materials, it is hard to identify the final products they are ultimately incorporated into. Several large food companies including Mars, Kraft and Unilever are all conducting research into food applications of nanomaterials.

WHAT ARE THE PROBLEMS?

Nanotoxicity
The commercial allure of nanomaterials has been their ability to open up a world of potential new applications. As discussed above, shrinking the size of a material to the nanoscale can produce vastly different properties. However, just as this is true for desirable properties, such as colour, strength and conductivity, it is also true of undesirable properties such as toxicity. A substance that is normally considered to be inert and non-toxic at a larger scale may become toxic when produced at the nanoscale.

Concerns about engineered nanomaterials were first raised by toxicologists who had been studying the health impacts of accidental and manufactured particles in air pollution (for example, vehicle exhaust and incinerator emissions) and in the workplace (for example, asbestos fibres, welding fumes and carbon black). Their research had already established that there was a general relationship between decreased particle size, and increased potential for toxicity[21]. The fact that some of the new engineered nanomaterials bore a striking resemblance to these older materials started to ring alarm bells[22].

The small size of nanomaterials affects their potential to be toxic in two ways:

Increased Mobility
For the vast majority of our evolutionary history, human beings (and other organisms) have hardy ever been exposed to nano-sized particles. Consequently our bodies are ill-equipped to recognise and deal with them. Nanoparticles are far more able than larger particles to evade the body's protective mechanisms. There is a growing amount of evidence suggesting that nanoparticles are able to enter the body via inhalation, ingestion and possibly through the skin, especially if it is damaged[23]. Once inside the body nanoparticles (dependent on their size) are then able to penetrate many internal barriers, including the blood-brain barrier and the placenta, and so enter the body's organs, tissues and cells.

Increased Reactivity
As well as becoming more mobile in the body as their size decreases, the reactivity of particles also increases. As a particle is made smaller the ratio of its surface area to its volume increases; proportionally more of the substance becomes available for chemical reactions, hence reactivity is increased. Increased reactivity in nanomaterials raises their potential to be toxic to the human body.

'There is evidence that UFPs [Ultra Fine Particles or nano-particles] can gain entry to the body by a number of routes, including inhalation, ingestion and across the skin. There is considerable evidence that UFPs are toxic and therefore potentially hazardous. The basis of this toxicity is not fully established but a prime candidate for consideration is the increased reactivity associated with very small size.
Professor Vyvyan Howard (School of Biomedical Sciences,
University of Ulster and Editor of the Journal of Nanotoxicology)[24]

Beyond size and surface area, factors such as surface chemistry, solubility and shape can also influence the toxicity of nanomaterials. Recent work has indicated the potential for a range of different engineered nanoparticles to cause inflammation and damage to cells, tissues and organs, potentially acting as a precursor to serious disease.

The degree and type of risk posed by nanomaterial based products is likely to vary both from product to product, and throughout the different stages of a product's lifecycle.

A composite material strengthened with carbon nanotubes (be it a car bumper, a tennis racket or a bicycle) is unlikely to pose a risk to its owner as a new, finished product. The nanotubes will be tightly bound up within a matrix of other materials. Times of higher risk occur at either end of the product's lifecycle: during manufacture, modification and; or disposal when both workers and the environment may be exposed to free (unbound) nanotubes.

The pattern of risk will be different for a cosmetic product containing engineered nanoparticles (such as C_{60} buckyballs or titanium dioxide). Again workers and the environment are likely to be exposed to 'free' nanoparticles during the product's manufacture. The finished product will also present a risk to the general public whilst wearing the product via exposure to free (or at best very loosely bound) nanoparticles, through skin contact and accidental ingestion or inhalation. The product will also be released to the environment when washed off, and when any remaining product is disposed of.

BUCKYBALLS AND BRAIN CELLS

In a 2004 study[25,26], fish exposed to a solution of fullerenes (C_{60} buckyballs) developed an increased level of brain tissue damage. Water fleas exposed to a weaker solution were killed .

In a 2006 study[27], cell cultures of mouse microglia (protective cells from the brain and central nervous system[28]) produced increased levels of 'reactive oxygen species' over a prolonged period of time, when exposed to 30nm titanium dioxide nanoparticles (similar to those used commercially in sunscreens). In a real-life scenario this would have the potential to cause 'oxidative stress' damaging surrounding brain tissue, which has been linked to some neurodegenerative diseases such as Parkinson's and Alzheimer's disease.

The term 'engineered nanomaterials' covers a wide range of different substances, in various forms, and at different sizes, not all of which will necessarily prove to be dangerous. Manufactured nanomaterials are being produced in increasing quantities, incorporated into an ever-increasing number of commercial products and as a result increasingly released into the environment in waste streams. However, against this backdrop there is still a dearth of information about the toxicological implications of manufactured nanomaterials for both humans and the wider environment[29]. At present scientists have yet to develop standard language, measurements and methodologies to describe, test and evaluate nanomaterials and their toxicity.

BEYOND NANOTOXICITY

Beyond nanotoxicity there are a number of concerns about the potential social and economic impact of engineered nanomaterials.

Nano Patents and Nano Monopolies[31]

Nanomaterials may have opened a new world of potential applications but in doing so they have also opened a new arena for corporate ownership and control. Just as biotechnology's ability to identify and manipulate genes went hand in hand with the patenting of life, so too nanotechnology's ability to engineer at the nanoscale has led to the patenting of matter. Recent years have seen a rush to claim patents at the nanoscale.

Corporations are already taking out broad ranging, monopolistic patents at the nanoscale, effectively ring-fencing key nanomaterial technologies as they emerge. For example IBM, NEC and Hyperion Catalysis own fundamental patents for methods of production of Carbon Nanotubes. Essentially, anyone wishing to work in these fields has to pay a license fee back to the original patent holder.

The fact that a few companies own patents on some specialised substances may seem innocuous enough until you consider how important some of these substances may well become, and how much economic power will be wielded by those who own them. For example, carbon nanotubes have the potential to become crucial to a wide range of industry areas including power transmission and storage, electrical devices and computers, strengthened materials, drug delivery and diagnostics.

Corporate Concentration

Just as biotechnology resulted in the emergence of the life science company (under which global chemical, pharmaceutical and seed interests were concentrated into a handful of companies), nanotechnology has a greater potential to change the shape of corporations resulting in further corporate concentration. Companies with traditionally very different areas of operation may well end up merging or buying each other due to similarities in their nano scale operations. Given the diverse range of industries embraced by nanotechnology, what are the corporate mergers of the future going to look like? How large and how powerful will those companies be and what priorities will they be governed by?

Nano Disruption

"Just as the British industrial revolution knocked handspinners and hand weavers out of business, nanotechnology will disrupt a slew of multi billion dollar companies and industries" Lux Nanotech Report 2004

Nanomaterials have the potential to cause economic and social disruption. There are many examples throughout history (from the mechanisation of the textiles industry to the introduction of synthetic dyes[32]) of how the introduction of a new technology can lead to massive social and economic disruption often felt hardest by the poorest and most marginalised sectors of society.

As nanomaterials become more widely used there is the potential for several major traded commodities, from iron and copper to rubber and cotton, to be replaced by nanomaterial equivalents. For example, the use of carbon nanotubes in the electronics industry has the potential to make a huge impact upon the copper extraction industry. The hardest impacts of these changes in commodity flows will be felt not by large corporations dealing in copper (who will see change coming and relocate or diversify their business) but by communities whose economies are underpinned by copper mining.

HOW ARE NANOMATERIALS REGULATED?

"Nanotechnology is no longer 'on the horizon'; it is fast becoming a facet of daily life. The nanoproducts now available came on to the market with limited public debate and with limited regulatory oversight that is specifically aimed at their novel features."
United Nations Environment Program 2007[33]

In 2003, spurred on by initial concerns about the safety of engineered nanomaterials, the UK government commissioned The Royal Society and Royal Academy of Engineers (RS/RAeng) to produce a report on the opportunities and uncertainties posed by nanotechnology. Their report, published in 2004, was a wake up call to regulators around the world[34]. The report raised serious concerns about the potential toxicity of engineered nanomaterials and the lack of adequate regulation in place to deal with them. The report stopped short of calling for a moratorium on the use of engineered nanomaterials on the understanding that precautionary regulation would soon be introduced. Amongst other proposals the report also called for the labelling of products containing engineered nanoparticles.

SMALL CLAIMS - NANOMATERIALS AND INSURANCE

Concern about nanomaterials has also come from the insurance industry. Worried about their own exposure to the risk of asbestos-like injury claims should it all go wrong, several leading reinsurance companies (the people who insure the insurers, including Munich Re[35], Swiss Re[36], General Re[37] and Allianz[38]) have issued position statements on nanomaterials. These reports have called for a precautionary approach to be taken to the use of nanomaterials, for stringent risk management procedures and a new regulatory framework to be put in place. Both General Re and Allianz have aired the possibility that some types of nanomaterials might be excluded from insurance cover.

Over two years since the publication of the RS/RAeng report and despite there being over one hundred products already on the market in the UK, there is still no regulation in the UK or EU that deals adequately with the specific set of problems posed by engineered nanoscale materials. A recent review of UK and EU legislation commissioned by the UK government revealed a number of regulatory gaps around nanotechnology[39]. Both current European and UK chemical regulation, (Existing Substances Regulation (ESR) and Notification of New Substance Regulations (NONS) and that which will soon supercede it (Registration, Evaluation and Authorisation of Chemicals (REACH), were written before the potential risks posed by engineered nanomaterials had been considered. At present, regulation is still unable to distinguish between an engineered nanoparticles of a material and a bulk quantity of the same material. This is despite the nanoparticle being effectively a new material, designed specifically to exhibit different properties to its parent bulk material. The RS/RAeng have recently issued a report critical of the UK government's failure to implement many of their original report's recommendations including the lack of funding for nanotoxicity research and lack of regulatory action on nanomaterials and nano-product labelling[40]. In their 'Global Environmental Outlook Year Book for 2007 the United Nations

Environment Program called for "swift action" from policy makers on funding nanotoxicity research and establishing nanomaterial regulation[41].

NANOREGULATION ELSEWHERE

Outside of the UK and EU some of the first small steps towards nanomaterial regulation beginning to happen in the US. Electronics giant Samsung will be one of the first companies to face the regulation of one of their nanomaterial products because of environmental concerns. Samsung manufactures a range of 'white goods' - fridges, washing machines, air conditioning units and vacuum cleaners - which use the antibacterial properties of nano-particle silver. The US Environmental Protection Agency (EPA) has concluded that the use of silver ions in Samsung's Silver Nano washing machines should be considered as a pesticide, as the substance is released into the laundry for the purpose of killing pests. Concerns have been raised about the environmental impact of nanoparticle silver in wastewater. Samsung will now be required to prove NanoSilver products will not cause harm to humans or the environment. This decision will have implications in the US for other silver nanoparticle based products which make germ killing claims[42]. A further step towards the regulation of nanomaterials in the US came at the end of 2006 when the City of Berkeley, California introduced a law requiring companies in the city to disclose details of nanomaterials that they manufacture[43]

In autumn 2006 the UK government introduced a two year voluntary reporting scheme for 'engineered nanoscale materials' through which industry are invited to volunteer information about engineered nanomaterials that they make, use or import, to a database maintained by the Department of Environmental, Food and Rural Affairs (DEFRA)[44] . The government's rationale for the scheme seems to be that although it does acknowledge that there are potential toxicity problems with engineered nanomaterials, it currently doesn't know enough about their behaviour to introduce regulation, and therefore hopes that the scheme will generate enough information for them to be able to introduce 'appropriate controls' at some point in the future.

A number of concerns have been raised about the scheme[45] : its lack of urgency (given that unregulated nanomaterial products are already on the market in the UK is a voluntary two year evidence gathering scheme an appropriate response?); its voluntary nature (will companies participate in the scheme? Will they volunteer all the information that they are asked for?); and its lack of transparency (any information gathered will be held by DEFRA and not placed in the public domain).

Take up of the scheme has been slow, only three submissions had been received by DEFRA during the scheme's first three months and only one of those submissions came from industry[46].

"There is clearly much still to understand about nanoparticle exposure. Nevertheless, a warning has been sounded- small particles behave differently and in general are more toxic than the same material in larger size. They thus require special attention from regulators."

Professor Anthony Seaton
(Institute of Occupational Medicine, Edinburgh)[30]

NANO MORATORIUM

In 2006 several environmental, social justice, development and animal welfare organisations issued the following response to the UK government's voluntary notification scheme for engineered nanomaterials[47].

We ask that the government scrap the current plans for a voluntary notification scheme and introduce more robust and comprehensive proposals that should include:

- A review of the level of scientific uncertainty and the ability to reliably assess the safety of existing products using the recent SCENIHR report[48] as a starting point.

- Comprehensive well funded research into the health and environmental risks and other potential impacts posed by nanomaterials. This should include human and environmental risk assessment that relies on sound scientific principles not dependent on animal tests, mandatory reporting, safety assessment, emissions minimisation, labelling and liability for new and existing nanomaterials.

- Any approval procedure for nanomaterials should be time limited, and a post-market monitoring plan should be implemented to gather data on their impacts.

- Government plans should be adopted to evaluate and address the wider impacts of the new and especially proprietary nanotechnologies beyond nanosafety questions (particularly the impact on trade, livelihoods, human rights and justice).

Such proposals should have a date for implementation spelled out in months not years.

Until and unless there is a robust body of scientific knowledge on the health and environmental impacts, a moratorium should be put in place on the commercial and environmental release of engineered nanomaterials, particularly free-engineered nanoparticles. This is particularly urgent for products intended for consumption, application to the skin or release to the environment.

Friends of the Earth (England, Wales and Northern Ireland)
Greenpeace UK
International Federation of Journalists
Soil Association
Practical Action
ETC Group
Animal Aid
Corporate Watch

CONCLUSION

The first generation of nanotechnology products is already with us. This briefing gives a snapshot of the nanoproducts landscape in the UK at the start of 2007. The one hundred plus products indicated in table 3 is likely to be an underestimate of the number and range of engineered nanomaterial based products currently available in the UK. The nanomaterials industry is still in its infancy and the market for engineered nanomaterials looks set to expand.

The rush to commercialise nanomaterial products has outpaced adequate consideration of their potential impacts. There is a growing body of evidence to suggest that nanomaterials pose a unique and as yet poorly understood range of toxicity problems. Their impact on human health and the environment is far from understood. There are also concerns about the potential social and economic impacts of nanomaterials.

Despite these very real concerns, regulation has yet to be introduced anywhere in the world to deal with the specific set of problems that nanomaterials raise. The UK government remains unable, or unwilling, to introduce nanomaterial regulation instead favouring voluntary arrangements with industry. The use of engineered nanomaterials continues to expand and accelerate ahead of regulation. As a result both the public and environment will be increasingly exposed to a new potentially dangerous class of materials which remain unlabelled and effectively unregulated.

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NANOMATERIALS

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