Friends of the Earth Australia

Way too little:

OUR GOVERNMENT'S FAILURE TO REGULATE NANOMATERIALS IN FOOD AND AGRICULTURE

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Contents

Acknowledgements

This report was written and edited by Jeremy Tager and Louise Sales from Friends of the Earth Australia and Dr Rye Senjen from the National Toxics Network. The report includes content from the BUND update of Friends of the Earth's 2008 Report "Out of the laboratory and onto our plates: Nanotechnology in Food and Agriculture" translated from the German by Dr Senjen.

Executive Summary

In the six years since our 2008 report *Out of the Laboratory and onto our Plates: Nanotechnology in Food and Agriculture*, the use of nanotechnology and nanomaterials across the entire food chain continues to increase. There are more products, more processes and an accelerating rate of commercialisation.

Nanomaterials are being used in a diverse range of products including food additives, supplements, packaging, sensors and coatings; sprays, and vitamins for livestock; pesticides and anti-microbial storage facilities.

In recent years there has been a dramatic increase in the number of nano products available and produced in Australia. Australian companies are now producing products such as nano coatings, nano sprays, nano polymers, liquid nano glass and nano capsules.

In Australia, there are virtually no restrictions on the import of nanomaterials or products containing nanomaterials and nano products can be purchased easily from overseas. Everything from dishwashers that release nano-silver to nano baby bottles, cutlery and cutting boards can be imported.

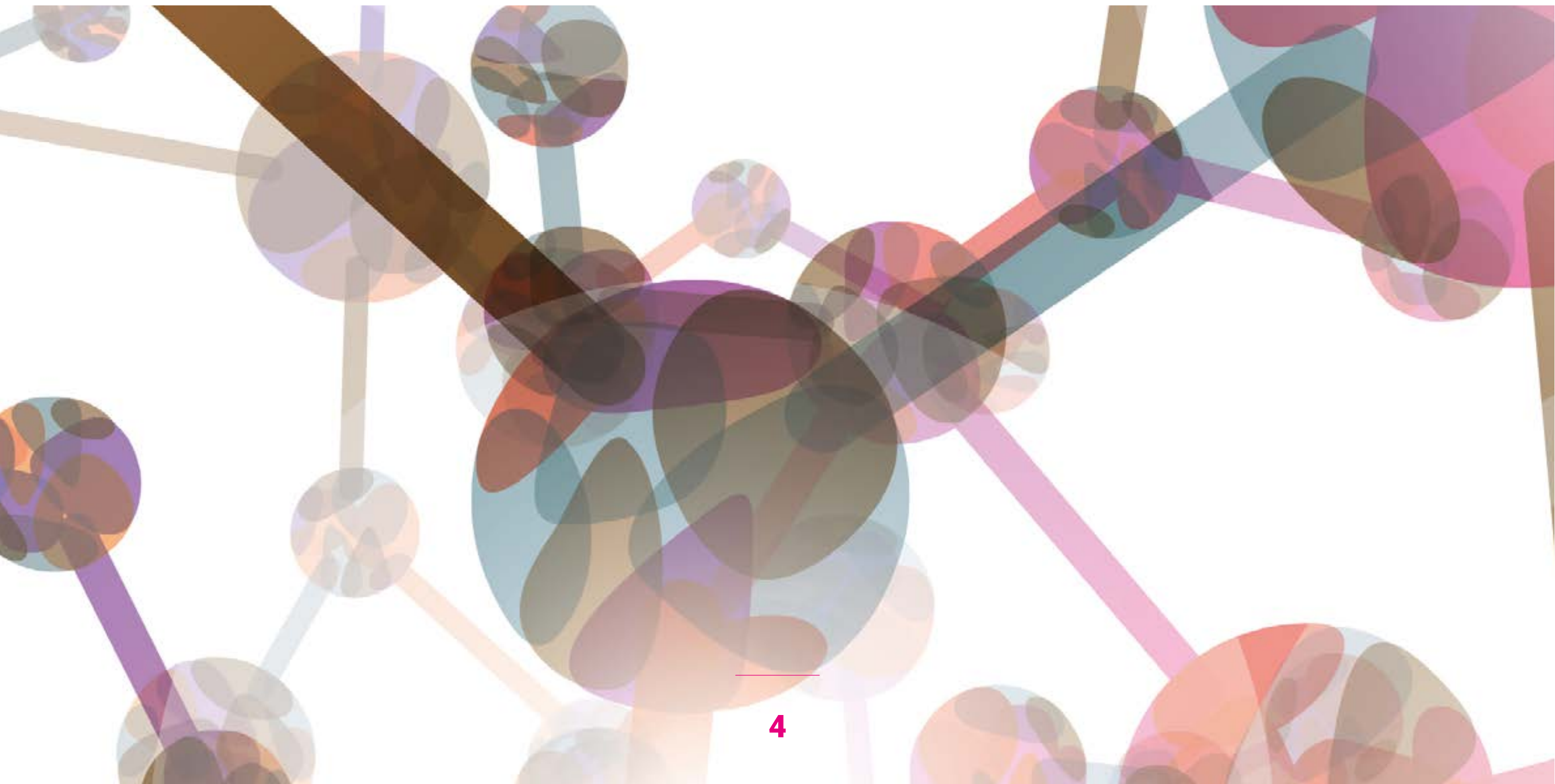
It is essentially impossible to give an accurate count of the number of nano products now available. This is partially due to the rapid expansion in the number of products since 2008 and partially because there is still no labelling or registration requirement that would allow the public to know what nano products they are consuming.

As this report makes clear, the pace of peer reviewed science examining the environmental, health and safety issues associated with nanotechnology lags far behind the commercialisation. Even basic data, methodologies and reference materials are often lacking, making consistent and reliable risk assessments difficult. There is little understanding of exposure pathways for nanomaterials and little work has been done to assess potential long-term environmental and health impacts.

Even so, since 2008 there has been a growing body of evidence indicating that certain nanomaterials may be harmful.

For example, there is growing evidence that two of the most widely used nanomaterials used in the food sector — nano-silver and nano titanium dioxide — may be harmful to human health.

At the same time, the public has not been kept well engaged or informed, either on the potential environmental, health and safety issues associated



with nanomaterials, or regarding the numerous products that now contain them.

Little seems to have been learned from the ongoing attempts by the biotech sector to shove genetically modified foods down the collective throats of the public. The absence of public support, evidence of safety and regulatory oversight is once again being seen as an opportunity by industry to occupy a market by stealth.

Regulatory intervention remains minimal. Australian regulators still don't even have an agreed nanomaterial definition, making regulation both more unlikely and difficult. Australian regulators maintain a determined hands-off attitude to regulation, preferring instead to keep a watching brief over an industry over which they have less and less control.

This report reveals that the claim by regulators that no food and agricultural products containing nanomaterials are available in Australia is incorrect and that chemical companies are not declaring the nanomaterials they are using. It is clear that our food regulator Food Standards Australia New Zealand (FSANZ) and our agricultural chemicals regulator the Australian Pesticide and Veterinary Medicines Authority (APVMA) are not exercising the necessary level of diligence.

It is past time for regulators to intervene in this market that currently has so few controls and so many concerns. If we continue with business as usual, Australians will be exposed to even greater and totally unnecessary risks.

While Friends of the Earth Australia (FoEA) makes a number of recommendations in this report in relation to the nanotech industry, there are three basic and critical steps that need to occur immediately:

1. A moratorium on the production and sale of new products containing nanomaterials until necessary research is conducted and regulations to protect human health and the environment are put in place;

2. A mandatory and public register of nanomaterials and products containing nanomaterials in Australia;

3. A labelling requirement for all products containing nanomaterials as recommended by the Federal Government's review of Australia's food labelling laws.[1]

Introduction

This report will examine the changes since our 2008 report including the development of new food, food contact and agricultural products. It will review the current literature relating to the potential environmental, health and safety impacts associated with nanotechnology and summarise the Australian regulatory responses to date.

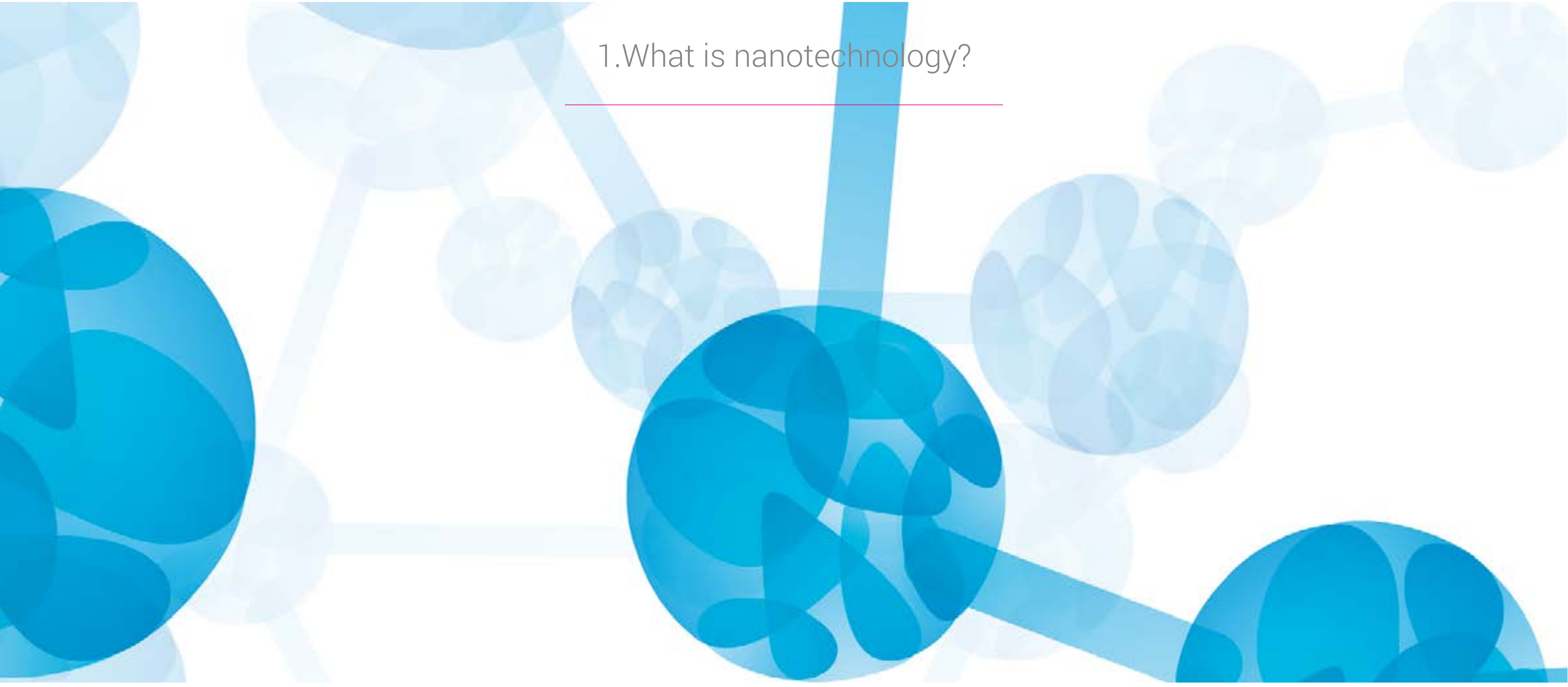
This updated report uncovers the:

- accelerating rate of commercialisation and rapidly increasing number of commercial products containing nanomaterials in the food and agricultural sectors;
- lack of information regarding which nanomaterials have been released and the likely exposure of humans and natural systems to these materials;
- lack of basic steps to allow us to track nanomaterials that have been released, such as labelling and a register of products containing nanomaterials;
- growing gap between the pace of commercialisation and environmental, health and safety assessments;
- increasingly large body of peer reviewed evidence that certain nanomaterials may cause harm to human health or the environment;
- failure of regulators to respond to the growing evidence of risks;
- lack of basic knowledge that is critical in order to fully analyse the particular environmental, health and safety issues associated with nanotechnology.

Six years ago, inaction was based on a perceived lack of data. Inaction is still the norm but that is no longer an excuse our Government can use. Scientists and scientific bodies such as the US National Research Council have given us more than enough evidence to justify a pro-active regulatory regime and a properly funded R&D program that will effectively target those areas of greatest environmental and health concern.

Unfortunately, our Federal Government seems unwilling to provide the levels of funding required for such work or to adopt appropriate regulation. The notion of precaution has been replaced with an attitude that it is the obligation of industry to determine whether their products are safe and regulators will only act when harm is shown. While France, Belgium and Denmark are implementing a mandatory register for nanomaterials and the EU's is in the process of implementing a nano food labelling regime, Australian consumers remain in the dark.

This needs to change.



1. What is nanotechnology?

The term 'nanotechnology' encompasses a range of technologies that operate at the scale of the building blocks of biological and manufactured materials – the 'nanoscale'. While most definitions of nanotechnology relate to a size of between 1-100 nm, there is concern that some particles larger than 100 nm exhibit behaviour similar to nanoparticles, such as very high reactivity, bioactivity and bioavailability.[2]

Nanomaterials have such diverse properties and behaviours that it is impossible to provide a generic assessment of their health and environmental risks.[3] Properties other than size that influence toxicity include chemical composition, shape, surface structure, surface charge, behaviour, extent of particle aggregation (clumping) or disaggregation, and the presence or absence of other chemicals attached to the nanomaterial.[4] For this reason even nanomaterials of the same chemical composition which have different sizes or shapes can have vastly different toxicity.[5]

Six years ago, inaction was based on a perceived lack of data. Inaction is still the norm but that is no longer an excuse our Government can use.

In Australia, only one regulator, the National Industrial Chemical Notification Assessment Scheme (NICNAS – our industrial chemicals regulator), has developed a definition of nanotechnology. It is still a 'working' definition[6]:

"…industrial materials intentionally produced, manufactured or engineered to have unique properties or specific composition at the nanoscale, that is a size range typically between 1 nm and 100 nm, and is either a nano-object (i.e. that is confined in one, two, or three dimensions at the nanoscale) or is nanostructured (i.e. having an internal or surface structure at the nanoscale)"

This is not a definition that is necessarily accepted by other Australian regulators. Already there has been a case of a regulator refusing to enforce the law prohibiting misleading conduct in trade because of a lack of a legislatively agreed definition of nanotechnology.[7]

2. Current trends in food and agriculture

Nanotechnology has broad existing commercial applications in the food and agriculture sectors, including food processing, supplements and packaging, food contact materials, food monitoring, agricultural chemicals, animal care products and the transport and storage of agricultural goods.

- The lack of any labelling or registration requirement means that information on the presence of nanomaterials in food, food contact materials and agricultural production is limited. It also means there is no reliable estimate of the number of nano products now on the market in the food and agriculture sectors.

- Determining which products contain nanomaterials is further hampered by the behaviour of companies themselves. In some sectors, fear of market rejection means that companies have removed their nano claims, whilst still potentially using nano-ingredients. Meanwhile other sectors such as supplements and agrichemicals actively market products as 'nano' when it is not always clear that they are.

In 2013, the French Government released an initial assessment of nanomaterial use in France, based on data provided by industry for France's mandatory nanotechnology register. This revealed the use of over 500,000 tons of nanomaterials and 3400 different nanomaterial based products in France alone in 2012.[8]

The Woodrow Wilson International Center for Scholars 2013 inventory of nano products lists 200 food and beverage products containing nanomaterials, up from 126 in 2010.[9]

It now appears likely that these estimates are too conservative.

FoEA estimates there are now hundreds of food products and food contact products available and produced in Australia. We base this estimate on the following sources: company claims; foods or food contact products identified in other countries as containing nanomaterials, which are sold here; patents or trademarks held in Australia for the use of nanomaterials in food or food contact materials; the operation in Australia of companies holding Australian patents; and finally the testing of selected products. Appendix 1 details just some of the food and agricultural products available in Australia that contain nanomaterials and Figure 1 lists some common foods which may contain nanomaterials.

Figure 1: Food product types that may include nanomaterials

- Cream cheese
- Cookies
- Doughnuts
- Coffee creamer
- Chocolate syrup
- Chocolate
- Pudding
- Mayonnaise
- Mints
- Chewing gum
- Popcorn
- Salad dressing
- Oils
- Yoghurt
- Breakfast cereal
- Lollies
- Crackers
- Pasta
- Sports drinks and other beverages

Uncertainty regarding the number and nature of products containing nanomaterials not only highlights the need for reliable information but raises immediate concerns regarding the capacity and interest of regulators in ensuring that human and environmental health are protected.

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The number of products containing nanomaterials will continue to expand rapidly
Both the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) assume that food will increasingly be produced using nanotechnology.[10] Economists estimate that by 2015, 40% of all businesses in the food industry will be working with nanotechnology, with the Asian markets leading, followed by the USA.[11]

Many of the world's largest food companies, including Heinz, Nestlé, Unilever and Kraft, are exploring nanotechnology for food processing and packaging, as detailed in Figure 2.[12] Many of the world's largest agrochemical and seed companies also have active nanotechnology research and development programs.

Figure 2: A sample of transnational food companies engaged in nanotechnology research and development [13; 14; 15]

- Altria (Kraft Foods)
- Associated British Foods
- Ajinomoto
- BASA
- Cadbury Schweppes
- Campbell Soup
- Dupon 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
- Nestlé
- Northern Food
- Nicherei
- Nippon Suisan Kaisha
- PepsiCo
- Sarah Lee
- Unilever
- United Foods

3. The use of nanotechnology in foods and food processing

Processing aids and food additives
Probably the most commonly used nanoscale processing aids are 'trickle and flow' aids. Nanomaterials such as synthetic amorphous silica (SAS - E551) are added to foods that are in powder form, e.g. salt, vegetable powder, whey powder, egg powder, creamer, instant drink powder (coffee powder), seasoning blends (chilli, garlic powder etc.), powdered sugar and soup powder.[16] SAS is also used as an anticaking agent, thickener and carrier of flavours and consumers are exposed to it on a daily basis.[17] Examples of commercially available nanosilica intended for use in food include Evonik's Aerosil 200F and Aerosil 380F.[18]

Titanium dioxide is a common additive in many food products and is used to bleach and brighten confectionery, cheese and sauces. A 2012 study looking at food grade titanium dioxide (E171) calculated that approximately 36% of the particles were nanoparticles.[19] The study found titanium dioxide in a wide range of foods including doughnuts, lollies, chewing gum and chocolate. The titanium dioxide content was as high as 100 mg per serving for powdered doughnuts. Testing undertaken by Friends of the Earth US in 2013 also found nano titanium dioxide on fresh pear, capsicum and apple samples.

Carotenoids of up to 200 nm are used as colourants or antioxidants in drinks or food.[20] The Allied Biotech Europe GmbH from Taiwan offers carotenoids as colourants under the name Altratene beta-carotene.[21] BASF also sells LycoVit – an antioxidant containing nano lycopene.[22]

Functional Foods
The food industry has invested heavily in products that they claim will bring consumers nutritional benefits such as yoghurts that are claimed to strengthen the immune system, improve digestion, or lower cholesterol. Dairy products, cereals, bread and drinks are mixed with vitamins and minerals like iron, magnesium or zinc, and enriched with probiotic substances, bioactive peptides, antioxidants and soy. Some of these substances are added to foods as nanoparticles. The world market for functional food in 2005 was approximately US$73.5 billion.[23] The market is growing at 4% per year, much faster than for 'normal' foods. Between 2003 and 2010, the market for these products has more than doubled.[24]

Some examples of nano functional foods that are already on the market, include yoghurt and drinks containing nanocolloidal platinum or gold that are marketed as 'anti-aging' foods,[25] and a Canola Active Oil from Israel, which claims to contribute to the reduction of Cholesterol.[26]

The United Nations' Food and Agriculture Organisation (FAO) notes that nanoselenium is being used in Green Tea with claims of health benefits.[27]

Supplements containing nanomaterials
A wide range of dietary supplements purportedly containing nanomaterials are on the market - for example BASF produces a range of microcapsulated vitamins that contain the vitamins in nanoparticle form.[28] However, it is a difficult market to track. It is often unclear whether a product actually contains nanomaterials or whether the term is merely being used in order to market a product. Manufacturers of dietary supplements, unlike food producers, often view nano content as an advantage rather than a disadvantage.

For example, in Australia, Supplements Direct[29] advertises nano peptides, nano creatine, nanobolics, nano tribestanol and nano glutamine, but neither distributor or manufacturer websites make clear whether supplements such as these in fact contain nanomaterials.

Nanoscale capsules
Nanoscale capsule are already being used in the processing and preservation of beverages, meats, cheeses and other foods. They are used to enclose

drugs, vitamins, preserving agents, and enzymes. In 2008, we reported that more and more manufacturers offer omega-3 fatty acids and other compounds in 30-40 nm sized capsules that are 4,000 times smaller than previously used microcapsules.

A number of companies offer nutritional formulas containing vitamins, carotenes or anti-oxidants in nano capsules.[30; 31]

Edible food coatings
Manipulation of materials at the nanoscale can allow food scientists to create 'edible nanolaminate films' which can be used as barrier layers to prolong shelf life. These films can include lipids or clays as moisture barriers; biopolymers such as carbohydrates as oxygen and carbon dioxide barriers; or nanoparticulates and emulsified nanodroplets, which could contain active ingredients to improve taste, texture or appearance.[32] Antibacterial substances can also be directly integrated into the edible coating, for instance for meat packaging.[33]

Edible coatings containing engineered nanomaterials are reportedly already being used on fruit and vegetables in markets in the US and Canada in order to extend shelf life. Tests conducted in Central and South American farms and packing stations found a number of fruits with a nano coating, including apples, pears, capsicum, cucumbers and other fruits and vegetables that are delivered to the US and Canada.[34]

4. The use of nanotechnology in food packaging

One of the earliest commercial applications of nanotechnology within the food sector was in packaging.[35] It is believed to be largest part of the nano food sector.[36]

Nano packaging comprises three primary types: barriers, anti-microbials and sensors. 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.[37;38] Visiongain, a 'business information provider', expected the global nano packaging market to have revenues of 'US$20 billion in 2013.[39]

A key purpose of nano packaging is to deliver longer shelf life by improving the barrier functions of food packaging in order to reduce gas and moisture exchange and UV light exposure.[40;41; 42; 43; 44]

Nanomaterials such as silver and gold, as well as zinc oxide, titanium dioxide, silica and carbon black can be used in packaging to protect food from UV light.[45; 46] For example, CSIRO has developed a nano coating for bottles that improves light shielding and thus extends shelf-life.

Barrier effects against gases and moisture are achieved with nanoscale silica, alumina and clay and are suitable for the production of films for the packaging of meat, sausage, cheese or fruit, and also for microwave products and plastic bottles.[47]

The use of composite nanomaterials such as nanoclay in bottles as barriers to oxygen and carbon dioxide is increasingly common and has been patented in Australia.[48] These are used in bottles for beer, soft drinks, 100% juices, sports drinks and specialty waters.[49]

Nano antimicrobial packaging and food contact materials

Nano packaging and coatings on food contact materials often incorporate antimicrobial nanomaterials so that the packaging itself acts as an antimicrobial agent. These products commonly use nanoparticles of silver, although some use nano zinc oxide or nano chlorine dioxide.[50; 51]

In 2011, Israeli scientists developed a 'killer paper' for food, which is capable of destroying bacteria such as E. coli within three hours, using colloidal (nanoscale) silver. It has been promoted as ideal for the packaging of meat.[52]

A large number of nano-based antimicrobial products are available in Australia (see Appendix 1).

Intelligent packaging with nano sensors
Packaging equipped with nano sensors is designed to track either the internal or external conditions associated with packaged food. These could indicate, for example, changes in temperature or humidity or whether the food has gone bad.

A New Zealand company offers ripeSense packaging which contains sensors that measure the oxygen content inside the package. An indicator on the outside of the packaging changes colour when the product has reached its optimum ripeness. The packaging is already being used on pears, kiwi, melon, mango, avocado and other stone fruits. The label was launched in Australia in 2005 by ripeSense and the Australian company J-Tech.[53]

An Australian patent application is pending for a 'nano-sniffer' less than 150 nm in size. The nano-sniffer will be used to detect chemicals and can include a radio signal using a carbon nanotube antenna. It is intended for a variety of chemical detection uses – including food packaging. The nano-sniffer, according to the application, is suitable for consumption.[54]

The potential human health impacts of consuming nanosensors is unknown. The extent to nanomaterials used in sensors can migrate into food is also unknown.

Biodegradable nano packaging
Bioplastics (plant based plastics) are generally less strong than petroleum-based plastics, which are commonly used for packaging and plastic bags. The development of nanomaterials to enhance these bioplastics is being promoted as a solution to this problem.[55] However, there is still no reliable assessment of the environmental risks of nanoscale fillers in these plastics and whether they are released into the environment when the bioplastics decompose.

The University of Queensland's Centre for High Performance Polymers is involved in the development of nanopolymers. Research from this group led to the establishment of the Victorian company Plantic Technologies Ltd.[56] They hold at least two Australian patents for starch nanocomposite materials used in packaging, although their website makes no mention of nanopolymers.[57; 58; 59]

Plantic customers include Kellogg's, Aldi, Sainsbury's, Cadbury and Freedom Foods.

5. Nanotechnology in agriculture

PHOTO: BRIAN ROBERT MARSHALL VIA WIKIMEDIA COMMONS

Nanotechnology is being used in products across the agricultural supply chain, including in chemicals, feed and supplements for farm animals, machinery and storage facilities.

Agrochemicals

Nanotechnology is introducing a new array of potentially more toxic pesticides, plant growth regulators and chemical fertilisers, further entrenching the current system of industrial and chemically intensive agriculture.

Some of the first nano agrochemicals in development are nano-reformulations of existing pesticides, fungicides, plant, soil and seed treatments.[60; 61; 62] 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, such as in response to sunlight, heat or the alkaline conditions in an insect's stomach.

All the leading producers of agricultural chemicals, including BASF, Monsanto and Syngenta are actively researching nanotechnology for use in agriculture and pesticides with nanoscale ingredients are already on the market.[63]

In the last ten years, over 3000 patents have been filed for pesticides with nanoscale ingredients.[64] These are mostly nanoscale versions of existing pesticides.[65] The Internet platform www.nano-technologien.com claims that "Bayer AG has been producing pesticides in this format size on a large scale".[66]

Nanoencapsulation

Since 2010, the Canadian company Vive has offered nanoscale capsules for use with herbicides. Vive Nano has one patent application filed in Australia for the use of nanoparticles with agricultural chemicals. [67] They are one of the few chemical companies openly promoting nanoscale pesticides for sale.

A number of new pesticide formulations are sold as 'microencapsulations'. Microencapsulation – like nanoencapsulation – is used as a means to improve product handling and delivery to the target pest. Microencapsulation may enhance herbicide transport through stubble, reduce adsorption, and increase herbicide longevity in soil due to the gradual diffusion and release of active ingredient from the capsule"[68] The companies patenting and marketing microencapsulations (including most of the big chemical companies) do not provide details on the size of these encapsulations. Products such as Syngenta's Subdue MAXX;[69] Ospray's Chyella;[70] Penncap-M;[71] and two pending patents for microencapsulated pesticides from BASF[72;73] may well be nanoscale.

For example, Syngenta has identified microencapsulation as one of the delivery mechanisms for these chemicals in an Australian 'patent',[74] claiming that its microcapsules 'usually' have a diameter of from 0.1 to 500 microns."[75] In other words, this product may be both micro and nano encapsulated.

Nano and micro emulsions

Syngenta's Primo MAXX, a growth regulator, Banner MAXX for fungal attack on lawns and Headway and Subdue MAXX, fungicides for turf, are commonly used and available in Australia. They are characterised as microemulsions, however, scientists at the University of Vienna have determined that they are actually nanoscale emulsions. It appears that the term microemulsion is commonly being used as a term for formulations containing organic nanoparticles.[76]

The International Union of Pure and Applied Chemistry (IUPAC) has defined a microemulsion as being between 1-100 nm.[77] Based on this definition, it appears that the microemulsions used by a number of companies in agricultural products should be understood as nanomaterials. FoEA has identified a number of agrochemicals sold as microemulsions:

- Syngenta's Banner MAXX;[78]
- Hymal's Maldison;[79]
- Thumper Insecticide;[80]
- Clipless – plant growth regulator;[81]

- Apple Lustr 331;[82]
- Rancona C – cereal seed treatment;[83]
- Greenor, Junction, Plenum 84160 ME, Bastion T (Dow AgroSciences);[85]

While it isn't clear whether these and other microemulsions are at a nanoscale, it is legitimate to assume they are in the absence of evidence to the contrary. Similarly, it isn't clear whether these emulsions contain pesticide nanoparticles. Nevertheless, they can be legitimately seen as new formulations because the active ingredients in microemulsions are intended to breakdown more slowly, be absorbed faster and provide greater bioavailability and faster delivery of bioactives.[86; 87]

The US EPA now requires registration of all pesticides containing nanoscale ingredients, regardless of whether they are active or inactive,[88] and the EU requires (EC Regulation 1107/2009) that "the interaction between the active substance, safeners, synergists and coformulants" must be taken into account in evaluation of such products.[89] The position of the Australian regulator, the Australian Pest and Veterinary Medicines Authority (APVMA) is less clear (see Section 10).

FoEA is concerned that the terms microencapsulation and microemulsion are being wrongly used to describe nanoscale encapsulation and emulsion, allowing companies to avoid regulation. The concern is based on the failure of many companies to declare the size of the capsules or emulsions being used. For example, Dow AgroSciences has a pending patent in Australia for 'Microcapsule suspensions including high levels of agriculturally active ingredients'. Even the patent specification document doesn't detail capsule or particle sizes.[90] As a recent review of the topic noted, "companies developing formulations in the nano range may choose not to refer to their new products as nanoformulations (e.g., the term microemulsions), as 'nano' may nowadays also be associated with a large public uncertainty on the fate of nanomaterials and effects on human and environmental health."[91]

Nanofertilisers

Fertilisers advertised as nanoscale are freely available on the market, but notably these are not produced by major chemical companies. Nano fertilisers are promoted as ways to improve nitrogen use efficiency, yields, control release, limit waste and improve quality.[92;93] Nano fertilisers may contain nano zinc, silica,[94] iron,[95] and titanium dioxide.[96] One Chinese company sells a fertiliser which it claims contains over 200 nano scale ingredients.[97]

Animal feed

Nano sized minerals, vitamins, additives or supplements in animal feed are already on the market. For example, a feed additive has been developed comprising a natural biopolymer from yeast cell walls that can bind mycotoxins to protect animals against mycotoxicosis.[98] Nano zinc oxide is sold for use as a growth promoter in animal feed.[99;100;101] Nano liquid vitamin mixes are also available for use in poultry and livestock feed.[102] A Thai company, Framelco, has also developed a nano coated zinc oxide to prevent diarrhea in piglets.[103] However, the use of nanomaterials in animal feeds and supplements does not currently appear to be widespread.

As with fertilisers, the dominant corporate interests in the animal feed sector appear absent from the field. It isn't yet clear if they are simply marketing nano products without revealing the use of nanomaterials or if they haven't yet entered the market.

Regulators should prioritise surveying these markets and ensuring that products are both properly characterised, labelled and evaluated.

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PHOTO: FIR0002/FLAGSTAFFOTOS VIA WIKIMEDIA COMMONS

6. On the Horizon?

The nanotechnology industry regularly makes outlandish claims about what might be possible using nanotechnology. It is difficult to assess the utility, likelihood and commercial viability of many of these proposed developments, but it is worth noting some of the claims and trends in relation to food and agriculture. These include:

- A variety of nanotechnology based functional foods with fewer calories and less fat, salt, and sugar while retaining flavor and texture;
- nanoscale vehicles for effective delivery of micronutrients and sensitive bioactives;
- re-engineering of crops, animals and microbes at the genetic and cellular level;
- nanobiosensors for detection of pathogens, toxins, and bacteria in foods;
- identification systems for tracking animal and plant materials from origination to consumption;
- integrated systems for sensing, monitoring, and active response intervention for plant and animal production;
- smart field systems to detect, locate, report, and direct application of water;
- precision and controlled release of fertilizers and pesticides;
- development of plants that exhibit drought resistance and tolerance to salt and excess moisture;[104]
- a range of uses in aquaculture, including delivery of antibiotics, anti-microbial surfaces, use of nano-sensors, stronger materials for cage and net construction and nano-foods.[105]

Can nanotechnology 'feed the world'?
In rhetoric mirroring the GM crop debate, it has been claimed that nanotechnology can help 'feed the world'. In assessing these claims it is important to bear in mind that the world.[106] already 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.[107] While over 500 million people are now clinically obese,[108] more than 850 million people experience extreme hunger.[109]

Over 2.5 billion people world wide rely on agriculture to make a living.[110] However control of the global food system, valued at US$4 trillion, is held by a small number of multinational companies.[111] Food distribution and retail sales are concentrated in the hands of a few big companies, who exert a significant influence over product supply and play a key role in determining which crops farmers grow, where - and at what price.[112; 113]

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.[114]

In rhetoric mirroring the GM crop debate, it has been claimed that nanotechnology can help 'feed the world'. In assessing these claims it is important to bear in mind that the world already 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. While over 500 million people are now clinically obese, more than 850 million people experience extreme hunger.

7. 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 seed treatments creates a host of new exposure pathways and a whole new array of risks for the public, workers in the food industry and farmers.[115] However, it is extremely difficult to quantify likely exposure levels since there is no register of which nanomaterials are used and in what quantity or what food products and food contact materials they are used in.[116]

Since our 2008 report, the evidence of potential harm associated with certain nanomaterials has become stronger.

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Why nanomaterials pose new risks

- Nanomaterials are generally more chemically reactive than larger particles of the same chemicals
- Nanoparticles have greater access to our bodies than larger particles
  - Greater bioavailability and greater bioactivity may introduce new toxicity risks;
  - Nanomaterials can compromise our immune system response;
  - Nanomaterials may have long term pathological effects.

Absorption through the digestive tract

Numerous *in vivo* experiments using rats and mice have demonstrated gastrointestinal uptake of nanoparticles[117; 118; 119; 120; 121] and small microparticles.[122; 123; 124] Pathological examination of human tissues suggests ingestion and translocation of microparticles up to 20 μm in size.[125; 126]

The absorption rate of substances via the gastrointestinal tract appears to depend on their properties such as size and surface structure. In one study looking at rats, the smaller the nanoparticles the higher the uptake via the digestive tract.[127] In another study mice were fed 4 nm gold particles. These were later detected in the liver, kidney, spleen, lung and brain. Larger 58 nm particles remained in the gastrointestinal tract.[128]

PHOTO BY JANET STEPHENS VIA WIKIMEDIA COMMONS

Studies have shown that nanomaterials may affect the human intestine. When human colon cells were treated with nano-sized polystyrene, which is commonly used in food packaging, these became more permeable to iron.[129] Powell *et al* have observed that the daily exposure of people in the Western world to sub-micrometre-sized mineral particles has resulted in 'pigmented cells' loaded with these particles in parts of the intestinal tract. The particles have been observed to be composed of aluminosilicates, titanium dioxide and a small percentage of non-aluminium-containing silicates such as silica (SiO2) and magnesium trisilicate (talc).[130]

Preliminary evidence suggests that existing levels of nanoparticles up to a few hundred nanometres in size in processed food may be associated with rising levels of immune system dysfunction and inflammation of the gastro-intestinal tract, including Crohn's disease.[131; 132; 133; 134] Individuals with Crohn's disease or colon cancer have been found with nanomaterials in their intestinal tissue.[135]

Nanomaterials in the human body
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.[136] Nanoparticles are also more adhesive than larger particles to surfaces within our bodies.[137] 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.

A growing body of evidence demonstrates that some nanomaterials are more toxic per unit of mass than larger particles of the same chemical composition.[138; 139; 140; 141]

Nanomaterials have been detected in the heart, liver, spleen, lung, kidney, brain and bone marrow. Insoluble nanomaterials may accumulate and remain in the body for extended periods.[142]

In one study, particles of 200-300 nm reached the foetus via the placenta. It is not known whether this causes harm to the placenta or the unborn child.[143; 144] Currently there is no data on whether it is possible for nanomaterials to pass into breast milk.[145]

The cell membrane is no obstacle to nanomaterials penetrating into cells, unlike larger particles. Studies show that 30 nm nanoparticles can even penetrate into the nucleus.[146]

Non-degradable nanoparticles may lead to long-term health damage, even in the absence of acute toxicity. 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', such as granulomas, lesions (areas of damaged cells or tissue), cancer or blood clots.[147; 148; 149] The Federal Institute for Risk Assessment and the Federal Environment Agency in Germany believe there is clear evidence that some nanomaterials have greater carcinogenic potential then microscale particles of the same material.[150]

Health concerns with nanomaterials in food and food contact materials

Silica
Uses: Used as a 'trickle and flow' aid in powdered food products, as a clearing agent in beer and wine, as a food additive and a food coating.

Health concerns:

- Several recent studies have shown liver toxicity when animals were injected with nanosilica.[151] Animal studies suggest that nanosilica can be absorbed from the gastrointestinal tract as nanoparticles, become systemically available, and accumulate in tissues. Once systemically available nanosilica appears to be mostly distributed to the liver and spleen, and to a lesser extent other tissues. Some studies suggest that nanosilica can cross the blood-brain barrier and possibly the placenta;[152]

- A recent study where rats were fed synthetic amorphous silica (SAS) - a form of nanostructured silica - found that SAS caused fibrosis of the liver and that the nanostructured silica accumulated in the spleen.[153] The paper's authors have called for further studies to be done to evaluate the biological relevance of this;

- Recently a consumer intake of silica from food was estimated at 9.4mg/kg of body weight per day of which 1.8mg/kg body weight per day was estimated to be in the nano size range.[154]

Nano-silver
Uses: In the Woodrow Wilson inventory of nano products, silver is the most common nanomaterial mentioned in product descriptions.[155] A recent court case in the US found that the use of nano-silver was 'ubiquitous' and that there was no way for consumers to avoid exposure.[156] Food and food contact products identified as containing nano-silver include baby bottles, food containers, packaging, cutting boards, salad bowls, appliances, cutlery, ice trays, filtration devices and collapsible coolers. In agriculture, it is used in poultry production and agricultural and aquacultural disinfectants.[157]

Health concerns:

- There is mounting evidence that nano-silver may have greater toxic effects when compared with bulk silver. Nano-silver can better penetrate biological barriers and attach itself to the outside of cells.[158] Nanoscale silver can also enter the bloodstream and reach all organs of the body including the brain, heart, liver, kidneys, spleen, bone marrow and nervous tissue;

- Animal studies have shown placental transfer and foetal uptake of nano-silver.[159] This finding is disturbing when one considers a recent study which found that exposure to nanosilver caused zebra fish embryos to develop with head abnormalities and no eyes. Zebra fish have been widely used as a model organism for the study of embryological development in other vertebrates including humans;[160]

- Health experts have also raised concerns that the widespread use of nano-silver in consumer products will further increase the problem of superbugs.[161]

Titanium dioxide
Uses: A whitener and brightener in a range of food products

Health concerns:

- ECHA is currently reviewing the safety of titanium dioxide (including the nano form) because of concerns it may be harmful to the environment and human health;[162]

- In contrast to bulk particles of titanium dioxide, nanoscale titanium dioxide is biologically very active. Studies show that titanium dioxide can damage DNA,[163] disrupt the function of cells, interfere with the defence activities of immune cells and, by adsorbing fragments of bacteria and 'smuggling' them across the gastro-intestinal tract, can provoke inflammation.[164; 165; 166; 167; 168; 169] A single high oral dose of titanium dioxide nanoparticles was found to cause significant lesions in the kidneys and livers of female mice;[170]

- In a 2010 study the German Federal Institute for Risk Assessment (BfR) and the German Federal Environment Agency (UBA) concluded that nanoscale titanium dioxide is a possible carcinogen if inhaled;[171]

- Nano titanium dioxide is highly mobile in the body and has been detected in both humans and animals in the blood, liver and spleen.[172] A study using pregnant mice found that they transfer nanoparticles of titanium dioxide to their offspring. This resulted in brain damage, nerve system damage and reduced sperm production in male offspring;[173]

- A human exposure analysis of titanium dioxide through foods identified children in the 2.5-4.5 year age range as having the highest exposure because the titanium dioxide content of sweets is higher than any other food products. It also calculated that a typical exposure for a US adult may be of the order of 1 mg of titanium per kilogram of body weight per day.[174]

Zinc oxide
Uses: Surface coatings

Health Concerns:

- Nanoscale zinc oxide (ZnO) is toxic when ingested and has been found to cause lesions in the liver, pancreas, heart and stomach.[175] A recent review of the safety of nano zinc oxide by the European Commission's Scientific Committee for Consumer Safety stated that "clear positive toxic responses in some of these tests clearly indicate a potential for risk to humans."[176] Inhalation exposure of nano zinc oxide induces lung inflammation, leading the SCCS to conclude that "the use of ZnO nanoparticles in spray products cannot be considered safe."[177]

Copper
Uses: dietary supplements[178]

Health Concerns:

- The German Federal Institute for Risk Assessment compared the acute toxicity of micro- and nanoscale copper. No adverse effects were observed with microscale copper – however, nanoscale copper showed adverse effects on the kidney, spleen and liver of mice.[179]

Carbon nanotubes
Uses: While there are no confirmed commercial food and food contact products containing carbon nanotubes, food packaging and food sensors containing carbon nanotubes have been developed.[180;181] The use of carbon nanotubes in fertilisers is also being researched but does not yet appear to have been commercialised.[182]

Health Concerns:

- The Australian National Industrial Chemical Notification and Assessment Scheme (NICNAS) and Safe Work Australia, which reviewed the safety of carbon nanotubes, found that multi-walled carbon nanotubes "have been shown to induce mesothelioma in rodents."[183]

Nano supplements could cause health problems

The head of the nanotechnology research group at the United Kingdom's Central Science Laboratory warns of unpredictable effects of nanoparticles and nano encapsulated additives: "They can be absorbed faster than desired or affect the absorption of other nutrients. We still know very little, if anything at all."[184]

In 2009, based on the growing number of commercially available nano supplements, the Woodrow Wilson International Center for Scholars' project on emerging nanotechnologies found that the United States Food and Drug Administration had neither the regulatory power nor the scientific expertise to determine if these supplements were safe.[185]

Health risks associated with nano packaging

It is possible that nanomaterials could migrate from food packaging into foods. Polymers and chemical additives in conventional food packaging are known to migrate from the packaging into food products.[186; 187] The Institute of Food Science and Technology has expressed concern that manufactured nanomaterials are already being used in food packaging, despite migration rates and exposure risks remaining unknown.[188] To date there are only a few studies that have investigated the migration of nanomaterials from food packaging into food and the results have been inconclusive.

Health risks posed by nano agrochemicals

There is a risk that the development of nano formulations of existing agrochemicals which are more reactive and bioactive may in turn increase the risk to human health. Many developments seem to be currently at the R&D stage and it is likely that the agriculture sector will see some large-scale applications of nanotechnologies in the future. Should this occur, this will increase the potential exposure to agrochemicals used in the agriculture sector.[189] Data on the health risks associated with agrochemicals is voluminous[190] but scarce for nano agrochemicals. In addition to concerns relating to worker inhalation and exposure, there are concerns regarding potential risks associated with bioaccumulation of nanoparticles in food crops[191] and the health impacts produced by interactions between both active and inactive ingredients in the new pesticide formulations.[192]

Recognising that many of these nanoscale reformulations are new, EU regulation (1107/2009) requires that "coformulants must not exhibit harmful effects on human and animal health." [193]

Occupational health and safety (OHS) concerns

In the food sector, workers may come into contact with nanomaterials during production, packaging, transport and waste disposal of food and agrochemicals.[194] To date, there is very little data relating to the exposure of workers to nanomaterials.

A number of nanomaterials used in the food industry such as zinc oxide and titanium dioxide have been shown to be harmful when inhaled, raising OHS concerns for workers handling these materials.[195] However the lack of a mandatory register and product labelling means that many workers may be unaware that they are handling nanomaterials and of the need to use protective equipment.

Studies have also shown that nanomaterials can enter the bloodstream via the lungs raising major OHS concerns.[196]

Based on a 2009 review of carbon nanotubes by Safe Work Australia and NICNAS, carbon nanotubes were declared a hazardous chemical for purposes of health and safety laws.[197] This ruling does not prohibit their use but means that carbon nanotubes used in the work place are supposed to be accompanied by a data safety sheet.

PHOTO BY LUIS MIGUEL BUGALLO SÁNCHEZ VIA WIKIMEDIA COMMONS

8. Environmental risks

The United Kingdom's Royal Society and Royal Academy of Engineering has called for the environmental release of nanomaterials 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."[198]

However, the use of products containing nanomaterials is already leading to the release of nanomaterials into the environment. Based on current trends this will increase rapidly. Waste and waste water from production, abrasion through manufacturing and use, disposal, incineration and recycling may all lead to the release of manufactured nanomaterials - as will the use of pesticides and fertilizers containing nanomaterials.

Since the publication of our 2008 report new insights into the environmental risks posed by nanomaterials have emerged, but the data is still inadequate to assess the dangers posed by the release of nanomaterials into the environment. However, a number of available studies give cause for concern.

In May 2013, a group of US scientists published the first global assessment of the likely emissions of nanomaterials into the environment and landfills. It was estimated that in 2010, 260,000–309,000 tonnes of global nanomaterial production ended up in landfills (63–91%), soils (8–28 %), water bodies (0.4–7 %), and the atmosphere (0.1–1.5 %). According to the authors, more accurate estimates of nanomaterial emissions were hampered by the lack of available data on use.[199]

The annual worldwide market for nanomaterials is estimated to be around 11 million tonnes. By far the largest share of the nanomaterials currently on the market is industrial carbon (85% by weight) and silica (12% by weight). Nanoscale titanium and nano-silver are believed to be the most used nanomaterials in food and food contact materials.[200]

Anti-microbial 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 agricultural and food industry may cause environmental harm. This is especially true for antibacterial nanomaterials such as nano-silver which is increasingly being added to food packaging and food contact materials including cling wrap, chopping boards, cutlery and food storage containers.

As the European Commission's Scientific Committee on Emerging and Newly Identified Health Risks has noted, "the increasing use of Ag-NPs [nano-silver] in consumer and medical applications implies that they will find their way into the environment. The activity that makes them desirable as an antimicrobial agent could also pose a threat to the microbial communities in the environment."[201]

Nano-silver waste that is not recycled will end up in the environment "either as solid waste in landfills, emission from wastewater treatment plants, or as residual waste from incineration plants."[202] One study estimated that up to 20 tons of silver from biocidal uses would be discharged to the European environment in wastewaters.[203] The rapidly growing number of products containing nano-silver certainly creates the possibility of a 'mass discharge into the environment'.[204]

Impacts on aquatic ecosystems
A recent review of toxicological research on nanometal oxides silver, copper and zinc oxide reported that they are extremely toxic to freshwater aquatic organisms including fish and algae, with crustaceans being most affected.[205]

Titanium dioxide, one of the most widely used nanomaterials, caused organ pathologies, biochemical disturbances, and respiratory distress in rainbow trout.[206] Nano titanium dioxide is also toxic to algae and to water fleas, especially after exposure to UV light.[207; 208]

Impacts on soils
According to a US study, emissions to soils represent up to about a quarter of nanomaterial flows, mostly from the disposal of biosolids onto agricultural land. This is concerning, since studies have shown that nanomaterials can potentially harm beneficial soil microorganisms, plants, nematodes and earthworms – and prevent nitrogen fixation.[209; 210; 211] In Australia, we produce approximately 300,000 dry tonnes of biosolids annually. Approximately 55% of this is applied to agricultural land.[212] A recent study by Colman *et al.* found an adverse impact on plants and microorganisms in a long-term field experiment following the application of sewage biosolids containing a low dose of nano-silver.[213] The nano-silver treatment led to changes in microbial community composition, biomass, and extracellular enzyme activity, as well as affecting some of the above ground plant species. It also led to an increase in nitrous oxide (N_2O) fluxes. This is significant as nitrous oxide is a notorious greenhouse gas, with 296 times the global warming potential of carbon dioxide.

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.[214]

Bioaccumulation of nanomaterials
A number of studies have shown that plant species can take up nanomaterials from soils.[215; 216; 217]

This suggests a potential route for nanomaterials from sewage waste to return into the food chain. A recent report by the European Environment Agency concluded that "the extent to which specific nanomaterials are bioaccumulative or lead to irreversible impact is largely unknown, but the current state of knowledge suggest[s] that the potential exists for such behavior under some circumstances"[218]

Risks from pesticides and fertilisers with nanoscale active ingredients
The use of pesticides with nanoscale active ingredients may pose particular risks because nanomaterials, which are more potent and behave differently to conventional chemicals, are applied in large quantities and over large areas in broadscale agriculture.

Conventional agrochemicals such as pesticides, fertilisers and seed treatments have already contributed to soil and water pollution, have caused significant disturbance of ecosystems and resulted in the loss of biodiversity.[219] There is a danger that the broad use of nano-chemicals will exacerbate existing problems.

Concerns regarding nano-fertilisers include chronic exposure of soil microbes and microfauna to levels of chemical reactivity that may be toxic and bioaccumulation of nanoparticles in soil.[220] US Department of Agriculture scientists have raised concerns about the potential impacts of nanomaterials on soil bioreactivity, the effect of soil type variation on bioreactivity and the "likelihood of extreme variability in the dose-response levels between different NPs [nanoparticles] and the microbial populations that regulate plant performance."[221]

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

Nanotechnology also appears likely to intensify existing trends towards ever larger industrial scale farming operations, and an even more narrow focus on producing specialised crops.[222; 223] This could lead to further losses of agricultural and ecological diversity.

9. Research needs

Scientists currently lack the information and tools necessary to do basic risk assessments for most nanomaterials. The European Food Safety Authority (EFSA) has admitted that risk assessments for nano-products in food and feed will inevitably have significant uncertainties, because testing methods and data on risk and exposure are missing.[224]

In relation to food, there are significant gaps in our knowledge including information on:

- The extent to which nanomaterials from packaging, surfaces and coatings migrate into foods;
- Where nanomaterials are distributed in the human body following ingestion;
- The long term chronic effects of ingesting nanomaterials, including impacts on sensitive populations;
- How nanomaterials interact with the human body and in the environment;[225]
- How and where and in what quantities nanomaterials enter the environment;[226]
- Once nanomaterials are released how durable they are and the extent to which they are transformed in the environment; [227; 228]
- The fate, behaviour and ecotoxicity of nanomaterials throughout their life cycle;
- How to characterise, track and detect nanomaterials in complex environments.[229]

In 2012 the US National Research Council (NRC) set out an environment, health and safety (EHS) research strategy for beginning to deal with the gigantic gaps in knowledge surrounding the environmental and human health impacts of nanomaterials. That research strategy became part of the National Nanotechnology Initiative (NNI) in the US, in what was supposed to be an integrated, collaborative effort by many departments to ensure that the development of nanotechnology industries was done well.

A year later, the NRC report, *Research Progress on EHS Aspects of Engineered Nanomaterials*[230], analysed progress to date. Of the 20 indicators the NRC used to assess progress, there has been little or no progress in 19.

These are not simply arcane research priorities but the basic research and knowledge that are needed both to understand, identify, assess, control and remediate potential impacts. It is the kind of knowledge that is necessary if we are going to have coherent regulation that ensures nanoproducts that aren't safe aren't released and that if unpredicted impacts occur, we have the tools to deal with them.

10. Australian Federal Regulatory Framework

Despite there being effectively no regulation of the use of nanomaterials in food and agriculture in Australia, there are a number of regulatory agencies that could regulate the use of nanomaterials in these sectors. In order for that to occur, however, regulators need to fill in the gaps in current regulations that were identified in a 2007 government commissioned review of nanotechnology and regulation.[231] Despite a growing body of peer-reviewed literature that suggests that potentially serious health and environmental concerns are associated with some nanomaterials, the regulatory response to nanomaterials in food and agriculture has generally been to avoid intervention.

Food Standards Australia New Zealand (FSANZ) is the primary agency responsible for ensuring the safety of food and food contact materials and for ensuring labelling requirements are followed. The agency has stated that it will require a risk assessment of "novel nano-particulates in the event that we receive an Application."[232]

FSANZ has amended its Application Handbook so that in cases where "particle size is important in achieving the technological function or may relate to a difference in toxicity" the applicant must provide details of the nature, distribution, morphology and size–dependent properties. This applies to food additives, processing aids and nutritive substances.[233]

This sounds more useful than it is. It appears that this does not necessarily apply to foods already approved for sale in Australia but which may now contain nanomaterials.[234] Equally, FSANZ has made clear that no proactive steps are being taken to ascertain whether nanomaterials in foods are already being unknowingly eaten by Australians.

FSANZ's response to nanomaterials in food packaging inspires even less confidence. "The responsibility rests with retailers to ensure their products are safe."[235] The absence of a register means that FSANZ does not know what nanomaterials in packaging are on the market in Australia. The lack of oversight will make the detection of any potential harm to human health slower and the tracking of the cause of harm much more difficult. This standard compares poorly to EU legislation, which requires authorisation for food packaging materials and food supplements that contain nanomaterials.[236]

Currently, there is no requirement to label foods that contain nanomaterials. The 2011 Federal Government food labelling review recommended labelling of products using new technologies. The Government's entire response was, 'not to pursue'.[237]

The TGA (Therapeutic Goods Association) regulates any therapeutic good, including supplements, which commonly contain nanomaterials. To date, the TGA has not regulated any nanomaterial nor have they specifically addressed the issue of nanomaterials in supplements. They note that "Therapeutic products containing nanomaterials in the form of metal oxides, liposomes, polymer protein conjugates, polymeric substances and suspensions have been registered in Australia," but have not taken steps to assess or regulate, concluding that there is 'no evidence' that therapeutic goods containing nanomaterials pose a greater risk than those containing bulk sized particles.[238] It is somewhat disturbing that this claim was written in 2008 and has not been updated despite significant volumes of peer reviewed work questioning that conclusion.

The APVMA (Australian Pesticide and Veterinarian Medicines Association) is responsible for nanomaterials contained in pesticides or veterinary medicines up to the point of retail sale. At that point the states become responsible. The APVMA, unlike FSANZ and other regulators has concluded that "existing substances reformulated at the nanoscale would be treated as new substances."[239]

The APVMA has a registration requirement for products containing nanomaterials if they are deemed 'novel'. They claim that "assessment of agricultural and veterinary chemicals and chemical products currently registered in Australia has not identified any to contain engineered nanomaterials"[240] This directly contradicts the evidence presented in this report.

The APMVA has registered one animal vaccine containing nanomaterials.

The Department of the Environment is responsible for regulating releases that may impact on 'matters of national environmental significance'.[241] They looked at the issue in 2010.[242] They are also responsible for advising on the environmental impacts of applications for use of nanomaterials by other agencies (such as the APVMA) but have no regulations relating to release. State Governments generally regulate waste, water treatment and most other water issues, but it appears no state has addressed the growing quantity of nanomaterial entering the waste stream.

11. Conclusion

We live in an era where public investment in science for the public good is rapidly being replaced by private investment for private interests. We live in an era where deregulation has become an ideological necessity and regulatory interventions are seen as impeding the growth of commerce - not as acts that protect the public interest.

Regulators not only resist regulation, they don't look for evidence of harm and when evidence is presented they resist, claiming uncertainty prevents them from acting —even though the uncertainty is in part a result of their own failure to act.

Contrary to the claims of a number of Australian regulators, nanomaterials are in the Australian food chain and are in agrochemicals being used in Australia. Appendix 1 lists just some of the products containing nanomaterials that are available in Australia.

Now it is up to those regulators to act and demand what they have promised – an assessment of the environmental health and safety of these nanomaterials.

The failure to treat new and powerful technologies with the kind of care that they demand is more than just a failure of regulation. It also highlights systemic problems in research and academic institutions and attitudes in industry towards risk that border on the negligent.

Nanotechnology is only one of a number of emerging powerful technologies and it is time to think about these technologies differently.

The recommendations that follow are designed to ensure that we have regulation that doesn't get left behind due to commercial pressures; that public interest science is made central to nanotechnology R&D; and that the Australian public can be active participants in making decisions about how and where nanotechnology is used in Australia.

Recommendations

1 A mandatory and public register of all nanomaterials and all products containing nanomaterials produced, imported and sold or used in Australia;

2 A moratorium on new releases of nanomaterials and products containing nanomaterials, pending a full safety assessment;

3 A comprehensive and precautionary regulatory regime for nanomaterials with all nanomaterials subject to environmental health and safety (EHS) assessment as new substances, even where the properties of large scale counterparts are well known;

- Assessment 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;
- Assessment must include a full life cycle analysis of the product;
- Social and cultural implications of nanotechnology's expansion into food and agriculture must be addressed along with EHS assessments;
- All relevant data related to EHS assessments and decisions made must be in the public domain.

4 The development and full funding of the environmental, health and safety research priorities identified by the US National Research Council;

5 A single agreed definition of nanotechnology based on a particle size of up to 300 nm and the specific qualities of the nanomaterial;

6 That all products containing nanomaterials for sale in Australia be labelled as such, ensuring consumer choice;

7 The public must be involved in all aspects of decision making regarding the use of nanotechnology in the food and agricultural sectors. The right to say no to nanotechnology must be ensured;

8 Begin the transition away from industrial agricultural and food models to a model based on sustainability.

APPENDIX 1

Table 1: Examples of food and agriculture products containing nanomaterials available in Australia

Category	Product	Manufacturer	Nano-content	Information from manufacturer
NANOMATERIALS IN FOOD PRODUCTS, INCLUDING SUPPLEMENTS				
Additives	HDK – Silica for feed and food as a drug carrier, tableting aid, anti-caking agent.	Wacker Chemie AG	Nano-silica	Trademark issued in Australia 2003 http://www.ipaustralia.com.au/applicant/wacker-chemie-ag/trademarks/973229/
Supplement	Nu-skin CoQ10	Nu-Skin enterprises	Coenzyme Q11	Nanotechnology Q10 as very fine particles Available from: http://www.fishpond.com.au/Health/NuSkin-Nu-Skin-Pharmanex-Nano-CoQ10/0338535211814
Supplement	Nano colloidal silver	Nano Silver	Nano-silver	Antibacterial, claims to strengthen the immune system http://www.fishpond.com.au/Health/Nano-Silver-40ppm-Colloidal-Silver-350mls-Each-Bottle-Small-Particle-Size-for-Superior-Effectiveness/0091131320204?gclid=CMLUwLDDsb0CFQZ9vQodI64ATQ Also, http://oz-organic-health.com/ and http://colloidalsilverasia.com/ - supplies Australian companies
NANOMATERIALS IN FOOD CONTACT MATERIALS, INCLUDING PACKAGING				
Packaging	Bairicade XT	NanoPack	Nano-clay 250 nm	Nano-clay layer for snacks, nuts, spices, sweets, coffee and tea http://www.nanopackinc.com/products.asp

Water filters	Water filter	Various	Nano-silver	http://www.alibaba.com/showroom/nano-silver-water-filter.html
Kitchen utensils	GreenPan Frying pan Thermolo	GreenPan	Polymer-ceramic-Nano-matrix	Available through various suppliers, eg www.everten.com.au/GreenPan;www.thefind.com/kitchen/info-cookware-9.5%22-fry-pan http://www.mnn.com/food/healthy-eating/stories/is-greenpan-cookware-really-green
Kitchen utensils	Cookware with nanosilver	Various	Nano-silver	http://www.tradekorea.com/products/2211/1/NANO_SILVER.html
Cleaning products	Zielotex cleaning cloth	Zielonka	Nano-silver	http://www.alibaba.com/showroom/nano-silver-cloth.html
Coating	Nanopool	Nanopool	Nano-silica 100 nm	Antibacterial coatings for tablecloths, oven, grill and refrigerators
NANOMATERIALS IN AGRICULTURAL PRODUCTS				
Agrochemical	Headway MAXX Banner MAXX Fungizid	Syngenta	Unspecified nano content	These pesticides are marketed as micro-emulsions.
Agrochemical	Nano-Gro	Agro Nanotechnologiy Corporation	Unspecified nano content	“the first plant growth stimulator based on nanotechnology” http://www.agronano.com/nanogro.htm
Vitamins for animals	KER	Nano-E	Nanodispersed vitamin E to be added to food	http://www.vetnpetdirect.com.au/kerx_nano_e

Table 2: Examples of products in the food and agriculture sectors containing nanomaterials produced in Australia

Category	**Product**	**Manufacturer**	**Nano-content**	**Information from manufacturer**
NANOMATERIALS IN FOOD PRODUCTS, INCLUDING SUPPLEMENTS				
Supplements	Nano-glutamine, nano creatine	Advanced Sports Nutrition	Unspecified nano content	http://www.asn-nutrition.com.au/index.php/products/item/nano-glutamine
Nano encapsulation, nano-particles	Product names not provided on website	Herames	Nano-silver, silica, silica oxide,alumina-oxide, titania-titanium-dioxide	http://www.hermesco.net/nano-structures.html
NANOMATERIALS IN FOOD CONTACT MATERIALS, INCLUDING PACKAGING				
Coatings	Liquid nano glass	Nanopools	Silicon dioxide	http://www.businessinsider.com.au/million-dollar-idea-spraying-liquid-glass-on-clothes-and-furniture-creates-an-instant-stain-and-bacteria-shield-2011-3
Coatings	DIY coatings for surfaces including kitchens	Nanokote	Unspecified nano content even in safety data sheet	http://www.nanokote.com.au/n/glass-ceramics SDS: http://www.nanokote.com.au/downloads/File/pdf/MSDS-Nanokote-Glass-and-Ceramics-Coating-DIY-Kit.pdf
Packaging	Fresh Produce Bags		Unspecified nano content	http://www.centurymail.com.au/shopping/kitchen/ Promises 30 days extra shelf-life
Packaging	Packaging boxes	Nanobox	Nano-silver	http://www.gohospitality.com.au/c/Hopack/Nanobox-Paper-Food-Packaging-by-Hopack-p101019
NANOMATERIALS IN AGRICULTURAL PRODUCTS				
Agrochemical	Herbagreen, Vitaflora (plant nutrients and fertisliers) Nanofeed, megamin (animals supplements)	Nano Growth Technologies	Unspecified nano content	http://www.ngtech.com.au/www.ngtech.com.au/index.htm
Anti-bacterials for animals		Herames	Unspecified nano content	http://www.hermesco.net/bio-and-medical.html

12. References

1. Blewett, N. *et al.* (2011) *Labelling Logic Review of Food Labelling Law and Policy*, http://www.foodlabellingreview.gov.au/internet/foodlabelling/publishing.nsf/content/labelling-logic (accessed 31 March 2014)

2. Garnett M, Kallinteri P. (2006) Nanomedicines and nanotoxicology: some physiological principles. *Occup Med* **56**:307-31

3. Maynard A. (2006) Nanotechnology: Assessing the risks. *Nanotoday* **1(2)**:22-33

4. Miller, G. & Senjen, R. (2008) *Out of the Laboratory and onto our Plates: nanotechnology in food and agriculture*, Friends of the Earth Australia, http://nano.foe.org.au/node/220 (accessed 23 April 2014)

5. Sayes C, Wahi R, Kurian P, Liu Y, West J, Ausman K, Warheit D, Colvin V. (2006) Correlating nanoscale titania structure with toxicity: A cytotoxicity and inflammatory response study with human dermal fibroblasts and human lung epithelial cells. *Toxicol Sci* **92(1)**:174–185

6. NICNAS working definition for 'industrial nanomaterial', http://www.nicnas.gov.au/communications/issues/nanomaterials-nanotechnology/nicnas-working-definition-for-industrial-nanomaterial (accessed 7 April 2014)

7. FoEA (2013) ACCC refuses to tackle widespread misleading conduct in the sunscreen industry http://nano.foe.org.au/accc-refuses-tackle-widespread-misleading-conduct-sunscreen-industry (accessed 23 April 2014)

8. Publication d'un premier bilan du dispositif national de déclaration des substances à l'état nanoparticulaire. http://www.developpement-durable.gouv.fr/spip.php?page=article&id_article=35990 (accessed 7 April 2014)

9. Woodrow Wilson International Centre for Scholars, Consumer Products Inventory, 2012, 2013, http://www.nanotechproject.org/cpi/

10. FAO/WHO (2010) *Expert meeting on the application of nanotechnologies in the food and agriculture sectors: potential food safety implications*, http://whqlibdoc.who.int/publications/2010/9789241563932_eng.pdf (accessed 7 April 2014)

11. LGL Bayern (Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit) (2012) *Nanomaterialien in Lebensmitteln und Verbraucherprodukten. Anwendungsbereiche, Analytik, rechtliche Rahmenbedingungen*, http://www.lgl.bayern.de/publikationen/doc/nanomaterialien_lebensmittel_produkte.pdf (accessed 7 April 2014)

12. See e.g. Kraft position on nanotechnology, http://www.kraftfoodsgroup.com/DeliciousWorld/food-safety-quality/nanotech.aspx (accessed 7 April 2014)

13. Innovest (2006). *Nanotechnology: Non-traditional Methods for Valuation of Nanotechnology Producers*. Innovest, Strategic Value Advisers

14. Wolfe J. (2005) Safer and guilt-free nano foods. Forbes.com, 10 August 2005, http://www.forbes.com/investment-newsletters/2005/08/09/nanotechnology-kraft-hershey-cz_jw_0810soapbox_inl.html (accessed 7 April 2014)

15. Renton A. (2006). Welcome to the world of nano foods. Guardian Unlimited UK 13 December 2006, http://observer.guardian.co.uk/foodmonthly/futureoffood/story/0,,1971266,00.html#article_continue (accessed 7 April 2014)

16. See e.g. Evonik, Selective Studies on Fumed Silica, http://nano.evonik.com/sites/nanotechnology/en/responsibility/safety-research/studies-on-fumed-silica/pages/default.aspx (accessed 7 April 2014)

17. Van der Zande, M. *et al.* (2014) Sub-chronic toxicity study in rats orally exposed to nanostructured silica, *Particle and Fibre Toxicology* **11**:8

18. Dekkers S, Krystek P, Peters RJ, Lankveld DX, Bokkers BG, van Hoeven-Arentzen PH, Bouwmeester H, Oomen A.G. (2011) Presence and risks of nanosilica in food products. *Nanotoxicology*, **5**:393–405

19. Weir, A. *et al.* (2012) Titanium dioxide nanoparticles in food and personal care products, *Environmental Science and Technology* **46**:2242-2250

20. TA Swiss (Zentrum für Technologiefolgen-Abschätzung) (2009) Nanotechnology in the Food Sector, http://www.ta-swiss.ch/nanofood/#downloads (accessed 7 April 2014)

21. Allied Biotech Europe GmbH (2012) http://www.altratene.com/dietary.php (accessed 7 April 2014)

22. F.J. Gutiérrez *et al.* (2013) Methods for the nanoencapsulation of b-carotene in the food sector, *Trends in Food Science & Technology* **32**:73-83

23. Miller, G. & Senjen, R. (2008) *Out of the Laboratory and onto our Plates: nanotechnology in food and agriculture*, Friends of the Earth Australia, p. 13

24. Leatherhead Food Research (2011) Long may the growth in functional foods continue, http://www.leatherheadfood.com/long-may-the-growth-in-functional-foods-continue (accessed 7 April 2014)

25. Bundesministerium für Gesundheit Österreich (2010) Zusatzstoffe, Aromen und Enzyme in der Lebensmittelindustrie, http://bmg.gv.at/cms/home/attachments/7/1/6/CH1250/CMS1288096887525/druckversion_zusatzstoffpaket_neu_30072010.pdf (accessed 23 April 2014)

26. Institut für Technikfolgen-Abschätzung der Österreichischen Akademie der Wissenschafte (2008) Nano trust Dossiert Nr. 004 Nanopartikel und nanostrukturierte Materialien in der Lebensmittelindustrie, http://epub.oeaw.ac.at/ita/nanotrust-dossiers/dossier004.pdf (accessed 7 April 2014)

27. FAO/WHO (2010) Expert meeting on the application of nanotechnologies in the food and agriculture sectors: potential food safety implications, http://whqlibdoc.who.int/publications/2010/9789241563932_eng.pdf, p13, (accessed 5 March 2014)

28. BASF (2000) ExAct, no. 4, April 2000, pp. 11-13, http://www2.basf.us/Pharma/pdf/ExAct_04.pdf (accessed 23 April 2014)

29. Supplements Direct, http://www.supplementsdirect.com.au/asn-nano-creapure-creatine-200g/ (accessed 5 March 2014)

30. High performance food antioxidants, http://neu.aquanova.de/likecms.php?dir=&site=index.html&siteid=47&nav=62 (accessed 4 April 2014)

31. Nanosized carotenoid cyclodextrin complexes – patent description, http://www.google.com.au/patents/US7781572 (accessed 4 April 2014)

32. Soutter, W. (2012) Nanotechnology in Functional Foods, http://www.azonano.com/article.aspx?ArticleID=3065#Introduction (accessed 7 April 2014)

33. FoodSafety magazine (2012) Potential Use of Edible nanoscale Coatings for Meat, http://www.foodsafetymag-digital.com/foodsafetymag/20120607?pg=4#pg54 (accessed 10 March 2014); Fraunhofer (2010) Nano-Anwendungen in der Lebensverpackung, http://www.nanowissen.bayern.de/docs/franz_fraunhoferivv.pdf and http://www.ube.de/index.html (both accessed 8 August 2012)

34. Schneider, A. (2010) Regulated or Not, Nano-Foods Coming to a Store Near You, http://www.aolnews.com/2010/03/24/regulated-or-not-nano-foods-coming-to-a-store-near-you (accessed 7 April 2014)

35. Roach S. (2006) Most companies will have to wait years for nanotech's benefits. Foodproductiondaily.com 21 August 2006, http://www.foodproductiondaily.com/news/ng.asp?id=69974 (accessed 17 January 2008).

36. FAO/WHO (2010) Expert meeting on the application of nanotechnologies in the food and agriculture sectors: potential food safety implications. Online at, http://whqlibdoc.who.int/publications/2010/9789241563932_eng.pdf, p4. (accessed 5 March 2014)

37. Helmut Kaiser Consultancy Group (2007) Nanopackaging Is Intelligent, Smart And Safe Life. New World Study By Hkc22.com/beijingOffice. Press Release 14.05.07, http://www.prlog.org/10016688 nanopackaging-isintelligent-smart-and-safe-life-newworld-study-by-hkc22-com-beijing-office.pdf (accessed 28 April 2014)

38. Reynolds G. (2007) FDA recommends nanotechnology research, but not labelling. FoodProductionDaily.com News 26 July 2007, http://www. foodproductiondaily-usa.com/news/ng.asp?n=78574-woodrow-wilsonnanotechnologyhazardous (accessed 24 January 2008)

39. Media release: Global Nano Packaging Market 2013-2023 - Opportunities for Nanotechnology, October 07, 2013, http://www.prweb.com/releases/2013/10/prweb11202425.htm (accessed 5 March 2014)

40. AzoNano (2007) Advanced Nanotechnology gets grant for food packaging. Nanotechnology News Archive, http://www.azonano.com/news.asp?newsID=3177 (accessed 28 April 2014)

41. Bayer undated. Securely wrapped: Nanoparticles make Durethan® films airtight and glossy. *Bayer Research* **15**:34-37, http://www.research.bayer.com/edition_15/15_polyamides.pdfx (accessed 15 December 2007)

42. Lagarón J, Cabedo L, Cava D, Feijoo J, Gavara R, Gimenez E. (2005) Improved packaging food quality and safety. Part 2: *Nano-composites. Food Additives and Contaminants* **22**(10):994-998

43. Sorrentino A, Gorrasi G, Vittoria V. (2007) Potential perspectives of bio-nanocomposites for food packaging applications. *Trends Food Sci Technol* **18**:84-95

44. CSIRO, Smart Product Packaging, http://www.csiro.au/Outcomes/Food-and-Agriculture/Packaging-Overview.aspx. Web page suggests this coating is commercially available. (accessed 10 March 2014)

45. BfR (Bundesinsitut für Risikobewertung) (2009) Die Datenlage zur Bewertung der Anwendung der Nanotechnologie in Lebensmitteln und Lebensmittelbedarfsgegenständen ist derzeit noch unzureichend, http://www.bfr.bund.de/cm/343/die_datenlage_zur_bewertung_der_anwendung_der_nanotechnologie_in_lebensmitteln.pdf (accessed 7 August 2012)

46. LGL Bayern (Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit) (2012) *Nanomaterialien in Lebensmitteln und Verbraucherprodukten. Anwendungsbereiche, Analytik, rechtliche Rahmenbedingungen*, http://www.lgl.bayern.de/publikationen/doc/nanomaterialien_lebensmittel_produkte.pdf (accessed 24/10/2013)

47. BfR (Bundesinsitut für Risikobewertung) (2009) *Die Datenlage zur Bewertung der Anwendung der Nanotechnologie in Lebensmitteln und Lebensmittelbedarfsgegenständen ist derzeit noch unzureichend.* http://www.bfr.bund.de/cm/343/die_datenlage_zur_bewertung_der_anwendung_der_nanotechnologie_in_lebensmitteln.pdf (accessed 7 August 2012)

48. A polymer/clay nanocomposite having improved gas barrier comprising a clay material with a mixture of two or more organic cations and a process for preparing same patent, http://www.ipaustralia.com.au/applicant/university-of-south-carolina-research-foundation/patents/AU2000020400/ (accessed 10 March 2014)

49. Multilayer Containers Featuring Nano-Nylon MXD6 Barrier Layers with Superior Performance and Clarity, presentation by Mitsubishi Gas Chemical Co and Nanocor, undated, http://www.nanocor.com/tech_papers/NOVAPACK03.pdf (accessed 10 March 2014)

50. AzoNano (2007) Advanced Nanotechnology gets grant for food packaging. Nanotechnology News Archive, http://www.azonano.com/news.asp?newsID=3177 (accessed 18 January 2008)

51. LeGood P, Clarke A. (2006) Smart and active materials to reduce food waste. SMART.mat, http://amf.globalwatchonline.com/epicentric_portal/binary/com.epicentric.contentmanagement.servlet. ContentDeliveryServlet/AMF/smartmat/Smartandactivepackagingtoreducefoodwaste.pdf (accessed 17 January 2008)

52. Foodproduktiondaily.com (2010) Fraunhofer develops nano-thin coating to enhance shelf life,http://www.foodproductiondaily.com/Packaging/Fraunhofer-develops-nano-thin-coating-to-enhance-shelf-life (accessed 10 March 2014)

53. j-tech systems, http://www.jtechsystems.com.au/News-Innovation/ArtMID/469/ArticleID/3/ripeSense174 (accessed 24 March 2014)

54. Method and apparatus for chemical detection and release, patent application, http://pericles.ipaustralia.gov.au/ols/auspat/applicationDetails.do?applicationNo=2009329868 (accessed 26 March 2014)

55. Miller, G. & Senjen, R. (2008) *Out of the Laboratory and onto our Plates: nanotechnology in food and agriculture*, Friends of the Earth Australia

56. Transforming Research and Education in Chemical Engineering, http://www.uq.edu.au/research/research-at-uq/chemical-engineering, (accessed 10 March 2014)

57. Starch nanocomposite materials patent, http://pericles.ipaustralia.gov.au/ols/auspat/applicationDetails.do?applicationNo=2008255573 (accessed 9 April 2014)

58. Plantic homepage, www.plantic.com.au, (accessed 10 March 2014)

59. Biodegradeable polymer patent, http://pericles.ipaustralia.gov.au/ols/auspat/applicationDetails.do?applicationNo=2002248988 (accessed 26 March 2014)

60. ETC Group (2004) *Down on the Farm*, http://www.etcgroup.org (accessed 17 January 2008)

61. Green J, Beestman G. (2007) Recently patented and commercialized formulation and adjuvant technology. Crop Protect 26:320-327

62. Joseph T, Morrison M. (2006) Nanotechnology in Agriculture and Food. Nanoforum Report, http://www.nanoforum.org/dateien/temp/nanotechnology%20in%20agriculture%20and%20food.pdf?08122006200524 (accessed 17 January 2008)

63. Hofmann, T. & Kah. M. (2012) Department für Umweltgeowissenschaften an der Universität Wien. Nano-pesticides in Agriculture: Opportunity or Risk? http://medienportal.univie.ac.at/presse/aktuelle-pressemeldungen/detailansicht/artikel/nano-pestizide-in-der-landwirtschaft-chance-oder-risiko/ (accessed 10 March 2014);

64. Kah, M. *et al.* (2013) Nanopesticides: State of Knowledge, Environmental Fate, and Exposure Modeling, *Critical Reviews in Environmental Science and Technology* **43**:16, 1823-1867

65. *Ibid*

66. Nano-technologien.com (2012) Nano in Agriculture, http://www.nano-technologien.com/nano-in-landwirtschaft (accessed 10 March 2014)

67. Petersen, B.B., P.J. Shea, and G.A. Wicks (1988) Acetanilide activity and dissipation as affected by formulation and wheat stubble. *Weed Sci.* **36**:243-249

68. Methods to produce polymer nanoparticles and formulations of active ingredients patent, http://www.ipaustralia.com.au/applicant/vive-nano-inc/patents/AU2009295586/

69. Subdue Maxx directions for use, http://amgrow.com.au/commerce/nuturf/label151.pdf (accessed 9 April 2014)

70. Cheminova website, chyella http://www.ospray.com.au/en/products/insecticides/cyhell.htm (accessed 9 April 2014)

71. Crop Protection Manual, http://aceohlsson.com.au/resources/crop-protection-manual.pdf (accessed 9 April 2014)

72. Agrochemical formulation comprising encapsulated pesticide patent, http://pericles.ipaustralia.gov.au/ols/auspat/applicationDetails.do?applicationNo=2012206618 (accessed 9 April 2014)

73. Agrochemical formulation comprising encapsulated pesticide patent application, http://pericles.ipaustralia.gov.au/ols/auspat/quickSearch.do?queryString=2012210662&includeAbstractText=on&resultsPerPage= (accessed 28 April 2014)

74. Herbicidal combination patent, http://pericles.ipaustralia.gov.au/ols/auspat/applicationDetails.do?applicationNo=2005315777 (accessed 9 April 2014)

75. Herbicidal combination patent specification document, http://pericles.ipaustralia.gov.au/ols/auspat/pdfSource.do?fileQuery=p%82%8D%85%88%7D%7CU%89%8D%81%7B%83%3E%7E%81%84%7D%86y%85%7DUYmJHHMKIMOOOYIJHHOHNHOF%88%7C%7E%3E%87%8E%7D%8AU%8C%80%7D (accessed 9 April 2014)

76. Hofmann, T. & Kah. M. (2012) *Nano-pesticides in Agriculture: Opportunity or Risk?* Department für Umweltgeowissenschaften an der Universität Wien. http://medienportal.univie.ac.at/presse/aktuelle-pressemeldungen/detailansicht/artikel/nano-pestizide-in-der-landwirtschaft-chance-oder-risiko/ (accessed 10 March 2014)

77. Surfactants and Microemulsions, IUPAC definition, http://surfactantsandmicroemulsions.wordpress.com/microemulsion/iupac-definition/ (accessed 2 April 2014)

78. Greencast website, Banner Maxx turf fungicide, http://www.greencast.com.au/media/275157/100921%20banner%20maxx%20label.pdf (accessed 9 April 2014)

79. Crop Care website, http://search.cropcare.com.au/default.asp?V_DOC_ID=1&function=SearchResults&CompanyID=275295&StartIndex=1&ProductName=AC&MaxReturn=9999&GroupBy=Active&PestGenie=N&MasterTypeID=0&SearchType=All&SelectedList= (accessed 2 April 2014)

80. Turf Culture, Thumper Miticide and Nematicide production description, http://www.turfculture.com.au/App_Save/Products/7dcb9a0f-0048-47ed-b155-c3cc6c0dd6fd/filePDFInfo.pdf (accessed 2 April 2014)

81. Etpturf.com, plant growth regulators, http://www.etpturf.com.au/index.php/products/plant-growth-regulators (accessed 2 April 2014)

82. Crop Protection Manual, http://www.aceohlsson.com.au/resources/crop-protection-manual.pdf (accessed 2 April 2014)

83. Government of South Australia, Cereal Seed Treatments, 2011, http://www.coxrural.com.au/media/Cropping%20Guides/CerealSeedTreatments2011-A4.pdf (accessed 2 April 2014)

84. Bozorgi, HO. (2012) Effects of Foliar Spraying with Marine Plant Ascophyllum Nodosum Extract and Nano Iron Chelate Fertilizer on Fruit Yield and Several Attributes of Eggplant (*Solanum melongena L.*) *Journal of Agricultural & Biological Science* **7(5)**:357-362

85. Dow AgroSciences, www.dowagro.com/au (accessed 27 March 2014)

86. Institute of Technology of the Austrian Academy of Science. What are synthetic nanoparticles; nanoemulsions, http://www.arhiv.mkgp.gov.si/fileadmin/mkgp.gov.si/pageuploads/EFSA/nov11/collected_dossiers_E.pdf (accessed 4 April 14)

87. Sekhon, B. (2010) Food Nanotechnology: An overview. *Nanotechnol Sci Appl* **3**:1-15

88. Regulating Pesticides that Use Nanotechnology. July 2011. US Environmental Protection Agency, http://www.epa.gov/pesticides/regulating/nanotechnology.html (accessed 8 April 2014)

89. Kah, M. *et al.* (2013) Nanopesticides: State of Knowledge, Environmental Fate, and Exposure Modeling, *Critical Reviews in Environmental Science and Technology* **43**:16, 1823-1867

90. Microcapsule suspensions including high levels of agriculturally active ingredients, patent application, http://pericles.ipaustralia.gov.au/ols/auspat/pdfSource.do?fileQuery=%60w%7EmzEj-zw%7Fv.nqtmviumEI%5D%3A899%3A%3E%3C%3E9%3BI9%3A89%3B89986xln.ti%82%81Ejzw%7Fv (accessed 8 April 2014)

91. Kah, M. *et al.*(2013) Nanopesticides: State of Knowledge, Environmental Fate, and Exposure Modeling, *Critical Reviews in Environmental Science and Technology*, **43**:16, 1823-1867

92. Bozorgi, HO. (2012) Effects of Foliar Spraying with Marine Plant Ascophyllum Nodosum Extract and Nano Iron Chelate Fertilizer on Fruit Yield and Several Attributes of Eggplant (*Solanum melongena L.*). *Journal of Agricultural & Biological Science*, **7(5)**:357-362

93. Xiao *et al.* (2008) Effects of slow/controlled release fertilizers felted andcoated by nano-materials on crop yield and quality. *Plant Nutrition and Fertilizer Science* 2008-05

94. Alibaba online, http://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=nano+fertilizer (accessed 7 April 2014)

95. Nano-organic Fertilizer Enhances Agro Production, http://neareast.fao.org/Pages/NewsDetails.aspx?ID=2400992&lang=EN&I=104171&CMSId=5001120 (accessed 8 April 2014)

96. DeRosa, M.C. *et al.* (2010) Nanotechnology in Fertilizers. *Nature Nanotechnology* **5**:91

97. Golden Group Company,http://www.goldengroupcoo.com/our-products-and-services/our-products/25-nano-liquid-fertilizer (accessed 7 April 2014)

98. Chaudhry, Q. and Castle, L. (2011) Food applications of nanotechnologies: An overview of opportunities and challenges for developing countries. *Trends in Food Science and Technology* **22(11)**:595–603

99. Application of nano-zinc oxide as animal feed additives (PAT - CN101218959), http://europepmc.org/patents/PAT/CN101218959;jsessionid=XnrmYDzJPSpn8L0pmuMt.20 (accessed 10 April 2014)

100. Shijiazhuang Metal Billion Import & Export Co., Ltd, http://www.alibaba.com/product-detail/animal-feed-used-active-zinc-oxide_1223358669.html (accessed 8 April 2014)

101. Hangzhou Vega Company, http://www.alibaba.com/product-detail/Chicken-feed-nano-zinc-oxide-animal_1770527708.html (accessed 8 April 2014)

102. FAO (2010) AGES (Österreichische Agentur für Gesundheit und Ernährungssicherheit). NANO-Nahrungsergänzungsmittel und Bioverfügbarkeit, http://nanotrust.ac.at/BMG2010/20100218_riediger.pdf (accessed 23 July 2012)

103. Nanotechnology in Animal Feed, http://www.allaboutfeed.net/Nutrition/Feed-Additives/2013/3/Nano-technology-in-animal-feed-1194836W/ (accessed 9 April 2014)

104. Chen *et al.* (2014) ACS Select on Nanotechnology in Food and Agriculture: A Perspective on Implications and Applications, *J of Agric Food Chem* **62(6)**:1209-1212

105. Handy, R.D. (2012) FSBI Briefing Paper Nanotechnology in Fisheries and Aquaculture, Fisheries Society of the British Isles, http://www. org.uk/assets/brief-nanotechnology-fisheriesaquaculture.pdf, (accessed 10 March 2014)

106. Sarchet, P. (2013) Nanotech's role in feeding the planet, http://www.theguardian.com/what-is-nano/nanotech-feeding-the-planet-nanotech-s-role-in-feeding-the-planet (accessed 27 March 2014)

107. FAO (2006) The state of food insecurity in the world, ftp://ftp.fao.org/docrep/fao/009/a0750e/a0750e00.pdf (accessed 17 January 2008)

108. World Health Organisation, Obesity and Overweight fact sheet, http://www.who.int/mediacentre/factsheets/fs311/en/ (accessed 25 March 2014)

109. FAO (2007) Achieving the right to food – the human rights challenge of the twenty-first century. World Food Day 16 October 2007, http://www.fao.org/fileadmin/templates/wfd2007/pdf/WFDLeaflet2007E.pdf (accessed 17 January 2008)

110. Why Agriculture Needs Young People, http://codrinpo.com/2014/03/24/why-agriculture-needs-young-people (accessed 10 April 2014)

111. U.S. DoA ERS (2005) *New Directions in Global Food Markets*. Regmi A and Gelhar M (Eds).Agriculture Information Bulletin Number 794, http://www.ers.usda.gov/publications/aib794/aib794.pdf (accessed 17 January 2008)

112. Reardon T, Timmer C, Barrett C, Berdegué J. (2003) The rise of supermarkets in Africa, Asia, and Latin America. *Am J Ag Econ* **5**:1140-1146

113. WHO Europe (2007) Proposed Second WHO European Action Plan for Food and Nutrition Policy 2007–2012. Regional Committee for Europe Fifty-seventh session Belgrade, Serbia,17–20 September 2007, http://www.euro.who.int/en/health-topics/disease-prevention/food-safety/policy/who-european-action-plan-for-food-and-nutrition-policy-20072012 (accessed 27 March 2014)

114. Scrinis G & Lyons K. (2007) The emerging nano-corporate paradigm: Nanotechnology and the transformation of nature, food and agri-food systems. *Internat J Sociol Agric and Food*, **15**(2), http://www.csafe.org.nz/ (accessed 2 March 2008)

115. TA Swiss (Zentrum für Technologiefolgen-Abschätzung) (2009) Nanotechnology in the Food Sector, http://www.ta-swiss.ch/nanofood/#downloads (accessed 10 March 2014)

116. EFSA (2009) The Potential Risks Arising from Nanoscience and Nanotechnologies on Food and Feed Safety, http://www.efsa.europa.eu/en/efsajournal/doc/958.pdf (accessed 10 March 2014)

117. Chen Z, Meng H, Xing G, Chen C, Zhao Y, Jia G, Wang T, Yuan H, Ye C, Zhao F, Chai Z, Zhu C, Fang X, Ma B, Wan L. (2006b) Acute toxicological effects of copper nanoparticles in vivo. *Toxicol Lett* **163**:109-120

118. Desai M, Labhasetwar V, Amidon G, Levy R. (1996) Gastrointestinal uptake of microparticles: Effect of particle size. *Pharm Res* **13(12)**:1838-1845

119. Hillyer J, Albrecht R. (2001) Gastrointestinal persorption and tissue distribution of differently sized colloidal gold nanoparticles. *J Pharm Sci* **90(12)**:1927-1936

120. Wang B, *et al.* (2007) Acute toxicological impact of nano- and submicro-scaled zinc oxide powder on healthy adult mice. *J Nanopart Res* **10(2)**:263-276

121. Wang J, *et al.* (2007) Acute toxicity and biodistribution of different sized titanium dioxide particles in mice after oral administration. *Toxicol Lett* **168(2)**:176-185

122. Hazzard R, Hodges G, Scott J, McGuinness C, Carr E. (1996) Early intestinal microparticle uptake in the rat. *J Anat* **189**:265-271

123. McMinn L, Hodges G, Carr K. (1996) Gastrointestinal uptake and translocation of microparticles in the streptozotocin-diabetic rat. *J Anatom* **189**:553-559

124. Wang B, Feng W-Y, Wang T-C, Jia G, Wang M, Shi J-W, Zhang F, Zhao Y-L, Chai Z-F. (2006) Acute toxicity of nano- and micro-scale zinc powder in healthy adult mice. *Toxicol Lett* **161**:115–123

125. Ballestri M, Baraldi A, Gatti A, Furci L, Bagni A, Loria P, Rapana R, Carulli N, Albertazzi A. (2001) Liver and kidney foreign bodies granulomatosis in a patient with malocclusion, bruxism, and worn dental prostheses. *Gastroenterol* **121(5)**:1234–8

126. Gatti A, Rivasi F. (2002) Biocompatibility of micro- and nanoparticles. Part I: in liver and kidney. *Biomaterials* **23**:2381–2387

127. LUBW (Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg) (2010) Nanomaterialien: Toxikologie/Ökotoxikologie, http://www.lubw.baden-wuerttemberg.de/servlet/is/62024/U10-S05-N10.pdf?command=downloadContent&filename=U10-S05-N10.pdf (accessed 25 July 2012)

128. SRU (Sachverständigenrat für Umweltfragen) (2011) *Vorsorgestrategien für Nanomaterialien*, http://www.umweltrat.de/SharedDocs/Downloads/DE/02_Sondergutachten/2011_09_SG_Vorsorgestrategien%20f%C3%BCr%20Nanomaterialien.pdf?__blob=publicationFile (accessed 9 July 2012)

129. Spiegel online (2012) Nanopartikel verändern Eisenaufnahme im Darm, http://www.spiegel.de/wissenschaft/medizin/diskussion-um-gefahren-nanopartikel-veraendern-eisenaufnahme-im-darm-a-814794.html (accessed 15 July 2012)

130. Powell JJ, Faria N, Thomas-McKay E, Pele LC. (2010) Origin and fate of dietary nanoparticles and microparticles in the gastrointestinal tract. *J Autoimmun* **34**:J226–J233; Powell JJ, Ainley CC, Harvey RSJ, Mason IM, Kendall MD, Sankey EA, *et al.* (1996) Characterisation of inorganic microparticles in pigment cells of human gut associated lymphoid tissue. *Gut* **38**:390–95

131. Ashwood P, Thompson R, Powell J. (2007) Fine particles that adsorb lipopolysaccharide via bridging calcium cations may mimic bacterial pathogenicity towards cells. *Exp Biol Med* **232(1)**:107-117

132. Gatti A, Tossini D, Gambarelli A. (2004) Investigation Of Trace Elements In Bread Through Environmental Scanning Electron Microscope And Energy Dispersive System. 2nd International IUPAC Symposium, Brussels, October 2004

133. Lomer M, Harvey R, Evans S, Thompson R, Powell P. (2001) Efficacy and tolerability of a low microparticle diet in a double blind, randomized, pilot study in Crohn's disease. *Eur J Gastroenterol Hepatol* **13**:101-106

134. Lucarelli M, Gatti A, Savarino G, Quattroni P, Martinelli L, Monari E, Boraschi D. (2004) Innate defence functions of macrophages can be biased by nano-sized ceramic and metallic particles. *Eur Cytok Net* **15(4)**:339-346

135. SRU (Sachverständigenrat für Umweltfragen) (2011) Vorsorgestrategien für Nanomaterialien. http://www.umweltrat.de/SharedDocs/Downloads/DE/02_Sondergutachten/2011_09_SG_Vorsorgestrategien%20f%C3%BCr%20Nanomaterialien.pdf?__blob=publicationFile (accessed 9 July 2012)

136. Oberdörster G, Oberdörster E, Oberdörster J. (2005) Nanotoxicology: an emerging discipline from studies of ultrafine particles. *Environ Health Perspect* **113(7)**:823-839

137. Chen, Z. *et al.* (2006) Acute toxicological effects of copper nanoparticles in vivo. *Toxicol Lett* **163**:109-120

138. Brunner T, *et al.* (2006) In Vitro Cytotoxicity of Oxide Nanoparticles: Comparison to Asbestos, Silica, and the Effect of Particle Solubility. *Environ Sci Technol* **40**:4374-4381

139. Chen Z. *et al.* (2006) Acute toxicological effects of copper nanoparticles in vivo. *Toxicol Lett* **163**:109-120

140. Long T. *et al.* (2006) Titanium dioxide (P25) produces reactive oxygen species in immortalized brain microglia (BV2): Implications for nanoparticle neurotoxicity. *Environ Sci Technol* **40(14)**:4346-4352

141. Magrez A. *et al.* (2006) Cellular toxicity of carbon-based nanomaterials. *Nano Lett* **6(6)**:1121-1125

142. European Food Safety Authority (2009) Scientific Opinion of the Panel on Plant Protection Products and their Residues (PPR), http://www.efsa.europa.eu/de/efsajournal/doc/1171.pdf (accessed 17 July 2012)

143. Eidgenössische Materialprüfungs- und Forschungsanstalt (2011) *Ten Years of Assessment of Nanomaterials,* http://www.bi-ozid.info/deutsch/aktuelles/meldung/?tx_ttnews[tt_news]=89&cHash=77f53ff8b00b1dd02f12dcbc0a78c798 (accessed 13 March 2014)

144. Umweltbundesamt (2009) *Nanotechology for Humans and the Environment*, http://www.umweltdaten.de/publikationen/fpdf-l/3765.pdf (accessed 13 March 2014)

145. European Food Safety Authority (2009) Scientific Opinion of the Panel on Plant Protection Products and their Residues (PPR), http://www.efsa.europa.eu/de/efsajournal/doc/1171.pdf (accessed 17 July 2012)

146. Umweltbundesamt (2009) Nanotechology for Humans and the Environment, http://www.umweltdaten.de/publikationen/fpdf-l/3765.pdf (accessed 13 March 2014)

147. Ballestri M. *et al.* (2001) Liver and kidney foreign bodies granulomatosis in a patient with malocclusion, bruxism, and worn dental prostheses. *Gastroenterol* **121(5)**:1234–8

148. Gatti A, Rivasi F. (2002) Biocompatibility of micro- and nanoparticles. Part I: in liver and kidney. *Biomaterials* **23**:2381–2387

149. Gatti A. (2004) Biocompatibility of micro- and nano-particles in the colon. Part II. *Biomaterials* **25**:385-392

150. Bundesinsitut für Risikobewertung und Umweltbundesamt (2010) Beurteilung eines möglichen Krebsrisikos von Nanomaterialien und von aus Produkten freigesetzten Nanopartikeln, http://www.bfr.bund.de/cm/343/beurteilung_eines_moeglichen_krebsrisikos_von_nanomaterialien_und_von_aus_produkten_freigesetzten_nanopartikeln.pdf (accessed 3 July 2012)

151. Nishimori H, Kondoh M, Isoda K, Tsunoda S, Tsutsumi Y, Yagi K. (2009) Histological analysis of 70-nm silica particles-induced chronic toxicity in mice. Eur J Pharm Biopharm 72:626–629; Nishimori H, Kondoh M, Isoda K, Tsunoda S, Tsutsumi Y, Yagi K (2009) Silica nanoparticles as hepatotoxicants. Eur J Pharm Biopharm, 72:496–501; Liu T, Li L, Fu C, Liu H, Chen D, Tang F (2012) Pathological mechanisms of liver injury caused by continuous intraperitoneal injection of silica nanoparticles. *Biomaterials* **33**:2399–2407; Cho M, Cho WS, Choi M, Kim SJ, Han BS, Kim SH, Kim HO, Sheen YY, Jeong J. (2009) The impact of size on tissue distribution and elimination by single intravenous injection of silica nanoparticles. *Toxicol Lett* **189**:177–183; Lu X, Tian Y, Zhao Q, Jin T, Xiao S, Fan X (2011) Integrated metabonomics analysis of the size-response relationship of silica nanoparticles-induced toxicity in mice. *Nanotechnology* **22**:055101; Downs TR, Crosby ME, Hu T, Kumar S, Sullivan A, Sarlo K, Reeder B, Lynch M, Wagner M, Mills T, Pfuhler S. (2012) Silica nanoparticles administered at the maximum tolerated dose induce genotoxic effects through an inflammatory reaction while gold nanoparticles do not. *Mutat Res* **745**:38–50; Xie G, Sun J, Zhong G, Shi L, Zhang D (2010) Biodistribution and toxicity of intravenously administered silica nanoparticles in mice. *Arch Toxicol* **84**:183–190.

152. Dekkers S, Bouwmeester H, Bos P, Peters RJ, Rietveld A, Oomen AG (2013) Knowledge gaps in risk assessment of nanosilica in food: evaluation of the dissolution and toxicity of different forms of silica. *Nanotoxicology* **7**:11

153. Van der Zande, M. *et al.* (2014) Sub-chronic toxicity study in rats orally exposed to nanostructured silica. *Particle and Fibre Toxicology* **11**:8

154. Dekkers S, Krystek P, Peters RJ, Lankveld DX, Bokkers BG, van Hoeven-Arentzen PH, Bouwmeester H, Oomen A.G. (2011) Presence and risks of nanosilica in food products. *Nanotoxicology* **5**:393–405

155. Scientific Committee on Emerging and Newly Identified Health Risks (2013) *Preliminary Opinion, Nanosilver: safety, health and environmental effects and role in antimicrobial resistance*, December 2013, p 21, http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_039.pdf (accessed 13 March 2014)

156. NRDC vs. US EPA and Heiq Materials AG (2013), http://cdn.ca9.uscourts.gov/datastore/opinions/2013/11/07/12-70268.pdf (accessed 7 April 2014)

157. Scientific Committee on Emerging and Newly Identified Health Risks (2013) *Preliminary Opinion, Nanosilver: safety, health and environmental effects and role in antimicrobial resistance*, December 2013, p 21-22, 24, http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_039.pdf (accessed 13 March 2014)

158. BfR (Bundesinstitut für Risikobewertung) 2010. *BfR rät von Nanosilber in Lebensmitteln und Produkten des täglichen Bedarfs ab*, http://www.bfr.bund.de/cm/343/bfr_raet_von_nanosilber_in_lebensmitteln_und_produkten_des_taeglichen_bedarfs_ab.pdf (accessed 12 August 2012)

159. Correia Carreira, S. (2013) The toxicity, transport and uptake of nanoparticles in the in vitro BeWo b30 placental cell barrier model used within NanoTEST, *Nanotoxicology* 1-14, http://informahealthcare.com/doi/pdf/10.3109/17435390.2013.833317

160. Browning, L.M. (2013) Silver Nanoparticles Incite Size- and Dose-Dependent Developmental Phenotypes and Nanotoxicity in Zebrafish Embryos, *Chem. Res. Toxicol.* **26**(10):1503–1513

161. FoEA (2011) Nano-silver: policy failure puts public health at risk, http://nano.foe.org.au/sites/default/files/Nano-silver_2011%20Aus%20v2%20web.pdf (accessed 27 March 2014)

162. ECHA (2013) *Justification document for the selection of a CoRAP substance – Titanium Dioxide*, http://echa.europa.eu/documents/10162/37e258fd-f57a-4957-b978-4f18fe593938 (accessed 24 March 2014)

163. ChemEurope.com (2009) Nanoparticles used in common household items caused genetic damage in mice, http://www.chemeurope.com/en/news/109581/nanoparticles-used-in-common-household-items-caused-genetic-damage-in-mice.html (accessed 27 July 2012)

164. Ashwood P. *et al.* (2007) Fine particles that adsorb lipopolysaccharide via bridging calcium cations may mimic bacterial pathogenicity towards cells. *Exp Biol Med* **232(1)**:107-117

165. Donaldson K. *et al.* (1996) Free radical activity associated with the surface of particles: a unifying factor in determining biological activity? *Toxicol Lett* **88**:293-298

166. Dunford R, Salinaro A, Cai L, Serpone N, Horikoshi S, Hidaka H, Knowland J. (1997) Chemical oxidation and DNA damage catalysed by inorganic sunscreen ingredients. *FEBS Lett* **418**:87-90

167. Long T, Saleh N, Tilton R, Lowry G, Veronesi B. (2006) Titanium dioxide (P25) produces reactive oxygen species in immortalized brain microglia (BV2): Implications for nanoparticle neurotoxicity. *Environ Sci Technol* **40(14)**:4346-4352

168. Lucarelli M, Gatti A, Savarino G, Quattroni P, Martinelli L, Monari E, Boraschi D. (2004) Innate defence functions of macrophages can be biased by nano-sized ceramic and metallic particles. *Eur Cytok Net* **15(4)**:339-346

169. Wang J, Zhou G, Chen C, Yu H, Wang T, Ma Y, Jia G, Gai Y, Li B, Sun J, Li Y, Jiao F, Zhano Y, Chai Z. (2007b) Acute toxicity and biodistribution of different sized titanium dioxide particles in mice after oral administration. *Toxicol Lett* **168(2)**:176-185

170. *Ibid*

171. Bundesinsitut für Risikobewertung und Umweltbundesamt (2010) *Beurteilung eines möglichen Krebsrisikos von Nanomaterialien und von aus Produkten freigesetzten Nanopartikeln*, http://www.bfr.bund.de/cm/343/beurteilung_eines_moeglichen_krebsrisikos_von_nanomaterialien_und_von_aus_produkten_freigesetzten_nanopartikeln.pdf (accessed 3 July 2012)

172. Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (2010) *Nanomaterialien: Toxikologie/*Ökotoxikologie, http://www.lubw.baden-wuerttemberg.de/servlet/is/62024/U10-S05-N10.pdf?command=downloadContent&filename=U10-S05-N10.pdf (accessed 25 July 2012)

173. Takeda, K. *et al.* (2009) Nanoparticles Transferred from Pregnant Mice to Their Offspring Can Damage the Genital and Cranial Nerve Systems. *Journal of Health Science* **55(1)**:95–102, http://jhs.pharm.or.jp/data/55%281%29/55_95.pdf

174. Weir, A. *et al.* (2012) Titanium dioxide nanoparticles in food and personal care products. *Environmental Science and Technology* **46**:2242-2250

175. Scientific Committee on Consumer Safety (2012) *Opinion on zinc oxide (nano form), COLIPA S 76*, pp. 30, 93, http://ec.europa.eu/health/scientific_committees/consumer_safety/docs/sccs_o_103.pdf, (accessed 7 April 2014)

176. *Ibid*, p. 96

177. *Ibid*

178. aid Informationsdienst (2011) *Nanotechnologien bei Lebensmitteln*, http://www.aid.de/shop/pdf/0085_2011_nanoflyer_x000.pdf (accessed 30 July 2012); Allied Biotech Europe GmbH (2012), http://www.altratene.com/dietary.php (accessed 22 July 2012)

179. Bundesinsitut für Risikobewertung (2012) *Nanosilver: Progress in analysis, gaps in toxicology and exposure*, http://www.bfr.bund.de/de/presseinformation/2012/08/nanosilber__fortschritte_in_der_analytik__luecken_bei_toxikologie_und_exposition-128936.html (accessed 1 August 2012)

180. ElAmin, A. (2007) Carbon nanotubes could be new pathogen weapon, http://www.foodproductiondaily.com/Safety-Regulation/Carbon-nanotubes-could-be-new-pathogen-weapon (accessed 8 April 2014)

181. Whitworth, J. (2014) Carbon nanotube sensors detect food dye, http://www.foodqualitynews.com/Innovation/Carbon-nanotube-sensor-detects-food-dyes

182. Bourzac, K. (2009) Carbon nanotubes are super fertilizers, http://www.technologyreview.com/view/415456/carbon-nanotubes-are-super-fertilizer/ (accessed 8 April 2014)

183. Safe Work Australia (2012) *Human Health Hazard Assessment and Classification of Carbon Nanotubes*, http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/725/Human_Health_Hazard_Assessment_and_Classification_of_Carbon_%20Nanotubes.pdf (accessed 13 March 2014)

184. Miller, G. & Senjen, R. (2008) *Out of the Laboratory and onto our Plates: nanotechnology in food and agriculture*, Friends of the Earth Australia

185. Woodrow Wilson International Centre for Scholars (2009) A Hard Pill to Swallow: Barriers to Effective FDA Regulation of Nanotechnology-based Dietary Supplements, http://www.nanotechproject.org/process/assets/files/7056/pen17_final.pdf (accessed 13 March 2014)

186. Franz R. (2005) Migration modelling from food-contact plastics into foodstuffs as a new tool for consumer exposure estimation. Food Additives and Contaminants **22(10)**: 920–937

187. Das R., Selke S. & Harte J. (2007) Development of electronic nose method for evaluation of HDPE flavour characteristics correlated with organoleptic testing. *Packaging Technology and Science* **20**:125-136

188. IFST (2006) Information Statement: Nanotechnology. Institute of Food Science & Technology Trust Fund, London, http://www.ifst.org/uploadedfiles/cms/store/ATTACHMENTS/Nanotechnology.pdf (accessed 15 January 2008)

189. FAO/WHO (2010) Expert meeting on the application of nanotechnologies in the food and agriculture sectors: potential food safety implications, http://whqlibdoc.who.int/publications/2010/9789241563932_eng.pdf, p18. (accessed 5 March 14)

190. See e.g. Evangelia E Ntzani, Chondrogiorgi M, Ntritsos G, Evangelou E, Tzoulaki I. Literature review on epidemiological studies linking exposure to pesticides and health effects. EFSA supporting publication 2013:EN-497, http://www.efsa.europa.eu/en/supporting/doc/497e.pdf. (accessed 9 April 2014)

191. *Nanomaterials in Agricultural Pesticides.* Center for Nanotechnology in Society. Arizona State University, http://nice.asu.edu/nano/nanomaterial-applications-agricultural-pesticides (accessed 8 April 2014)

192. Kah, M. *et al.* (2013) Nanopesticides: State of Knowledge, Environmental Fate, and Exposure Modeling, *Critical Reviews in Environmental Science and Technology* **43**:16, 1823-1867

193. *Ibid*

194. EFSA (2009) The Potential Risks Arising from Nanoscience and Nanotechnologies on Food and Feed Safety, http://www.efsa.europa.eu/en/efsajournal/doc/958.pdf (accessed 10 March 2014)

195. Scientific Committee on Consumer Safety (2012) *Opinion on zinc oxide (nano form), COLIPA S 76*, p. 96, http://ec.europa.eu/health/scientific_committees/consumer_safety/docs/sccs_o_103.pdf; Scientific Committee on Consumer Safety (2013) *Opinion on titanium dioxide (nano form)*, http://ec.europa.eu/health/scientific_committees/consumer_safety/docs/sccs_o_136.pdf (both accessed 13 March 2014)

196. Oberdörster G, Maynard A, Donaldson K, Castranova V, Fitzpatrick J, Ausman K, Carter J, Karn B, Kreyling W, Lai D, Olin S, Monteiro-Riviere N, Warheit D, Yang H. (2005) Principles for characterising the potential human health effects from exposure to nanomaterials: elements of a screening strategy. *Particle Fibre Toxicol* **2**:8

197. Safe Work Australia (2012) *Human Health Hazard Assessment and Classification of Carbon Nanotubes*, http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/725/Human_Health_Hazard_Assessment_and_Classification_of_Carbon_%20Nanotubes.pdf (accessed 13 March 2014)

198. RS/RAE (Royal Society / Royal Academy of Engineering) (2004) *Nanoscience and nanotechnologies: opportunities and uncertainties*, http://www.nanotec.org.uk/finalReport.htm, Section 5.7: paragraph 63 (accessed 5 July 2012)

199. Keller, A.A. et al. (2013) *Global life cycle releases of engineered nanomaterials, J Nanopart Res* **15**:1692

200. EU Commission (2012) Chemicals Thematic studies for Review of REACH 2012. Review of EU legislation (REACH) concerning nanotechnology, http://ec.europa.eu/enterprise/sectors/chemicals/documents/reach/review2012/nanotechnology_en.htm (accessed 21 November 2012)

201. Sweet *et al.* (2011) cited in Scientific Committee on Emerging and Newly Identified Health Risks (2013) *Preliminary Opinion, Nanosilver: safety, health and environmental effects and role in antimicrobial resistance*, December 2013, p 16, http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_039.pdf (accessed 13 March 2014)

202. Scientific Committee on Emerging and Newly Identified Health Risks (2013) *Preliminary Opinion, Nanosilver: safety, health and environmental effects and role in antimicrobial resistance*, December 2013, p 4, http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_039.pdf (accessed 13 March 2014)

203. Blahttp://pericles.ipaustralia.gov.au/ols/auspat/applicationDetails.do?applicationNo=2005315777ser, S.A. M Scheringer, M Macleod and K. Hungerbuhler (2008) Estimation of cumulative aquatic exposure and risk due to silver: Contribution of nano-functionalized plastics and textiles. *Science of the Total Environment* **390**: 396-409

204. Luoma, S., (2008) *Silver Nanotechnologies and the Environment: Old problems or new challenges?* http://www.nanotechproject.org/process/assets/files/7036/nano_pen_15_final.pdf

205. Bondarenko O, Juganson K, Ivask A, Kasemets K, Mortimer M, Kahru A. (2013) Toxicity of Ag, CuO and ZnO nanoparticles to selected environmentally relevant test organisms and mammalian cells in vitro: a critical review. *Archives of Toxicology* **87(7)**:1181-200

206. Federici G, Shaw B, Handy R. (2007) Toxicity of titanium dioxide nanoparticles to rainbow trout (*Oncorhynchus mykiss*): Gill injury, oxidative stress, and other physiological effects. *Aquatic Toxicol* **84(4)**:415-430

207. Hund-Rinke K, Simon M. (2006) Ecotoxic effect of photocatalytic active nanoparticles (TiO2) on algae and daphnids. *Environ Sci Poll Res* **13(4)**:225-232

208. Lovern B, Klaper R. (2006) *Daphnia magna* mortality when exposed to titanium dioxide and fullerene (c60) nanoparticles. *Environ Toxicol Chem* **25(4)**:1132-1137

209. Ruitenberg, R. (2013) Earthworm Health Hurt by Nanoparticles in Soil in Alterra Study, Bloomberg, www.bloomberg.com/news/2013-01-29/earthworm-health-hurt-by-nanoparticles-in-soil-in-alterra-study.html

210. Unrine, J.M. *et al.* (2013) Trophic transfer of Au nanoparticles from soil along a simulated terrestrial food chain. *Environ Sci Technol* **46(17)**:9753-9760

211. Priester, J.H. (2012) Soybean susceptibility to manufactured nanomaterials with evidence for food quality and soil fertility interruption, *PNAS* **109(37)**: 14734–14735

212. Australian & New Zealand Biosolids Partnership (2009) Benefits of land application, http://www.biosolids.com.au/benefits-land-application.php

213. Colman, B.P. *et al.* (2013) Low Concentrations of Silver Nanoparticles in Biosolids Cause Adverse Ecosystem Responses under Realistic Field Scenario, *PLOS ONE* **8(2)**:1-10

214. Melhus A. (2007) Silver threatens the use of antibiotics. Unpublished manuscript, received by email 30 January 2007

215. Colman, B.P. *et al.* (2013) Low Concentrations of Silver Nanoparticles in Biosolids Cause Adverse Ecosystem Responses under Realistic Field Scenario, PLOS ONE, 8(2):1-10

216. Priester, J.H. (2012) Soybean susceptibility to manufactured nanomaterials with evidence for food quality and soil fertility interruption, *PNAS* **109(37)**: 14734–14735

217. Hernandez-Viezcas, J.A. (2013) In Situ Synchrotron X-ray Fluorescence Mapping and Speciation of CeO2 and ZnO Nanoparticles in Soil Cultivated Soybean (*Glycine max*). *ACS Nano* **7 (2)**:1415–1423

218. Hanson, S.F. *et al.* (2013) Nanotechnology – early lessons from early warnings, from *Late lessons from early warnings: science, precaution, innovation*, EEA Report No 1/2013, Ch 22, p 542

219. Miller, G. & Senjen, R. (2008) *Out of the Laboratory and onto our Plates: nanotechnology in food and agriculture*, Friends of the Earth Australia

220. Suppan, S. (2013) Nanomaterials in Soil. Our future food chain? The Institute for Agriculture and Trade Policy, http://www.iatp.org/files/2013_04_23_Nanotech_SS.pdf (accessed 8 April 2014)

221. *Ibid*

222. ETC Group (2004) *Down on the Farm*, http://www.etcgroup.org (accessed 17 January 2008)

223. Scrinis G and Lyons K. (2007) The emerging nano-corporate paradigm: Nanotechnology and the transformation of nature, food and agri-food systems. *Internat J Sociol Agric and Food* **15(2)**, http://www.csafe.org.nz/ (accessed 2 March 2008)

224. EFSA (2008) Inability to assess the safety of a silver hydrosol added for nutritional purposes as a source of silver in food supplements and the bioavailability of silver from this source based on the supporting dossier, http://www.efsa.europa.eu/de/efsajournal/doc/884.pdf (accessed 10 March 2014)

225. Hanson, S.F. *et al.* (2013) Nanotechnology – early lessons from early warnings, from Late lessons from early warnings: science, precaution, innovation, EEA Report No 1/2013, Ch 22

226. Royal Commission on Environmental Pollution (2008) Novel Materials in the Environment: The case of nanotechnolgy, http://nanotech.law.asu.edu/Documents/2009/07/Michael%20Vincent%20Royal%20Commission%20on%20Enviro%20Pollution%20%282008%29,%20Novel%20Ma_169_2476.pdf (accessed 10 March 2014)

227. NRC (2013) Research Progress on Environmental, Health, and Safety Aspects of Engineered Nanomaterials, http://www.nap.edu/catalog.php?record_id=18475 (accessed 27 March 2014)

228. Sachverständigenrat für Umweltfragen (2011) Vorsorgestrategien für Nanomaterialien, http://www.umweltrat.de/SharedDocs/Downloads/DE/02_Sondergutachten/2011_09_SG_Vorsorgestrategien%20f%C3%BCr%20Nanomaterialien.pdf?__blob=publicationFile (accessed 19 July 2012)

229. NRC (2013) *Research Progress on Environmental, Health, and Safety Aspects of Engineered Nanomaterials*, http://www.nap.edu/catalog.php?record_id=18475 (accessed 27 March 2014)

230. NRC (2013) *Research Progress on Environmental, Health, and Safety Aspects of Engineered Nanomaterials*, http://www.nap.edu/catalog.php?record_id=18475 (accessed 27 March 2014)

231. Ludlow, K., Bowman, D. & Hodge, G. (2007) *A Review of Possible Impacts of Nanotechnology on Australia's Regulatory Framework*, http://nano.foe.org.au/sites/default/files/Review%20of%20Nanotechnology%20Regulation%20in%20Australia%20-%20Monash%20Report%20July%202008.pdf (accessed 27 March 2014)

232. Fletcher, N. & Bartholomaeus, A. (2011) Regulation of Nanotechnologies in Food in Australia and New Zealand, *International Food Risk Analysis Journal* **33**, http://www.intechopen.com/source/pdfs/26273/InTech-Regulation_of_nanotechnologies_in_food_in_australia_and_new_zealand.pdf (accessed 27 March 2014)

233. NRC (2013) *Research Progress on Environmental, Health, and Safety Aspects of Engineered Nanomaterials*, p 35, http://www.nap.edu/catalog.php?record_id=18475 (accessed 27 March 2014),

234. Fletcher, N. & Bartholomaeus, A. (2011) Regulation of Nanotechnologies in Food in Australia and New Zealand, *International Food Risk Analysis Journal* **33**, http://www.intechopen.com/source/pdfs/26273/InTech-Regulation_of_nanotechnologies_in_food_in_australia_and_new_zealand.pdf (accessed 27 March 2014)

235. Fletcher, N. & Bartholomaeus, A. (2011) Regulation of Nanotechnologies in Food in Australia and New Zealand, *International Food Risk Analysis Journal* **33**:35

236. EU Commission (2011) Plastic Implementation Measure (PIM), EU Directive 10/2011 on plastic materials and articles intended to come into contact with food, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:012:0001:0089:EN:PDF (accessed 10 March 2014)

237. Review of Food Labelling Law and Policy (2011), http://www.foodlabellingreview.gov.au/internet/foodlabelling/publishing.nsf/content/ADC308D3982EBB24CA2576D20078EB41/$File/FoFR%20response%20to%20the%20Food%20Labelling%20Law%20and%20Policy%20Review%209%20December%202011.pdf, (accessed 10 March 2014)

238. TGA (2008) Nanotechnology and therapeutic products, http://www.tga.gov.au/industry/nanotechnology-qa.htm#.Uy-9l_mSzwI (accessed 10 April 2014)

239. Australian Pesticides and Veterinary Medicines Authority, *Nanotechnology and Agvet Chemicals*, http://www.apvma.gov.au/supply/nanotechnology/index.php (accessed 24 March 2014)

240. Australian Pesticides and Veterinary Medicines Authority, *Nanotechnology and Agvet Chemicals*, http://www.apvma.gov.au/supply/nanotechnology/ (accessed 24 March 2014)

241. Environment Protection and Biodiversity Conservation Act 1999. See, http://www.environment.gov.au/topics/about-us/legislation/environment-protection-and-biodiversity-conservation-act-1999/what (accessed 27 March 2014)

242. CSIRO (2010) *Fate of Manufactured Nanomaterials in the Australian Environment*, http://www.environment.gov.au/system/files/pages/371475a0-2195-496d-91b2-0a33f9342a6d/files/manufactured-nanomaterials.pdf (accessed 7 April 2014)

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