NANOTECHNOLOGY

and how it will affect the world

by
Alex Pokrovsky & Alan Smith

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INTRODUCTION

Technologies seem to come along in waves. We have seen electronics leading on to all the devices we know today, and biotechnology has resulted in improvements in healthcare. Nanotechnology is in its infancy and is expected to have just as much impact over the next twenty years.

Nanotechnology gets its name from the ancient Greek word *nanos*, which means 'dwarf' or 'very tiny'. However, that does not give an accurate idea of just how small a nanometre is.

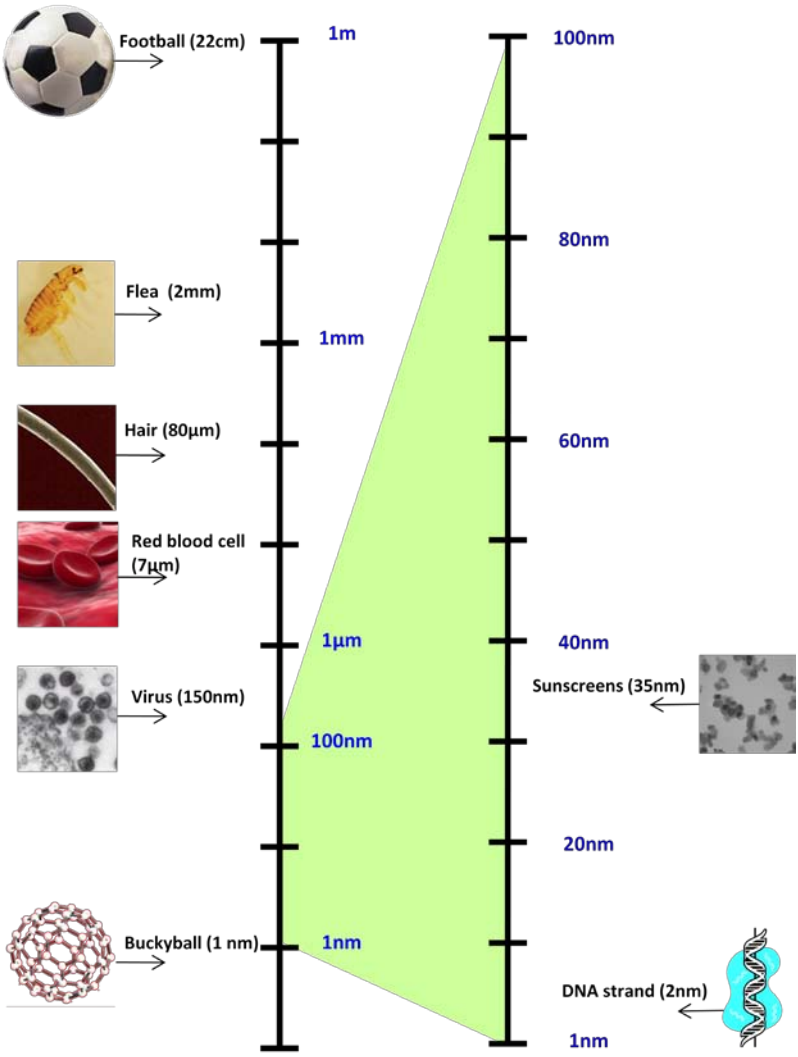
A nanometre is one billionth of a metre, or one millionth of a millimetre – it is fairly difficult to imagine something that small!

1 nanometre (nm) x 1,000 = 1 micrometre (µm)
1 micrometre (µm) x 1,000 = 1 millimetre (mm)
1 millimetre (mm) x 1,000 = 1 metre (m)

To help you appreciate just how small a nanometre is - a human hair is about 100,000 nanometres across. If a gull landed on the deck of an aircraft carrier, the battleship would sink lower in the water by about one nanometre.

A typical nanoparticle is about 30 nm in diameter. If you multiplied that by one hundred million it would be about the size of a football. If you multiplied the football by one hundred million, it would be the size of the moon.

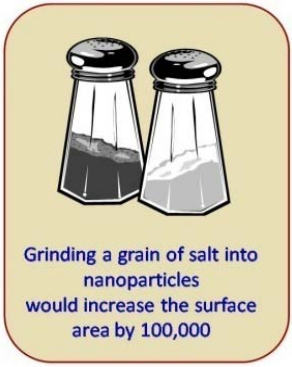
The following diagram helps to show the size of things. When talking about nanotechnology, scientists usually mean about 1 nm to 100 nm.



A normal optical microscope that you find in schools enables you to see the fine hairs on a fly's leg fairly easily, but it cannot look at the nano scale. For that you need something more powerful. The scanning tunnelling microscope (STM) is a type of electron microscope that shows three-dimensional images of a sample. With an STM, the structure of a surface is studied using a stylus that scans the surface at a fixed distance from it.

To bring the scale of things home to you, imagine a 1 centimetre cube of something, for example a cube of sugar, then around one in ten million of the atoms are actually on the surface of the cube. If it was a nanometre cube of sugar, then 80% of the atoms are on the surface. It is because of all these atoms that are now available to do things, which has aroused all the recent interest in nanotechnology.

A grain of sand from a beach would take 34 million years to dissolve if it was left to stand in a glass of water. However, if it was a nanometre cube of sand it would take about a second to dissolve!



These dramatic changes that occur at the nano-scale are just some of the examples of how properties can be altered. In fact, changes can occur with the strength of materials, the weight of plastics, the colour of things, the electronic properties

of materials, the heat resistance of materials, and a whole host of other properties.

An interesting example, of nanotechnology in action, is the gecko. It can run upside down on the sealing all because of nanotechnology. It has nano-sized hairs on its toes which individually are attracted to the ceiling by a very small force, but when it has millions of these nano-hairs on each toe then it can hold on very well. In fact, if you tied a weight to the gecko, equivalent to its own body weight, then it would still be able to run along the ceiling really fast.

There are lots of examples of nanotechnology in nature, where creatures and plants have evolved over millions of years to make use of properties at the nano-scale in the most efficient manner. Scientists are now trying to copy applications that have evolved in nature, and this is known as ‘biomimetics’.

These and other applications are now being used in everyday things that we come across all the time. Some of these are described in the following pages.

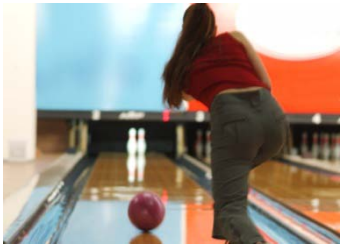
TRANSPORT

The trend with motor cars is to replace as much of the metal as possible with lighter weight plastics. It has been found that by using what have become known as nanocomposites, strong, lighter weight polymeric materials are a good replacement for many metal components in automobiles. These nanocomposite materials provide more miles per gallon because of the weight saving, and they are basically normal plastics, but with around 20% of clay materials incorporated into them. Clays are made up of layers of tiny platelets, and if the polymeric material forces those layers apart at the nanoscale, then the resulting material is very strong and much lighter weight than metal.

Many car models now use this technology; for example, Ford's Thunderbird has plastic bumpers, hood and bonnet, and most UK cars today have a much higher proportion of plastics which have replaced metals. An additional advantage of plastic components is that they are cheaper to produce, in different colours, than metals, which require a smooth surface before they are painted with several coats.

Another use of nanotechnology for cars is the incorporation of certain nanoparticles (often based on sand i.e. silica) into plastics for engine covers. All engine covers were once metal, and in order to again save weight, polymeric materials are now used with silica nanoparticles in them. These particles reflect the heat from the engine away from the plastic engine cover. A conventional plastic would melt and the polymer would run over the engine, but these new nanocomposites can stand much greater temperatures. The Mitsubishi Shogun was an early user of this technology, but now, if you look under the bonnet of most new cars, you will find that the engine cover is plastic.

A further application for nanotechnology in the automotive sector is as an anti-scratch surface. Mercedes Benz models have something like seven layers of paint on them to ensure that the surface always looks good. The final coat is a lacquer film that is transparent and contains either silica, or alumina, nanoparticles which provide an anti-scratch surface that stays brighter much longer that a normal lacquer.



These anti-scratch surfaces were first used on ten-pin bowling balls to make sure that the balls look better and do not

get scratched as much. Conventional bowling balls take a lot of knocks and look very dull after just one evening out down the bowling alley; these new balls stay shiny for months.

Of course, it is not just the automotive sector which will benefit from weight saving. The aircraft industry has major projects trying to reduce the weight of components. The new Boeing Dreamliner will have plastic wings, and a huge overall weight saving over previous models because over 50% of the plane is composite material (not quite at the nanoscale yet).

However for the future generations of aircraft, it is expected that nanotechnology will result in planes being around 80% composites, based on carbon nanotubes, which are hollow tubes of carbon that are only about one nanometre across and several hundred nanometres long. These carbon nanotubes are said to be one fifth the weight of steel and very much stronger.

These carbon nanotubes also have the ability to conduct heat and electricity. As a result, most new cars in the United States are doing away with metal fuel lines which have to be earthed, and are now

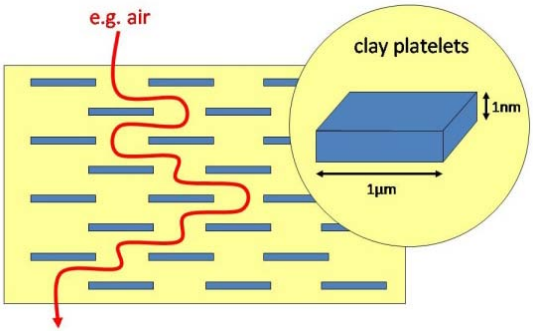
using plastic fuel lines, since any potential charge that could ignite the fuel are leaked away by the carbon nanotubes in the plastic pipe.

Although not an application in the transport sector, this type of technology is being developed for use in three-pin electrical plugs. Replacement of the brass earthing plug by a carbon nanotube containing plastic, as shown in the prototype, reduces the weight of that part of the plug by 80% and gives an overall cost saving of 40% on the plug itself. The electrical standards that a brass plug has to meet are easily achieved with the new nanocomposite material.

Clearly we will see a lot of effort being directed at energy saving through the increased use of nanotechnology.

SPORTS AND LEISURE

Another application for clay platelets is as a barrier in tennis balls. Wilson Sports' tennis balls have a layer of butyl rubber into which has been incorporated clay material to give a nanocomposite layer. When Roger Federer hits the ball at around 140 miles per hour the ball gets squashed and with a normal ball the air gets forced out. However with these new balls the air would have to take a very tortuous route around all the tiny clay platelets to escape.



The new balls will mean that the call for "change balls please" will be heard less frequently. As the air is forced out of tennis balls the professional cannot get the same power and spin on the ball. It is the same for footballs; David Beckham would not be able to bend the ball as well if the pressure in the ball was too low, so some work has been done to keep the pressure maintained by using a nanocomposite layer, but the Football Association has not yet approved the use of this new technology.

However, the use of carbon nanotubes in sports and leisure goods is the fastest growing application for nanotechnology. Incorporated into plastics these materials provide incredible strength and are much lighter weight than conventional materials.

It was again Wilson Sports that started using carbon nanotubes in their products, with tennis racquets. Roger Federer, who is sponsored by Wilson Sports, was the first professional to pioneer the new N-Code racket. If you pick up one of these racquets, the reaction is “wow” because it is so light weight. Further developments with this technology, where the carbon nanotubes are now locked chemically to polymers in the plastic, are now marketed as K-Factor racquets. In case you are wondering, Rafael Nadal’s Babolat racquet is now also based on nanotechnology.

Most of the more expensive racquets for squash and badminton are now made of these new nanocomposite materials, because of the lighter weight, extra strength, and also because of the “flex” that they have.

Golf club shafts have also started to use these nanocomposite materials, again because of the extra power that can be achieved with them. Padraig Harrington won the British Open in 2008 using Wilson NanoTECH woods. Wilson Sports also sell golf balls that are nanocomposite materials, which are claimed to give extra length to shots.

Baseball bats from Easton, which also have carbon nanotube based shafts, are used by professional players in the United States because of the extra power that they can get from them. However, they have been banned for youngsters, because the little pitcher, having thrown the baseball, could not get out of the way fast enough if the hitter connected well. A few kids got damaged so they now only allow adults to use them. Even the baseballs themselves now have a nanotechnology based waterproofing layer on them so that the pitcher can still give spin to the ball under wet conditions.

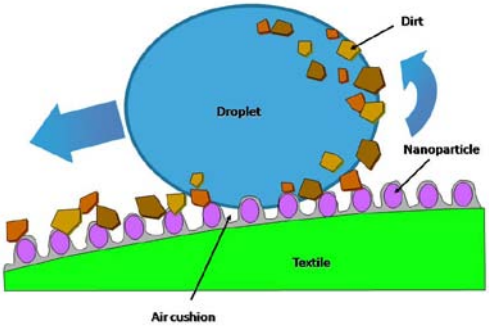
Best quality hockey sticks, both blades and shafts, are also now made with these nanocomposite materials, as are snowboards, skis, fly-fishing rods and fishing poles. A four metre fishing pole made of wood or aluminium is still quite heavy, but with a carbon nanotube based plastic one, the weight can be less that a kilo.

Cyclist Floyd Landis finished first in the Tour de France in 2006 on a bike that had a plastic frame, rather than an aluminium one. This was again carbon nanotube based. However, he was fired by the Swiss Phonak team after he tested positive for drugs, despite his protestations.

HOME

There are already many applications of nanotechnology in your homes, let us take your clothing first. It is possible to purchase stain resistant garements such as shirts and trousers that actually repel stains. Early clothing came from the United States, from Eddie Bauer outlets, under the name Nano-Tex. If you spill red wine over these fabrics, instead of leaving an unsightly red stain which is very difficult to wash out, a quick wipe is sufficient to have the garment looking like new.

The way nanotechnology works in this case is known as the “lotus effect” because, as with a lotus leaf, it is difficult to have things stick to it, especially if they are water based. The fabrics have a thin film on the surface, which copies the bumpy pattern found on a lotus leaf. When a droplet lands on the fabric, a cushion of air is created under it, and this acts



a bit like a hovercraft and pushes the droplet away. As it rolls off the fabric it gathers up dirt as well and leaves a clean textile.

These surfaces are known as super-hydrophobic surfaces, which means that they repel water much more than a conventional surface. Such surfaces are not actually new. There is a beetle (the stenocara beetle) in the Namid desert in Southern Africa which only goes out at night foraging for food, because it is too hot during the day. Its back has a super-hydrophobic surface except for some small bumps along its back. There is precious little moisture in the atmosphere there, but some of it condenses on the beetle's bumps. When a droplet of water forms, it rolls off onto the super-hydrophobic surface and is channelled straight into the creature's mouth!

Nano particles of silver have also found application in a number of products found in the home where they act as anti-microbial agents. It has been known for centuries that silver has such properties. The Assyrians around 2,500 BC stored their water in silver containers because they knew it would stay fresher for longer. Even today, the Bedouins put a silver coin in their leather water carriers to keep the water fresher. It is thought that silver ions are interfering with the microbes' metabolism, and presumably with

nanoparticles of silver, the ions are more accessible that with larger particles.

Samsung and Daewoo have been adding silver nanoparticles into the surfaces of refrigerators to prevent growth of mould in the fridge. Silver nanoparticles are being used also in wound dressings to keep the wound cleaner for longer periods.

Plastic food containers are also using this nanotechnology in the polymers from which the containers are made. The food stays fresher for a much longer time than without the silver nanoparticles.

Returning to clothing, Rohan sell silver nanoparticle impregnated socks that cut down smelly feet problems. They also have silver nanoparticles in underpants so that if you are out on a camping trip and do not have a regular change of clothing, it stays a bit fresher down in that region! Army personnel use the nanotechnology based underpants when they are out on

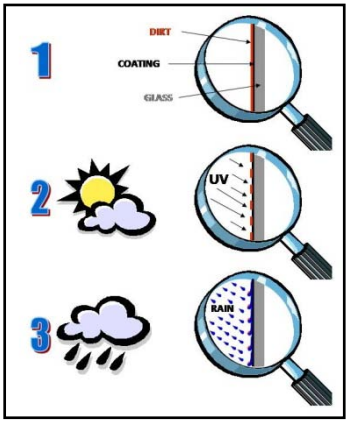
manoeuvres. Marks and Spencer have trialled nano-silver pyjamas which are clinically proven to reduce the risk of contracting MRSA.

Rohan also sell winter jackets that are insulated with goose down. It is very difficult to wash goose down since it goes into clumps that are less insulating. Rohan have used the stain resistant nanotechnology coating on the outside of the jacket, and have put the nano-silver material on the inside to stop underarm odours. As a result the jacket does not need to be washed.

When Napoleon lost his campaign in Russia in 1812, it is said that the reason for his defeat was that his troops were eating with wooden spoons and caught food poisoning, typhoid, and cholera, while he stayed healthy because he was eating with silver cutlery. Presumably, the lower ranks were too sick to be up at the front fighting.

Other outdoor clothing makes use of Gortex fabrics which are also based on nanotechnology, providing wind resistance but breathable material which is also waterproof.

Nanotechnology can also provide other coatings that are finding applications in the home and elsewhere. New paints have been developed which last much longer than conventional paints. For example, painting the first steel bridge in the world, the Firth of Forth railway bridge, was a never ending task. When the team finished painting it, it was time to start all over again. Just recently though they used a new nanotechnology paint that will last for 25 years. The way these types of coating work is by the nanoparticles going down into the rough surface better that larger particles would, thereby giving improved corrosion resistance. Similarly wood preservatives and coatings based on nanotechnology also go deeper into the pores of the wood and therefore given much better protection for longer periods. There are also improved waterproofing coatings for masonry in places where damp environments are a problem.



A further application being used in homes is self-cleaning glass, developed by the firm Pilkingtons. Known as “Activ”, it has a thin coating, only 35 nanometres thick, of titanium dioxide on the surface of the glass. When dirt sticks on the glass, and the sun is

shining, the titanium dioxide acts to breakdown the dirt. The next time it rains the residue is washed off.

On a building like an all-glass skyscraper, new windows with this coating are a real bonus since they do not need cleaning as much as normal glass, and window cleaners in cradles do not have to operate so often.

A visit to the bathroom will reveal even more nanotechnology applications. Many of the top quality sunscreens you can buy today contain nanoparticles of titanium dioxide. The purpose of these is to repel the bad cancer causing sunlight, but let through the safe tanning sunlight. The particles are so small that you cannot see them, so the cream does not leave the white colour of larger particles on the skin.

The same titanium dioxide nanoparticles are also used in many cosmetic formulations that are sold as anti-wrinkle or anti-ageing creams. Again their purpose is to prevent the skin

from harmful sun damage.

Also in the bathroom, a number of toothpastes contain nanoparticles. One product, BlanX BioRepair, contains nanoparticles of hydroxyapatite. These are natural ingredients which help fill the minute cracks in teeth that make eating ice cream painful.

There are also a number of hair products on the market which are designed to prevent cracked hair by filling the nanoscale cracks with harmless ingredients.

The kitchen is not exempt from nanotechnology based products. Just as some tennis balls and footballs use clays in thin films as barrier properties, food is also packed in nanocomposite clay based packaging. The purpose is to keep the foodstuff fresher by stopping air getting to the product, and retaining any inert gas that is used to store the foodstuff. In the United States, beer bottles tend to be plastic and the flavour is kept fresh by nanoscale films on the bottle, to maintain the pressure in the bottle and stop the product degrading.

HEALTHCARE

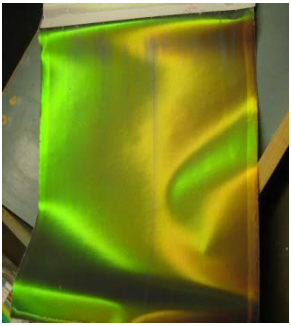
There is a great deal of interest in nanotechnology within the healthcare sector, since at the nano-scale things happen more rapidly and much more sensitively. The goal is therefore to detect diseases before they have taken a hold on the body. As this becomes possible, it will mean fewer people having to go to hospital, and there is the likelihood that we will live longer because our bodies will not have been burdened so much with debilitating diseases.

There are already products appearing on the market that are down or close to the nano-scale. Roche Diagnostics have a test kit for diabetes, with the name Accu-Chek Aviva Nano. We can expect many more quick test kits for disease monitoring in the near future.

Some of the test kits will rely on colour changes and this is another area where nanotechnology can take a leading role. To understand this, let us first look at a paua shell from New Zealand. These abalone shells are used for jewellery because when viewed from different angles they appear iridescent. There is no pigment in them to give the attractive colours; it is simply light being diffracted off the layers,

separated by nanometres, making up the shell. This is the same for things like butterfly wings and many other colours in nature.

Christian Dior's Pure Poison perfume bottle looks like pearl because on the inside of the glass they have two nano-layers, of silica and titania, that make the glass look like pearl. Such effects are commonly used in jewellery and household products giving novel visual effects.



In order to produce coloured films for packaging, it is now possible to avoid using pigments to give the required colour. By changing the surface of a plastic film, it is possible, through diffracted light to get different coloured effects.

Returning to healthcare though; the objective is to use nanoparticles that diffract light to give a specific colour, and then flocculating those particles to give larger particles which provide a different colour.

It is interesting to note that the different colours of sunsets are due to particles in the atmosphere, much of them at the nano-scale, diffracting light in different ways. After Krakatoa erupted in 1883, there were bright red sunsets for decades.

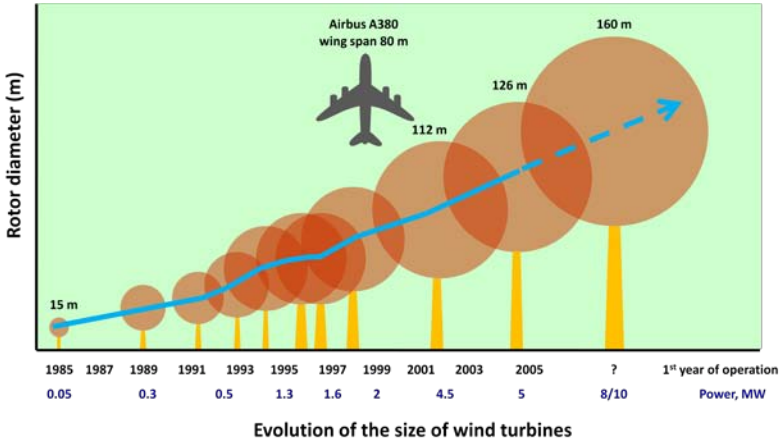
Nanoparticles are also beginning to be used for imaging in hospitals, where you might be given something to drink or have it injected into you, so that they can track where a particular problem might be. If it is nanoparticles that they are tracking, then it is possible to have a clearer, better defined, picture of a diseased area. Nanoparticles are even being tailored to be attracted to specific diseased cells, so that they can be activated to kill the problematic cells before they grow into a serious problem.

Conventional drugs, reduced down to the nano-scale, are being designed to be more effective because of the increased surface area that is available. This means that less of the drug needs to be used to overcome the problem, and there is less chance of harmful side effects.

Nanotechnology is in its early days in the healthcare sector, but it is here where the new developments will have a very major impact.

ENERGY

Light weight materials are going to make a major impact on different aspects of the energy sector. For wind power the diameter of the turbines is now about the size of an Airbus A380. The larger the diameter, the more power can be generated. However, the blades need to be lighter weight and stronger, in order to avoid breakages in very high wind conditions.



Evolution of the size of wind turbines

Development work is being carried out by the German company Bayer, on carbon nanotube based polymers which should provide the properties required.

Nanotechnology coatings to prevent wind turbines from icing up are also being examined. For devices gathering tidal or wave power, lighter weight materials are also needed, but in addition, anti-corrosive nano-coatings would be advantageous.

There is also a lot of development activity going on with solar energy. There are two aspects to this. The first is where heat from the sun is used to provide heat for homes. This thermal energy is usually collected by sunlight falling on tubes carrying water. It has been found that if nanoparticles are included in the heat-collecting liquid, then heat is transferred much more efficiently.

The second route is to gather sunlight and convert it into electrical energy, using what are called photovoltaic cells. There is a lot of work going on copying nature, where plants and trees, for example, gather sunshine and convert it into energy so that they can grow. Several companies are using nanoparticles to convert sunlight into electrical energy, and one company, G24 Innovations, in the United Kingdom is using these photovoltaic cells to power mobile phones and lights, especially where power supplies are not easily accessible. This can be done through a small pack or by putting the cells onto clothing.

ENVIRONMENT

The fact that nanotechnology is already reducing the weight in vehicles is a step forward in saving energy. Also harder surfaces and other components will mean that things will last longer, which also makes a contribution to saving our environment.

Even self cleaning windows, and stain resistant clothes, result in less energy being used to wash the windows or even to produce the detergents that we use to clean our clothes.

However there are more direct ways in which nanotechnology is helping clean up the environment. A church in Rome, the Jubilee Church, has been coated with nanoparticulate titanium dioxide. This has the same effect as the self-cleaning windows, where the coating of titanium dioxide, along with sunlight, catalyses the breakdown of the dirt landing on the windows. The coating on the church also uses sunlight, but it helps breakdown the gases polluting the atmosphere in cities like Rome where the pollution from cars and concentrated urban environments is a real problem. This is likely to become a large application for nanotechnology in

other cities where smog, caused by too many badly maintained cars, is prevalent.

This type of technology is also being used in kitchen products. NanoBreeze in the United States has a nano-based titanium dioxide air purifier which decomposes allergens, odours, germs, gases and fumes.

A major step forward is the development of nanotechnology membranes, especially for cleaning up water. The pores in these membranes are able to filter out bacteria and viruses, as well as unwanted chemicals such as arsenic, mercury and pesticides. According to the World Health Organisation, 3.6 million people die each year from water related diseases, so these new membranes have the potential to reduce that number dramatically, especially in developing countries.

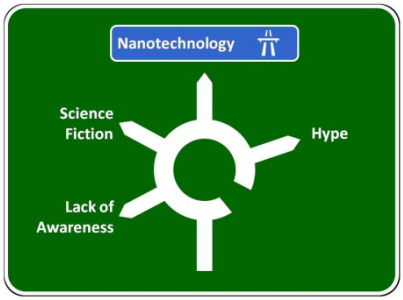
Nano-membranes are also beginning to be used for desalination of sea water, and initial success has shown that there is potential to reduce the cost of taking salts out of sea water. Again, this will have a marked effect on communities in coastal areas, especially in the Middle East.

RISKS AND BENEFITS

Michael Crichton, the author of Jurassic Park, wrote a book called Prey a few years ago. It was all about nanobots, nanosized robots, escaping from a laboratory and turning everything they came in contact with into 'grey goo'. Unfortunately, many people with no science base believed that this could actually happen. It was excellent science fiction, but even when Nobel Prize winners confirmed that it was not possible, some people still wanted to encourage concerns about nanotechnology. The same groups create worries about any new science, because it gets them attention, and encourages people to sponsor them.

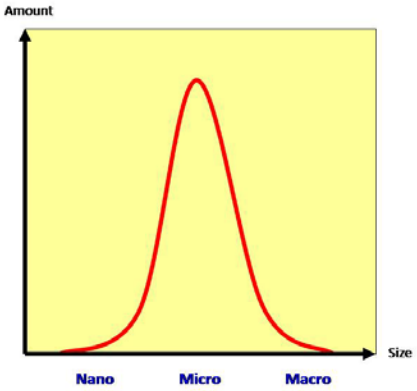
However, it is good scientific practice to make sure that products are safe before they are put onto the market, and there are strict procedures that companies have to follow. It is clearly in the companies' interests to make sure their products are totally safe otherwise their whole business could be ruined by adverse litigation.

There has been so much hype with nanotechnology. Many companies exaggerate claims for its potential, in order to get more money from governments for development work; universities also make bold claims to get grant money for their



research; and lobby groups falsify information to encourage people to join their membership.

Nanotechnology is a very broad topic, and clearly much of the technology is simply copying nature and has been around since creation. For example, blood is a nanofluid, and milk contains nanoparticules of casein, and even our bones are self-replicating nano-structures. Grinding things down, such as flour, produces the micro-particle size requires, but there will also be larger particles and some nanoparticles.



In addition, yogurt, and many other foodstuffs contain nano-sized ingredients.

When you burn your toast, it is known that minute amounts of carbon nanotubes are produced, and barbequed food produces even more.

Currently the largest user of nanoparticles is the tyre industry. 6,000 tons of nanoparticulate carbon black is used each year for new tyres. A small amount of that will be in the form of nanotubes.

There have been reports that carbon nanotubes are similar to asbestos, but are not likely to be a problem if they are locked in plastics. Other reports say that they are not a problem. The way forward is to proceed with caution.

Unlike in Europe, the Far East has fewer concerns about aspect of nanotechnology. In Hong Kong you can buy Nano Water. Nano in that part of the world is a marketing ploy; it indicates something that is new and exciting. In Thailand, you can buy Nano Breast Serum, which if you rub it on stops your boobs sagging! There are even Nanofibres that stop you looking bald.

The nano iPod is another product that uses the name nano to encourage people to purchase it. There is probably some of the circuitry down at the nano-scale, but nothing else other than the fact that it is small.

The Indian company Tata have launched their Tata Nano, a small car that can seat four adults. The nano name is presumably used to convey size.

Printing inks contain nano-scale ingredients in order to make them dry faster, and the top quality papers the inks are printed onto also have nano-scale ingredients, again to enable rapid drying.

As with all technologies one has to balance the risks and the benefits that products will bring. We accept nowadays that it is acceptable to drive cars at high speeds even though there are a large number of deaths each year from accidents. Some people choose to smoke cigarettes even though they know it is likely to give them health problems.

The benefits brought by nanotechnology already outweigh any risks.

THE FUTURE

A report from the Nanotechnology Law and Business Journal has identified the top ten ways nanotechnology will impact on our lives:

1. Diagnosing disease
2. Treatment of cancer and other disease
3. Widespread adoption of solar energy
4. New batteries and other forms of portable power
5. Blending electronics and paper-based products
6. Lighter, stronger, and more conductive materials
7. Clean water
8. Low emission automobiles
9. Responding to terrorism and environmental disaster
10. Increased monitoring of consumer products

The first two are concerned with the healthcare sector, and the next four impinge on energy applications. Of these, a particularly interesting area is in nano-electronics where more complex circuits are likely to be put down, giving faster computers and smaller, more complex chips. In addition, to get away from the hugely expensive silicon chip fabrication factories, there is a trend to what is becoming termed “plastic electronics” where flexible circuits are created by printing them onto plastic films; the potential is massive.

The last four in the top ten list are directed at environmental and societal issues.

It is early days, at the moment, for nanotechnology, but the feeling is that we are just seeing the tip of the iceberg; there are many more exciting applications to come which will change our lives and impact on all industry sectors.

NOTES