



Nanotechnology and the environment: A mismatch between claims and reality

Nanotechnologies are presented as providing unprecedented technological solutions to many environmental problems including climate change, pollution and clean drinking water. Proponents claim that it enables economic growth through better products and new markets while dramatically reducing our ecological footprint. However there is emerging evidence these claims do not provide the whole picture, with serious environmental risks and costs being trivialised or ignored.

Any reductions in environmental impacts or apparent reduction of our ecological footprint, achieved by nanotechnology applications, need to be carefully assessed against the possibility that the environmental costs of nanomaterials production (such as increased energy and water demands) and broader environmental costs (such as expanded production, etc) outweigh the potential environmental gains for the environment. These 'downsides' to nanotechnology are rarely acknowledged, while 'benefits' claimed are often exaggerated, untested, and are, in many cases, years away from realisation.

Our concerns about the potential negative environmental impacts and costs are made worse by the apparent reluctance of governments to develop appropriate and responsible oversight mechanisms in a timely fashion. Below, we develop in more detail our concerns and propose solutions.

Claims of environmental benefits are not matched by reality

The OECD suggests that nanotechnology offers environmental benefits in the following principle areas: cleaner production, pollution reduction, and other environmental benefits. However we question nanotechnology's capacity to deliver; in each case the claims are not borne out by reality, and environmental costs are consistently ignored.

Cleaner or dirtier production?

Claim: Nanotechnology will deliver cleaner production (e.g. through green chemistry; synthesis and processing of nanoscale materials that will reduce consumption of raw materials and natural resources such as water and energy, and improved chemical reactions and catalysis).

Reality: In addition to nanomaterials fabrication requiring large amounts of water and energy, the chemicals required are often highly toxic, as are many nanomaterials themselves. The concept of 'safety by design', widely promoted, is an illusion without a proper life cycle analysis and validated nano-specific risk assessment methodologies which may be 15 years away.

Energy saving or demanding?

Claim: Nanotechnology will deliver applications to reduce energy consumption (e.g. through efficiencies in production, improved energy storage, generation and conservation)

Reality: Manufacturing nanomaterials and nano-devices (including nanomaterials to be used in energy generation, storage and conservation applications) is extremely energy-intensive. Early life cycle assessments shed doubt on the claim that nano-applications will save energy.

Broader environmental benefits or costs?

Claim: Nanotechnology will deliver other environmental benefits (e.g. environmental remediation and monitoring, water filtration, and reduction of agricultural pollution).

Reality: There is no full ecotoxicological profile for any of the nanomaterials available today and the existing scientific results identify potential serious health and environmental concerns. Much more research and ecotoxicological modelling is therefore required before we should consider large-scale environmental release of nanomaterials for use in remediation or other purposes. Nanotechnology has the potential to deliver useful water treatment in some areas (Meridian Institute 2006). However, even if disregarding potential human toxicity issues, there is a real danger that other water treatment methodologies, including effective, community-controlled methods will be sidelined as priority is given to patented, corporate controlled nano-water treatment applications.

In agricultural applications, even if smaller quantities of nano-chemicals are used in agriculture, because of their far greater potency, this could still pose a greater toxicological burden. Furthermore, use of nano-pesticides in agriculture will entrench our chemical dependence at a time when there is growing recognition and action to limit use of chemicals altogether.

Various aspects of this reality are detailed below together with concrete proposals.

Accounting for environmental costs when evaluating the potential for environmental benefits

Manufacturing nanomaterials has huge energy and environmental costs

Nanotechnology proponents have claimed that nanomaterials will lower energy and resource use. This is because small quantities of more potent nanomaterials can theoretically accomplish the tasks of much larger amounts of conventional materials, and because materials such as carbon nanotubes are predicted to enable lighter industrial components whose use will require less energy. However Şengül et al. (2008) found that the manufacture of nanomaterials has an unexpectedly large ecological footprint. This was related to: highly specialised production environments, high energy and water demands of processing, low product yields, high waste generation, the production and use of greenhouse gases such as methane and the use of toxic chemicals and solvents such as benzene.

In a separate life cycle study of carbon nanofibre production, Khanna et al. (2008) found that their potential to contribute to global warming, ozone layer depletion, environmental or human toxicity may be as much as 100 times greater per unit of weight than those of conventional materials like aluminium, steel and polypropylene.

Nanomaterials are likely to be used in far smaller quantities than conventional substances, so a life cycle assessment of the products they are used in would give a more accurate impression of total energy and environmental impacts. Nonetheless, these early findings led scientists to conclude that any environmental gains of nanomaterials may be outweighed by the environmental costs of production.

Many commercially used nanomaterials are toxic to the environment

Nanomaterials themselves constitute a new generation of toxic chemicals. As particle size decreases, in many nanomaterials the production of free radicals increases, as does toxicity. Test tube studies have shown that nanomaterials now in commercial use can damage human DNA, negatively affect cellular function and even cause cell death. There is a small but growing body of scientific studies showing that some nanomaterials are toxic to commonly used environmental indicators such as algae, invertebrate and fish species (Hund-Rinke & Simon 2006; Lovern &

Klaper 2006; Templeton et al. 2006; Federici et al. 2007; Lovern et al. 2007). There is also evidence that some nanomaterials could impair the function or reproductive cycles of earthworms which play a key role in nutrient cycling that underpins ecosystem function (Scott-Fordsmand et al. 2008). Most recently, disturbing new evidence has shown that nanomaterials can be transferred across generations in both animals (mice; Takeda et al. 2009; Tsuchiya et al. 1996) and plants (rice; Lin et al. 2009).

Furthermore, even if used in smaller quantities than conventional chemicals, nanomaterials may have a greater toxicological burden. In 2006 the Woodrow Wilson International Center for Scholars' Project on Emerging Nanotechnologies (PEN) estimated that 58,000 metric tons of nanomaterials will be produced world-wide from 2011 to 2020. PEN stated its concerns that given the potency of nanomaterials, this could have an ecological impact equivalent to 5 million metric tons - or possibly even 50 billion metric tons - of conventional materials (Maynard 2006).

Solar energy achievements remain incremental, while giving rise to concerns about toxic nanomaterials used

Proponents predict that eventually nano-solar panel efficiency will reach 60% (as opposed to around 40% for conventional panels). Today's figures are less impressive. Nanoparticles such as titanium dioxide, silver, quantum dots and cadmium telluride have been used to increase the efficiency of thin film solar cells and gains, to date, have been modest. For instance, Nanosolar, a US firm, produces thin film cells of up to 14% efficiency and claims to be nearing economic production at US\$1/watt (Bergeson 2009). However conventional wafer-based crystalline silicon panels remain much more efficient at around 25%, and are also much cheaper. While it is very difficult to compare the cost per watt, European figures for "conventional" solar power systems are around US\$0.50/watt (Greenpeace and EPIA 2008).

Nano-solar applications have permitted the production of much more flexible solar panels, and 'reel to reel' printing of panels, which are both distinct advantages. However many of nano solar's more transformational predicted applications, such as energy generating plastic-based paint that can harvest infrared (non-visible) light, are still at an exploratory research stage and remain wholly unproven.

As yet there is no life cycle assessment of nano solar products, so it is unclear whether in order to produce solar energy, large amounts of energy are required in their manufacture. What is known is that many thin film technologies are using nanoparticles that pose potentially serious toxicity problems (e.g. cadmium, quantum dots, silver and titanium dioxide nanoparticles).

Carbon nanotubes proposed for super-capacitors, batteries and light-weight super parts for planes and cars pose asbestos-like health risks

Carbon nanotubes are already being used to reinforce specialty parts of planes and cars and high performance plastics, in fuel filters, electronic goods and carbon-lithium batteries. Their future use has been predicted to enable super lightweight planes and cars that will use much less fuel, dramatically reducing the environmental costs of air travel. They are also mooted for use in textiles, pharmaceuticals, food packaging and a range of other applications.

Using nanotechnologies to fabricate materials that are lighter and stronger than conventional materials, as in the case of carbon nanotubes, translates to clear fuel efficiency gains in cars or planes. Using nano-sized catalysts in car engines (e.g. substances that speed chemical reactions) result in using 70-90% less of the same catalyst in bulk form. Storage capacity, lifetime and safety of batteries are also said to benefit from nanotechnologies (Ortego 2008). However there are still no product life cycle assessments that tell us whether or not the energy savings made in product use exceed the energy demands of nanomaterials manufacture.

There are also serious concerns about nanotubes' health and environmental risks, in particular, that some carbon nanotubes can cause asbestos-like health harm if inhaled. In 2004, the United

Kingdom's Royal Society and risk specialists at the world's second largest reinsurance agent Swiss Re warned that nanotubes may behave like asbestos once in our lungs (RS/RAE 2004; Swiss Re 2004). Since then, a series of experiments have demonstrated that when introduced into the lungs of rodents, certain carbon nanotubes cause inflammation, granuloma development, fibrosis, artery 'plaque' responsible for heart attacks and DNA damage (Donaldson et al. 2007; Lam et al. 2006; Muller et al. 2006). Two independent studies have shown that some carbon nanotubes can also cause the onset of mesothelioma – cancer previously thought to be only associated with asbestos exposure (Poland et al. 2008; Takagi et al. 2008).

Carbon nanotubes also diminish rice yields and make wheat more vulnerable to other pollutants

A new study has found that two types of carbon nanomaterials - C70 fullerenes and multi walled nanotubes (MWNT) - delayed rice flowering by at least 1 month (Lin *et al.* 2009). They also reduced significantly the yield of exposed rice plants (C70 reduced seed set by 4.6%, MWNT by 10.5%). Seeds exposed for only 2 weeks to C70 fullerenes passed these onto the next generation of seeds. Exposure to carbon nanotubes also makes wheat plants more vulnerable to uptake of pollutants (Wild and Jones 2009). Carbon nanotubes pierced the cell wall of wheat plants' roots, providing a 'pipe' through which pollutants were transported into living cells.

Rice and wheat are staple crops which feed a large proportion of the world's people. At a time of unprecedented global food crisis, these preliminary studies suggest that carbon nanomaterials could reduce yields of one of the world's most important staple crops and leave another more vulnerable to pollutant uptake.

Water filtration/ decontamination technologies largely perform similar functions to current technologies, but remove community control

Proponents of nanotechnology-based water treatment technologies have claimed that they will be cheaper, more durable, and more efficient than those used currently (Hillie et al. 2007). Nanotechnologies commercially available or under development include nano-membranes, nano-meshes, nano-fibrous filters, as well as nano-ceramics, clays and adsorbents, zeolites and nano-catalysts. Depending on the technology used they can perform similar functions to conventional methods. However, in addition to raising new safety concerns, their manufacture requires sophisticated technological capabilities, currently only available in specialised facilities, mostly in the developed world. This would continue to leave communities reliant on the ongoing willingness to trade of distant water treatment companies, or on technological charity.

A case in point is a pilot project in Bangladesh on an effective and affordable means to reduce cholera bacteria in local water. The project trialled the use of old Sari cloth (folded four times) and it proved a simple, affordable, and reportedly successful method to remove 99% of cholera bacteria from the water (Hillie et al. 2007). While nano-treatment could additionally allow the filtration of salts and some other substances, it would also take the control of this technology away from the local people.

There is concern that deployment of nano-water treatment technologies may increase the market access of private, profit-driven companies in the critical area of water services. General Electric, Dow Chemicals, Siemens and others have billion dollar stakes in the water market, and have made large investments in nanotechnology-based water treatment research (Barlow 2007). Nanotechnology will do nothing to redress the economic and political factors the UN World Water Development Report has cited as key reasons for a lack of water access around the globe (UNESCO 2006).

Conclusion: Better governance of technological innovation with clearer sustainability objectives and higher quality environmental risk and life cycle assessment

Nanotechnology is the latest technological innovation promising to cure many human health and environmental ills. In dealing with nanotechnology in isolation, the risk is of focusing only and too closely on the technology-related impacts (including materials behaviour). Nanotechnology's development stems from an approach that identifies technological innovation as a potential solution to existing problems while providing economic benefits.

Tensions and disagreements arise around the potential benefits of developments such as nanotechnologies when proponents make exaggerated claims about these benefits, whilst overlooking some serious and chronic potential negative impacts.

Nanotechnology, like biotechnology, goes beyond our knowledge of natural systems and cycles, and our ability to monitor or control unintended negative effects. As we continue to develop market applications that go beyond our knowledge on basic natural support systems, the tensions and disagreements mentioned earlier will only continue to increase. This leads to societal unrest as the public is less able to participate in societal decision-making due to their lower level of understanding of the issues being discussed, and their level of trust of public authorities and corporate interests is further eroded.

Better governance of technological innovations is fundamental if we are to reduce these societal tensions, and help to guide innovation in publicly acceptable areas. Technological innovation is seen as a means of progress, and a potential source of solutions to environmental problems, but not if it creates problems in areas where we have less scientific knowledge or if it simply shifts them to other known areas – e.g. from energy consumption to pollution.

Technology must operate in the service of society, which means that it needs to be controlled and guided by societal structures. Public debate is needed on acceptable developments of technologies, and on responsibility for damage. Key industrial and research policies should include elaborated sustainability objectives (beyond 'reduced environmental impact') and use sustainability assessment of technologies as a tool to identify more acceptable technological developments.

In the context of nanotechnologies, early evidence of the much greater energy demands of producing nanoparticles, the significant quantities of potentially toxic waste their production generates, and the ecotoxic behaviour of many nanoparticles themselves has cast doubt on industry claims that nanotechnology offers 'green' solutions to the current ecological crises.

In many ways, nanotechnologies are an example of attempted technological-fix to problems that in reality require social, economic and/or political solutions. We are therefore concerned that rather than providing real solutions to our most pressing problems, nanotechnologies will underpin a new wave of industrial expansion that will magnify existing resource and energy use and exacerbate environmental destruction.

Without a proper and comprehensive risk and life cycle analysis to balance the current commercialisation of high-risk applications with little or no proven societal benefits, environmental costs could be high and the technology as a whole distrusted or rejected by the public.

The European Environmental Bureau (EEB) is the environmental voice of European citizens, standing for environmental justice, sustainable development and participatory democracy. We want the EU to ensure all people a healthy environment and rich biodiversity. We are Europe's largest federation of environmental citizens' organisations, representing over 145 organisations in 31 countries.

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