Environmental Impacts of Nanosilver

An ICON Backgrounder
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The growing use of silver nanoparticles in a wide range of consumer products has raised concerns about its impact on the environment. This backgrounder reviews three papers relating to this question.

Contents

Featured Papers

- Benn, T. M. and P. Westerhoff (2008). "Nanoparticle silver released into water from commercially available sock fabrics." Environmental Science & Technology 42(11): 4133-4139. [abstract]
- Mueller, N. C. and B. Nowack (2008). "Exposure modeling of engineered nanoparticles in the environment." Environ. Sci. Technol. 42(12): 4447-4453. [abstract]
- Blaser, S. A., M. Scheringer, et al. (2008). "Estimation of cumulative aquatic exposure and risk due to silver: Contribution of nano-functionalized plastics and textiles." Science of the Total Environment 390(2-3): 396-409. [abstract]

Conclusions

While silver ion toxicity is well understood, predicting the impacts to the environment of widespread use of nanosilver is complicated by uncertainties in the amount of nanosilver and related silver ions that are released into the environment, the chemical form nanosilver adopts upon release and the concentration that could result in toxicity. Of three independent studies that attempted to answer one or more of these questions:

- Two studies estimate that sewage treatment plants could likely handle the amount of silver introduced into the septic waste stream from certain products containing nanosilver. One estimates that at predicted concentrations effluent from silver treated socks would not exceed existing federal standards for silver ions [Benn]. The other concludes that microbes important to sewage treatment would not be impacted by nanosilver as currently used in plastics and textiles [Blaser].
- Sewage treatment plants can handle between 10-100 times the amount of nanosilver currently released or estimated to be released in the near future. [Mueller, Blaser]
- One study posited that the amount of nanosilver that might accumulate in sewage sludge could limit its application as an agricultural fertilizer. [Benn]
- Two studies came to different conclusions about whether aquatic species were at risk from nanosilver. One concluded that aquatic species were unlikely to be at risk [Mueller] while the other could not rule out unwanted impacts on freshwater ecosystems [Blaser].
- Insufficient data exist to estimate the risks to terrestrial ecosystems resulting from releases into the air or soil [Blaser, Mueller].
- All three studies rely on assumptions whose validity should be reevaluated as more data are obtained.

These socks were shown to contain nanosilver.
https://www.shop.eclecticsilver.net/

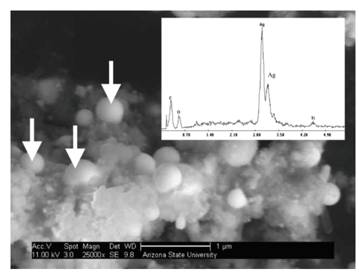

Image of nanosilver particles from socks. Inset demonstrates the particles contain silver. [Benn]

To understand how nanosilver might impact the natural environment we must first understand a few things about the different forms of silver currently being used in consumer products, the prospect that nanosilver or silver ions may be released into the environment and then the potential consequence of

What is a nanoparticle?

Nanotechnology is a term referring to a wide range of technologies that measure, manipulate or incorporate materials and/or features with at least one dimension between approximately 1 and 100 nanometers (nm). A nanometer is one-billionth of a meter or about 80,000 times narrower than the width of a single human hair.

Nanoparticles are a subset of nanotechnology and include nanoscale versions of conventional substances, such as silver, iron or clay, as well as particles that have no direct analog, including buckyballs and nanotubes (nanoscale carbon) and dendrimers (nanoscale organic compounds). Nanoparticles have thousands of atoms in them, making them larger than atoms and most molecules and smaller than other particles. About the only thing these nanomaterials all have in common is that one or more dimensions range between 1-100 nm. Otherwise, they have distinct physical and chemical properties and one type may behave differently in the body or the natural environment than another type.

What is nanosilver? >

What is nanosilver?

Nanosilver is a nanoparticle of the metal element silver. There is a lot of confusion about nanosilver, primarily because the term is used in different and often contradictory ways. To conform to most definitions of nanotechnology, a particle of nanosilver will measure between 1 and 100 nanometers (nm) in one or more dimensions. If it is larger than 100 nm then technically it is not nanosilver; if it is simply a single silver atom (Ag) or silver ion (Ag+) then it is not nanosilver. A nanosilver particle may or may not be charged on its surface or generate silver ions.

A 9-nm nanoparticle contains around 24,000 silver atoms.

Here are some terms that one may run across in reading about silver:

Term	Symbol	Diameter (nm)	Attributes
Elemental; Metallic	Ag (from Latin argentum)	0.288	The form found in silver jewelry, coins and utensils. Not found in nature as a single atom.
Ionic; Silver ion	Ag^{+}	0.258	A single silver ion can be dissolved in water. Ionic silver is much smaller than nanosilver.
Nanosilver; Nanoparticulate silver	No special symbol has been adopted. May be referred to as nano-Ag.	1-100	Can be suspended in water or embedded into fabrics or plastics.
Colloidal	No special symbol has been adopted.	1-1000	A colloid is a mixture containing particles larger than those found in a solution but small enough to remain suspended in the fluid for a long time Only those colloids measuring between 1-100 nm satisfy most accepted definitions of “nano”.

Some of the concern about nanosilver stems from its ability to act as a long-term source of silver ions, which has been well-characterized with respect to its chemical, physical and toxicological properties. Thus, concerns about nanosilver relate not just to its toxicity alone, but also to risks that may be associated with the amount of silver ions released as a result of its use.

What is nanosilver being used for?

Like ionic silver, nanosilver is a very potent killer of bacteria and has been shown to kill fungi, algae and some viruses, including HIV. As a result, the most common application of nanosilver is as an antimicrobial agent in products such as wound dressings, textiles, food storage containers and personal care appliances. Washing machines that contain “ion-generating” devices designed to release silver into the wash water most likely release silver ions (Ag+) and not nanosilver, though this distinction has not been independently verified. Colloidal silver, a liquid suspension that may or may not contain nanosilver, has long been promoted and sold as an over-the-counter health tonic.

Will nanosilver end up in the environment in harmful quantities?

Very few studies have documented the potential for nanosilver to themselves be released or to release silver ions from consumer products and make their way into the air, water or soil. Three of the leading studies available are summarized below.

- Benn, T. M. and P. Westerhoff (2008). "Nanoparticle silver released into water from commercially available sock fabrics." Environmental Science & Technology 42(11): 4133-4139.

One notable paper published this year tested the release of nanosilver from several brands of socks during a simulated laundering process. [Benn] The researchers purchased six brands of socks reported by their manufacturers to contain nanosilver to reduce the growth of odor-causing bacteria, tested their silver content prior to washing, and then tested the wash water for the presence of silver. Five of the six socks were found to contain detectable amounts of silver prior to washing; three of these contained silver particles ranging in size from less than 100 nm to 500 nm in diameter. [Note: Particles larger than 100 nm would be considered too large to meet the definition of nanosilver.] Three of the six socks released silver into pure water. The researchers then estimated the amount of silver likely to make it into waste water from commercial use of socks and compared that to federal drinking water and agricultural fertilizer standards. (The sludge from sewage treatment plants, which captures many of the sewage's harmful components, can be used as fertilizer if contaminant levels fall below federal standards.) The authors ran the sock wash water through a full-scale and a lab-scale waste treatment plant to determine the amount of silver in the liquid waste product coming out of the treatment plant (the effluent) based on the amount of silver input (the influent). They estimate that the effluent would exceed silver water standards only when influent silver concentrations exceeded 2900 ppb (salt water) and 4250 ppb (fresh water). These values are 3000 times higher than typical levels observed at waste water treatment plants. The authors estimate that increasing consumer use of nanosilver in consumer products is unlikely to overwhelm the ability of a waste water treatment plant to successfully remove silver for the purpose of meeting drinking water and effluent standards but may limit the use of sludge for agricultural fertilization.

Bottom line: The authors estimate that silver concentrations reaching a sewage treatment plant would have to exceed 2900 ppb (salt water) or 4250 ppb (fresh water) for the effluent to fail EPA standards for treated water. These concentrations are 3000 times higher than levels typically measured in a sewage treatment plant. However, increased use of nanosilver in consumer products may result in sludge that is too concentrated to use legally as fertilizer.

- Mueller, N. C. and B. Nowack (2008). "Exposure modeling of engineered nanoparticles in the environment." Environ. Sci. Technol. 42 (12): 4447-4453.

Another recent study modeled the movement of nanosilver throughout the waste treatment process in Switzerland to estimate how much would end up in the environment in a high-emission scenario and a realistic scenario. [Mueller] Using assumptions about worldwide production volume, incorporation into products such as textiles, paints, and plastics, release from those products into the waste treatment plants and "flow" from waste treatment plants to environmental compartments (water, air, soil), the predicted environmental concentration (PEC) of nano-Ag is estimated in the high-emission scenario to be no greater than 4.4×10^{-3} µg/m^3 air, 0.08 µg/L water and 0.1 µg/kg soil. The authors estimate the concentration required to cause harm to species in water is 0.04 mg/L, which is 500 times higher than their high-emission scenario. Therefore they conclude that the amount of nanosilver released into the environment will likely pose little to no risk to soil or water-borne organisms. Sludge from waste treatment plants is not applied to soil in Switzerland so the authors caution against extending this analysis to countries where this is common practice as it could increase the PEC (soil) to 1 µg/kg. Application of nanosilver-containing sludge to fields would significantly increase the environmental concentrations presented to soil-borne organisms and other terrestrial species. Releases of nanosilver into the air are generally expected to be very low.

An important caveat about this study is that the risk from silver ions released by nanosilver was not considered. Given ionic silver's well documented ecotoxicity, the authors acknowledge that the risk resulting from environmental exposure to nanosilver release is less important than the risk from the silver ions released by nanosilver. Lessening some of the concern is the fact that silver ions easily combine with many substances present in the environment, such as sulfide, chloride and thiosulfate ions, to create insoluble precipitates that are no longer considered hazardous. The authors acknowledge the great uncertainty underlying many of the assumptions and assert that many more data are needed to make their estimates more robust.

Bottom line: Based on many unverified assumptions, little to no risk from nanosilver is predicted to water-borne organisms unless there is a 100-fold increase in nanosilver production volume. Contributions from ionic silver released by the nanoparticles were not considered.

- Blaser, S. A., M. Scheringer, et al. (2008). "Estimation of cumulative aquatic exposure and risk due to silver: Contribution of nano-functionalized plastics and textiles." Science of the Total Environment 390(2-3): 396-409.

A third study estimated the predicted environmental concentration of silver released from silver nanoparticles embedded in plastics and textiles and its effect on freshwater ecosystems. [Blaser] The study focused on only two product categories, plastics and textiles, (omitting cosmetics, paints or other applications of nanosilver), and assumed that the products released only silver ions, not the nanoparticles themselves. The analysis estimated the amount of silver entering the environment from nanosilver-containing plastics and textiles via effluent from sewage treatment plants, application of sludge to agricultural soils, incineration, and leaching from landfills and compared those values to the concentrations believed to cause adverse effects. This analysis predicts that the concentration of silver would have to be 10-100 times greater than the predicted value to have an adverse effect on the microorganisms important to the operation of a sewage treatment plant. Therefore no adverse impacts on these microorganisms are anticipated. However, the authors could not rule out adverse impacts to freshwater ecosystems, particularly sediments, at the predicted concentrations. Calculating the impact on aquatic species was complicated by a poor understanding of the toxicity of the exact chemical forms of silver in a real-world environment.

Bottom line: Based on very limited data , silver concentrations that the authors estimate would be released from certain silver-treated plastics and textiles currently in use are likely to be 10-100 times lower than the threshold levels estimated to threaten microbes important to sewage treatment plant function. However, these same levels may pose a risk to freshwater ecosystems at concentrations predicted for the year 2010.

< [What is nanosilver?] | [What is the toxicology of nanosilver ?] >

What is the toxicology of nanosilver?

Impact on microbes

Most of the scientific research on nanosilver has investigated its effects on microbes such as bacteria and, to a lesser extent, fungi, algae and viruses. Nanosilver is highly toxic to several strains of bacteria, including *V. cholerae* (the organism that causes cholera), *E. coli* and, significantly, methicillin-resistant *Staphylococcus aureus* (MRSA), which is responsible for infections that resist treatment by conventional antibiotics. The concentration that inhibits 50% of microbial growth or is bactericidal differs for each microbe and has been reported as low as 0.14 µg/mL. Nanosilver's antimicrobial activity has been exploited in wound dressings applied to burn patients, whose skin injuries make them more susceptible to a variety of infections.

Nanosilver has recently been found at concentrations as low as 0.14 µg/mL to be toxic to several species of nitrifying bacteria, which play an important role in the environment by converting ammonia in the soil to a form of nitrogen that can be used by plants. Nitrifying bacteria are also used by sewage treatment plants (STPs) to convert raw sewage into less harmful products. Nanosilver's toxicity to these organisms has raised concerns that release of nanosilver to the environment may disrupt the operation of STPs as well as natural processes in the ecosystem that support plant life. However, one recent analysis estimated that concentrations of nanosilver expected to be released from certain textile products currently in use would not likely reach high enough levels to threaten microbes important to STP operation [Benn].

Impact on aquatic organisms

Research into nanosilver's toxicity to more complex life forms is much more limited. Recent studies investigated the impacts of exposure to nanosilver on zebrafish embryos. Zebrafish are small minnows that are popular in aquaria and as model organisms in toxicity studies because their embryos are easy to manipulate and study. Two independent studies found that exposure to particles of nanosilver between 5 and 46 nm resulted in increased mortality, heart malformation and other developmental deformities in zebrafish at concentrations as low as 5 µg/mL.

Impact on fowl

Nanosilver's ability to kill bacteria is being investigated within the agricultural community as a potential replacement for traditional antibiotics. As a result, a few studies of nanosilver's impacts on fowl have been published. In one experiment, silver nanoparticles injected into fertilized chicken eggs at a concentration of 10 ppm had no measurable effect on embryo development according to one accepted standard but did induce changes in cells important to the immune system. In another study, nanosilver in concentrations up to 25 µg/mL was fed to a species of quail to determine if it could decrease the proportion of harmful bacteria in their intestines, thereby reducing the spread of disease in the animal population. Benign lactic acid bacteria populations within the quail intestine increased and no damage to the intestine was observed.

Impact on humans

Toxicity research of high relevance to human health is very limited. When human skin cells grown in a Petri dish were exposed to nanosilver particles 7-20 nm in size, concentration-dependent changes to cell morphology including abnormal size, shrinkage and rounded appearance were observed at concentrations above 6.25 µg/mL. Another paper describes the result of exposure to nanosilver in a wound dressing used to treat a severe burn victim. After a week of treatment with a wound dressing impregnated with nanosilver, the patient developed reversible signs of liver toxicity and a grayish discoloration of his face similar to that found in patients diagnosed with argyria. The dose received by the patient was not measured but the patient's blood plasma and urine were found to have an elevated concentration of silver (107 and 28 µg/kg, respectively). When the wound dressing was removed, all clinical symptoms returned to normal within ten months. Other studies have explored the effectiveness of nanosilver-impregnated wound dressings in a variety of clinical settings. How microbes acquire resistance to nanosilver and how those mechanisms might affect the efficacy of other classes of antimicrobials has not been established.

Is nanosilver being regulated?

Nanosilver's primary use as an antimicrobial has attracted the attention of the US Environmental Protection Agency, which enforces the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). Under FIFRA, if a product incorporates a substance intended to destroy pests, including microbes, EPA considers that product a pesticide and requires the manufacturer to register it. Registration may not be required if the product's marketing does not make a pesticidal claim. Two recent actions demonstrate how EPA is interpreting its authority to regulate silver-containing consumer products.

In September 2007, EPA clarified its position on ion-generating devices, stating that it had determined they are pesticides because they make a claim to kill bacteria. However, in its notice, EPA explicitly disavowed the press articles calling this decision a regulation of nanotechnology, saying it had "not yet received any information that suggests that this product uses nanotechnology," and that "the notice does not represent an action to regulate nanotechnology." This is because the ion-generating devices likely release ionic solver, not nanosilver, into the wash water. [EPA]

In March 2008, EPA's Region IX office fined ATEN Technology, Inc. $208,000 over the failure of its subsidiary IOGEAR to register several antimicrobial products and for making unsubstantiated claims about their effectiveness. At issue were computer mouse and keyboard/mouse combinations that have been sprayed with a titanium dioxide-silver coating to kill bacteria on contact. Again, the issue for EPA was not whether the product contained nanosilver, but whether the manufacturer made a health claim that was unproven and failed to register the product under FIFRA. An EPA official asserted that the agency takes this very seriously "whether the claim involves use of an existing material such as silver, or new nano technology." [EPA]

In Europe the key question is whether nanosilver will be considered a new substance and therefore subjected to the rigorous notification procedure required under the new Registration, Evaluation, and Authorization of Chemicals (REACH) law. If nanosilver is already listed in the European Inventory of Existing Chemical Substances (EINECS), registration under REACH may not be required. However, recent guidance published by the European Commission states that a nano version of a substance already on the market in non-nano form will require a modification of the registration to include the special properties of the nano version, different labeling and additional risk management measures. [EC]

Resources on Nanosilver

- Silver Nanotechnologies and the Environment: Old Problems or New Challenges? (Sam Luoma for Project on Emerging Nanotechnologies)
- The Adequacy of FIFRA to Regulate Nanotechnology-Based Pesticides (American Bar Association Section of Environment, Energy, and Resources)
- Our Silver-coated Future, (Natural Resources Defense Council)
- Nanosilver – a threat to soil, water and human health? (Friends of the Earth Australia)
- Nanotech Law Report blog on nanosilver
- EPA clarifies position on ion-generating devices
- EPA fines company over unregistered antibacterial product
- European Commission issues guidance regarding nanomaterials and REACH

Papers Featured in this Backgrounder

- Benn, T. M. and P. Westerhoff (2008). "Nanoparticle silver released into water from commercially available sock fabrics." Environmental Science & Technology 42(11): 4133-4139. [abstract]
- Mueller, N. C. and B. Nowack (2008). "Exposure modeling of engineered nanoparticles in the environment." Environ. Sci. Technol. 42(12): 4447-4453. [abstract]
- Blaser, S. A., M. Scheringer, et al. (2008). "Estimation of cumulative aquatic exposure and risk due to silver: Contribution of nano-functionalized plastics and textiles." Science of the Total Environment 390(2-3): 396-409. [abstract]

Other Papers Consulted for this Backgrounder **(not exhaustive but representative of the literature)**

- Arora, S., J. Jain, et al. (2008). "Cellular responses induced by silver nanoparticles: In vitro studies." Toxicology Letters 179(2): 93-100.
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- Choi, O., K. K. Deng, et al. (2008). "The inhibitory effects of silver nanoparticles, silver ions, and silver chloride colloids on microbial growth." Water Research **42**(12): 3066-3074.
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- Morones, J. R., J. L. Elechiguerra, et al. (2005). "The bactericidal effect of silver nanoparticles." Nanotechnology 16(10): 2346-2353.
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- Sawosz, E., M. Binek, et al. (2007). "Influence of hydrocolloidal silver nanoparticles on gastrointestinal microflora and morphology of enterocytes of quails." Archives of Animal Nutrition **61**(6): 444 - 451.
- Trop, M., M. Novak, et al. (2006). "Silver coated dressing Acticoat caused raised liver enzymes and argyria-like symptoms in burn patient." Journal of Trauma-Injury Infection and Critical Care 60(3): 648-652.

Other ICON Backgrounders

- Multi-walled Carbon Nanotubes and Mesothelioma
- Nanoparticles and Amyloid Diseases

< What is the toxicology of nanosilver? | Beginning