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# Waste Minimization for the Safe Use of Nanosilver in Consumer Products – Its Impact on the Eco-Product Design for Public Health

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## 1. Introduction

Winslow (1920) has defined the meaning of public health as "the science and art of preventing disease, prolonging life and promoting health through the organized efforts and informed choices of society, organizations, public and private, communities and individuals". Thus, the focus of public health intervention is the improvement of health and quality of life through the prevention and treatment of disease, and promotion of healthy behaviors. Promotion of hand washing is a typical common public health practice to prevent the spread of "unwanted" diseases (Samuel et al., 2005).

With the rapid increase on applications for nanoparticle silver, its potential impact on public health has become a critical issue. Nanosized silver can be made with different shapes such as particles, wires, and rods. Silver nanoparticles (AgNPs; many other names such as nanosilver (nAg) and colloidal silver) have already been used in everyday consumer

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products requiring broad spectrum antibiotic performance because of their enormous surface area and reactivity. Faunce & Watal (2010) recently analyzed international regulatory issues for medical and domestic use in the United States, European Union, United Kingdom, and Australia. They found that despite the numerous studies reported in recent decades, many scientists are still uncertain of its safety. Very recently, Powers (2010) showed positive that Ag<sup>+</sup> and AgNPs are developmental neurotoxins *in vitro* and *in vivo*. Therefore, there is a need to conduct a study to identify a global landscape of AgNPs, their products, and their manufacturers. A market-based intellectual property (IP) study has been conducted to examine the current global patent landscape of companies using AgNPs in their consumer product development and production from 1980 to 2010 (Lem et al., 2012). Information on materials, compositions, formulation, manufacturing processes, and ultimate application were extracted using a “two-stage” stage-gate process using the IP activity in the use of nanosilver in consumer products. The two stages studied were commercial and consumer products. In the first stage for AgNPs and AgNPs-based commercial products, Lem et al. (2012) reported that there were 7,422 patent families from January 1, 1980 to December 31, 2010. In the second stage for AgNPs-based consumer products, 932 patent families from January 1, 1980 for to December 31, 2010 were found.

Korea, China and the USA were found to be the major players in AgNPs and AgNPs-based commercial and consumer products. Korea has been the leader and consumer products containing nanosilver are even sold on the streets. Due to its enormous surface reactivity, nanosilver has already found utility in everyday products that require antibiotic performance, such as materials that contact food, textiles and fabrics, appliances, consumer products, children’s toys, infant products, ‘health’ supplements, cosmetics and pharmaceuticals (Chaloupka et al., 2010). Thus, safety has become a potentially critical issue for companies that make products containing nanosilver. For product stewardship to their customers, suppliers must address environmental health and safety issues in terms of real risks, perceptual risks, and government regulation.

In this chapter, we evaluate consumer products containing nanosilver especially in Korea using an IP landscaping study. We examine the recent literature regarding the effect of silver and nanosilver on public health from a clinical medicine perspective. We then evaluate the concept of waste generation and waste minimization in the material life cycle. We examine the flow of silver and nanosilver in the life cycle of food metabolism to identify ways to minimize potential adverse effects of nanosilver and to provide concepts of eco-products to minimize exposure to nanosilver for public health. Coupling the recent literature and the IP landscaping study, together with Design for Lean Six Sigma – Green (DFLSS-G) and TRIZ, we demonstrate the concept of waste minimization by controlling the release of nanosilver (Lem et al., 2011; Liu JG et al., 2010) in eco-product design.

## 2. Manufacturing commercial AgNPs products

Nanoproducts can be produced in two ways: top-down or bottom-up. A top-down approach is essentially tearing down of a device to gain insight into its components, materials and compositions (e.g., ball milling). A bottom-up approach is the piecing together of materials to give rise to components and finally to build a device (e.g., chemical precipitation).

Figure 1 gives a roadmap of top-down and bottom-up development of nanoproducts under a value chain of “material – properties – processing – structure – performance – applications”. This roadmap helps to identify the unmet needs from materials to/from applications in nanoproduct development and manufacture.

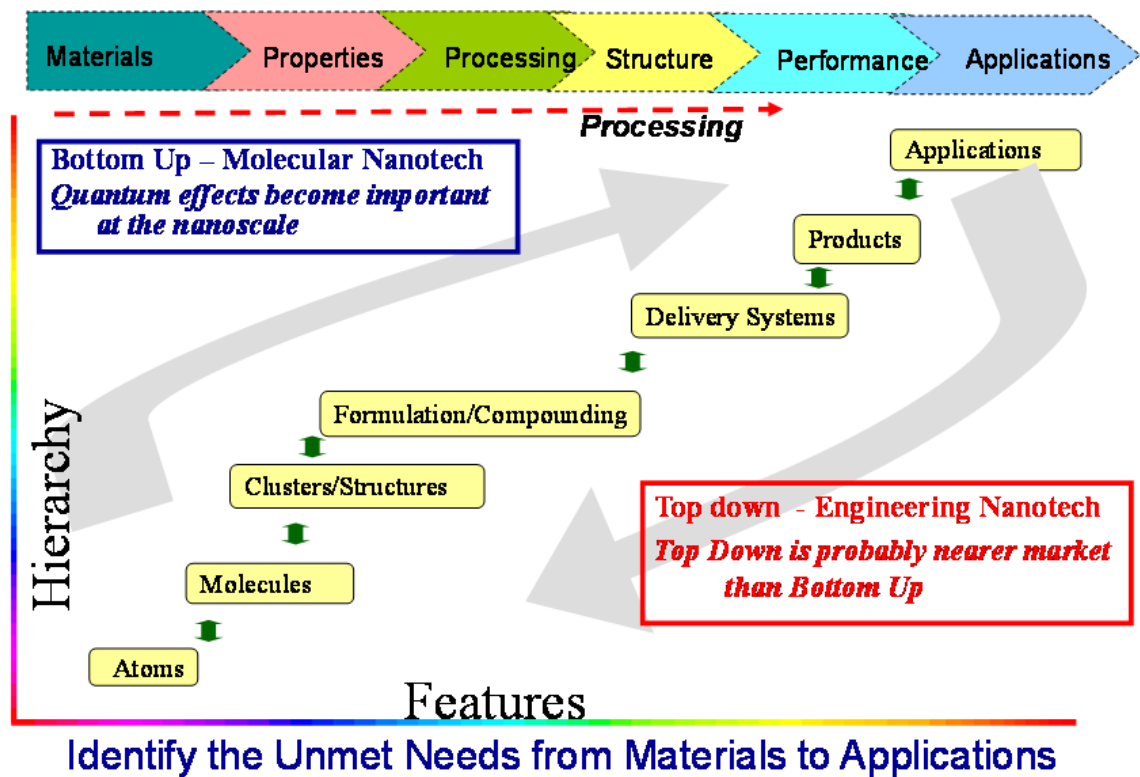


Fig. 1. Top-Down and Bottom-Up Development [Lem et al., 2009; Brauer et al., 2009]

Commercial AgNPs products are typically produced via a bottom-up process, while analysis of environmental impact by AgNPs products is a top-down process (Tolaymat et al., 2010).

In order to use nanosilver for different applications, various chemical and physical methods are used to synthesize the nanosilver. One of the best recent overviews is the U.S. EPA’s report by El-Badawy et al. (2010). Chemical methods usually require a silver salt precursor, a reducing agent (formaldehyde, glucose or hydrogen peroxide.), a solvent, a stabilizer and a capping agent. Silver nitrate is a commonly used precursor to produce silver nanoparticles (Mousa & Linhart, 2010). Alternatively, the wet/dry electroplating method (Yang et al, 2006), electric spark bombardment (Koecher et al., 2009), and other mechanical techniques (polishing and grinding) are used as physical methods to produce nanoparticles.

Fabrication of nanosilver in the nanofiber form is usually done by electro spinning techniques. Other methods are being explored in applications to wound dressing and textile or personal care products.

Coatings have been used to employ the antibacterial property of nanosilver in biomedical devices or electronic devices. The nanosilver coating techniques include technologies such as spraying , chemical vapor deposition, dipping, printing knife-coating, transfer coating, and spin coating (Koecher et al., 2009).

Furthermore it is known that functionalizing the nanosilver with different functional groups/moieties can make nanosilver suitable for specific applications like biomedical devices, dye-doped particles, biomedical imaging, *etc.* One interesting example uses glycosaminoglycan conjugated nanosilver particles for biomedical devices (Mousa & Linhart, 2010). Anti-coagulation is another active area for research where a core of metal silver is coated with a surface layer of silver oxide (Zhu et al., 2002; Zhu & Zhu, 2004). One method of increasing sterilizing power and antibacterial property of nanosilver is by mixing it with nanosulfur compounds (Oh, 2002). Coated nanoparticles are produced by precipitating nanoparticle cores from two aqueous reactant solutions in a microemulsion, and adding a coating agent to coat the cores (Tan, 2003).

**3. The landscaping of consumer products containing nanosilver**

To have a better global picture of nanosilver in commercial and consumer products, Lem et al. (2012) have conducted an exhaustive intellectual property (IP) search study using a “two stages” stage-gate process. This search is divided into three parts based on timelines.

- Part A. Before 1980 “pre nano”: In this the search is done to identify patent documents which have a mention of nano sized silver material before nanotechnology became an establish field of science and technology.
- Part B: Jan 1980 to Jul 2008: Time prior to EPA expressing their concern about toxicological uncertainty as a consequence of using nano scale silver.
- Part C: Aug 2008 to Dec 2010: This is the time after the EPA has started showing concern towards toxicological uncertainties as a consequence of using nano scale silver. The search is terminated 2010 to avoid complications of handling data for the incomplete year 2011.

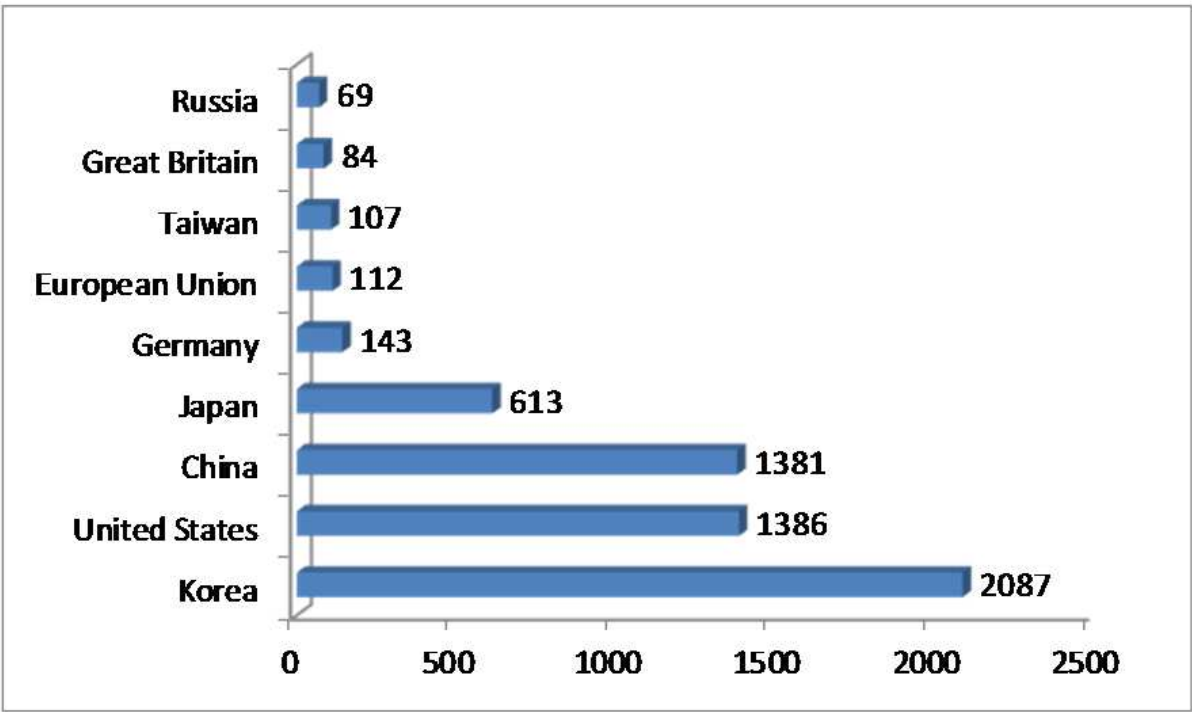


Fig. 2. AgNPs Patent Filing Countries (Adopted from Lem et al., 2012)

The details of the search methodology and results are not the subjects of this article. They have been reported recently by Lem et al. (2012). Figure 2 shows the countries researching AgNPs. Figure 2 shows that out of all the major patenting authorities, South Korea is leading with 2087 publications. The U.S. is second and China is third. These three countries have about 80% of the total patent publications. It is important to note that Chinese patent numbers are over-weighted by their Chinese Utility Model Patents that only protect the shape and/or structure of a product for 10 years and are not subject to substantive examination. The International Bureau or WIPO's Patent Cooperation Treaty (PCT) is a parallel patenting route that covers most of the world's patenting countries.

Due to its antiseptic and biocidal nature, more than 50% patenting activity of AgNPs is seen in the area of pharmaceuticals, healthcare, consumer goods, preservatives, sterilization, and water treatment. Using the patent landscape analysis, we identified relevant patents for pharmaceutical, healthcare, and consumer goods patents. Intensive IP analysis, such as broadness of claims, details of office actions can help in identifying the share of the market that can be attributed to current and future technology. Active companies in the technology space were identified as they can influence the market. For example, LG Household and Health Care Ltd (health care) and L'Oreal (cosmetics) are amongst the major assignees in the space of pharma and consumer goods patents.

Several observations were found in the 932 patent families from January 1, 1980 to December 31st, 2010 that was related to AgNP in consumer products. These 932 patent publications were reviewed to distil information with respect to:

1. Nanosilver size or percentage loading,
2. Nanosilver form or geometry,
3. Material composition, and
4. Application area and products.

Among these 932 publications, cosmetics, personal care, medical, and health care occupy more than 70% of the application areas as shown in Figure 3.

In order to analyze the data in more detail, we defined four different classes of formulation to examine the role of the concentration of nanosilver (e.g., dose) used in the formulations on these applications:

1. Trace dose, less than 0.01 wt. %.
2. Low dose, 0.01 to 1.0 wt. %.
3. Medium dose, 1.0 to 10 wt. %.
4. High dose, greater than 10 wt. %.

Clearly trace dose formulation found applications in foods, drinking water, drugs, facial mask, cream, wound care, gel, and textiles (Lem et al., 2012). At low and medium doses, the formulations found applications in household products materials, medical, personal care and cosmetics. Typical medical applications include catheter, endotracheal tube, and subcutaneous central venous port; pacemakers, prosthetic heart valves, prosthetic joints, voice prostheses, contact lenses, stents, heart valves, penile implants, small or temporary joint replacement, urinary dilators, cannulae, and intrauterine devices; catheter lock, needle, luer-lok (medical device) connectors, needleless connectors, clamps, forceps, scissors, skin hooks, tubing, needles, retractors, sealer, drills, chisel, rasps, surgical instruments, dental instruments, intravenous tubes, breathing tubes, dental water line, dental drain tubes, feeding tubes, bandages, wound dressings, orthopedic implants, and saws (Lem et al., 2012).



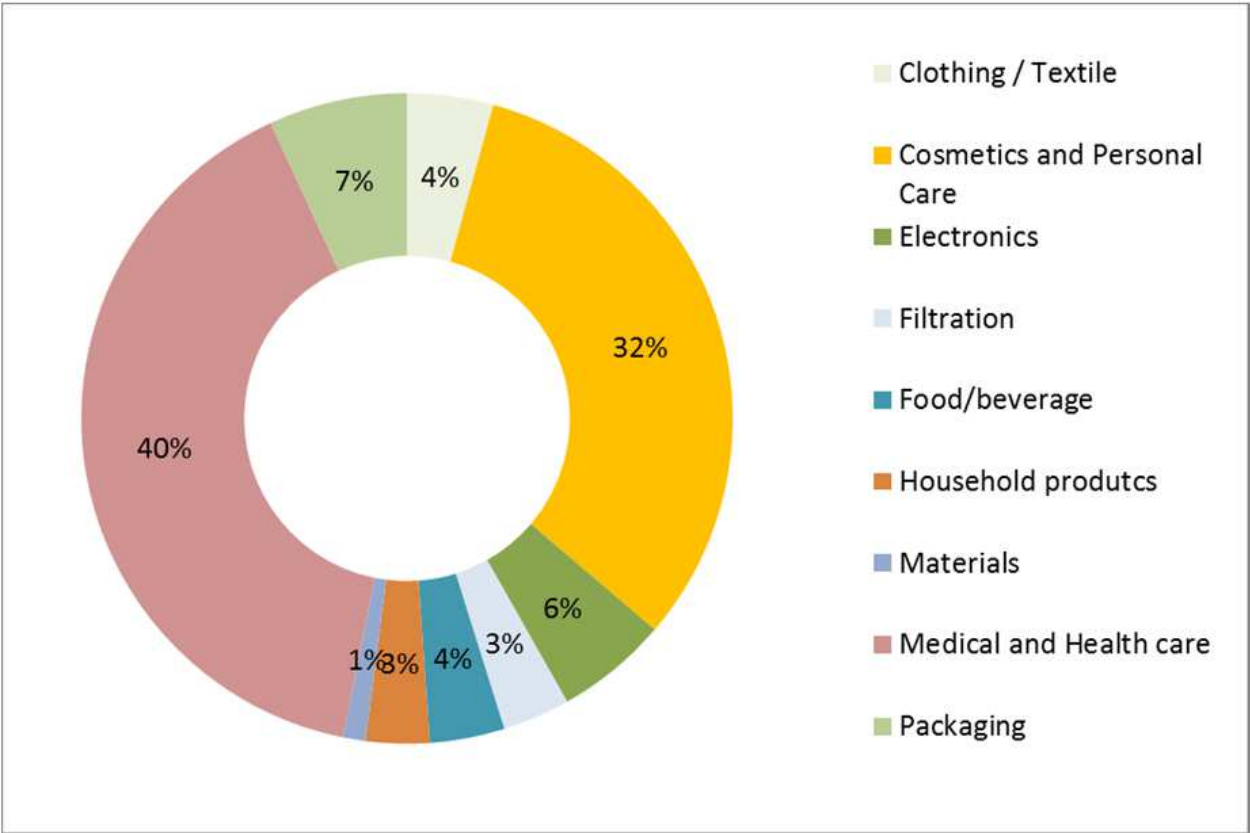


Fig. 3. Nanosilver in Various Application of Consumer Products (Adopted from Lem et al., 2012) (January 1, 1980 to December 31, 2010)

High dose formulation applications were in antimicrobial pharmaceuticals, hair mousse, biocides, disinfectants, electronic chemicals, silver conductive ink, medical applications, solar panels, smart glass, and suppository (Lem et al., 2012).

4. The landscaping of consumer products containing nanosilver in Korea

As indicated earlier, Korea is a leader in patent publications for use of nanosilver in consumer products. Cosmetics and personal care, medical, and health care occupy 65% of the Korean applications shown in Figure 4. This is a similar percentage as the global consumer products shown in Figure 3. Comparing Figure 3 and Figure 4 illustrates some of the Asian cultural and societal differences. While the world is spending more (40%) on medical/ health care and little less (32%) on cosmetics/ personal care, Korea invested more than twice in cosmetic/personal care (47%) than in medical /health care (18%) (Lem et al., 2012).

Koreans spent about \$130 per person in 2008 on makeup and skin care products and use in plastic surgery clinics doubled to about 1,000 facilities between 2004 and 2007 (Shin, 2008; Barry, 2002; U.S. Commercial Service, 2011; Consumer Demand Beneficiaries in Korea, 2008). Several reasons accounted for the strong growth of cosmetics in the Korean market.

- 1. Life expectancy of Koreans has increased from 62 in 1970 to 79 years in 2006 (Shin, 2008).
- 2. Korea’s rapidly aging population and increasing female workforce are now driving the demand for beauty and personal cares products in the domestic market. Also the

- life expectancy of female Korean has increased from 66 in 1970 to 82 in 1986 (Shin, 2008).
3. A notable trend is the rising demand of the male consumer. Male Korean life expectancy has increased from 59 in 1970 to 79 in 2006 (Shin, 2008).
  4. The younger populace is looking for general skin care and hair care products while the older generation has more specific needs for their cosmetics products.
  5. There is a clear trend of the market heading towards premium cosmetic products that need new technology, especially nanotechnology.

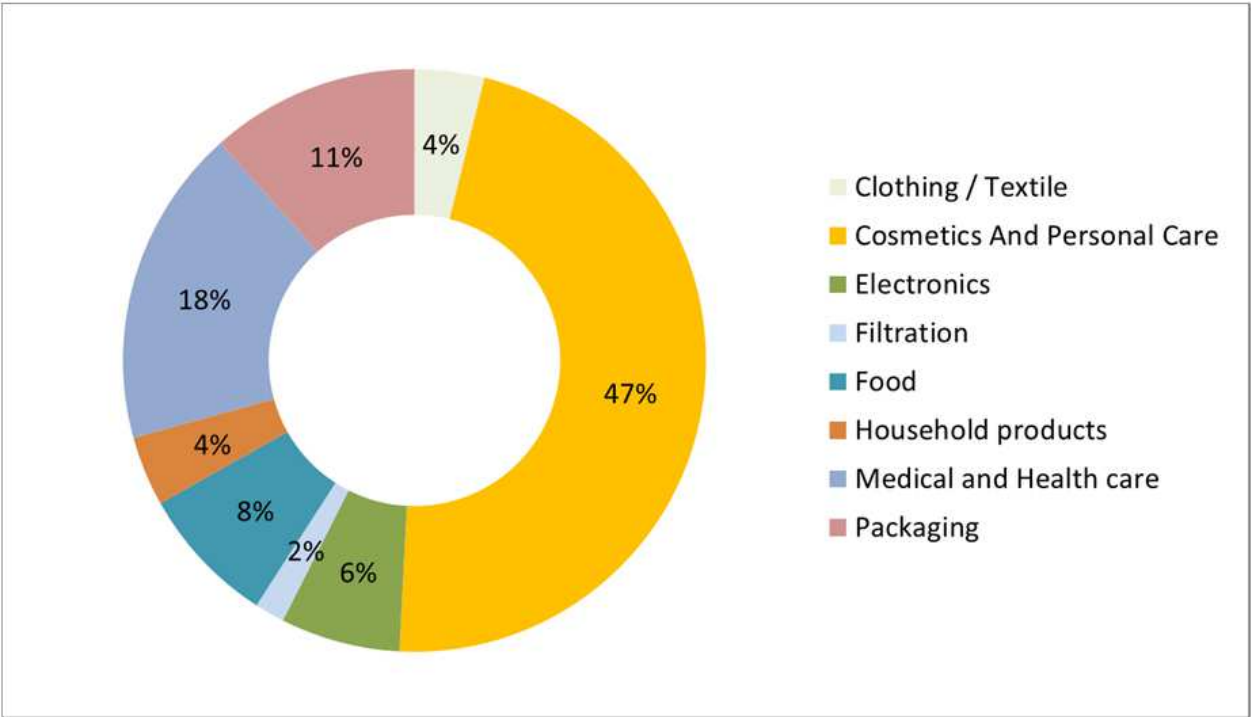


Fig. 4. Nanosilver in Different Application Areas in Korea (Adopted from Lem et al., 2012) (January 1, 1980 to December 31, 2010)

Recently, nanosilver has also found use in everyday products such as antimicrobial products, consumer products, and electronic products. Consumer products containing nanosilver have been selling everywhere in South Korea, especially on the streets of her capital – Seoul as illustrated in Figure 5.

At this juncture, it should be pointed out that not all the consumer products claimed to contain AgNPs indeed have AgNPs. Using energy dispersive X-ray spectroscopy (EDS) analysis (Yang et al., 2011), we have found that not all the commercial products sold in Korea claimed to have AgNPs indeed contain AgNPs (Kim et al., 2011; Yang et al., 2011). These experimental results are not unusual, though negative results can also be due to washing away over time. However, it appears that marketing (especially by street vendors) of AgNPs is not always directly tied to science. Even with a sophisticate Cloud Point Extraction-Based Separation together with EDS, SEM, TEM, and UV analyses, Chao et al., (2011) reported that only three out of six tested antibacterial AgNPs containing commercial products actually contained AgNPs.





Fig. 5. Selling AgNPs Consumer Products on the Street in Seoul, Korea

## 5. Silver/nanosilver and public health

Today, about 320 tons/year of AgNPs are produced and used worldwide in industrial products (Nowack et al., 2011). Stensberg et al. (2011) reported that an estimate of 1,120 tons of AgNPs will be used in 2015. They also reported that the number of products that contain AgNPs has increased from 30 in 2006 to over 300 at the beginning of 2011. In any event, the assumption that silver is benign to humans or that health effects are relatively mild cannot be made without further research to confirm these views. The existence of previous studies show, if anything, that there are potentially very real and severe side-effects which must be addressed prior to increasing the use of silver and especially nanosilver in health, consumer, and professional settings. Therefore, whether it is an old or new problem, we must deal with it seriously.

The growth in investment in nanoscience and nanotechnology has been astounding. Among the \$12.4B spent in 2006 worldwide nanotechnology research funding (Mamikunian, 2007), at least 50 %, that is >\$6B, was spent on the effect of size on the development of nanomaterials and devices.

Nanotechnology application focuses on exploitation of the size effects to create structures, devices and systems with novel properties and functions. The focus of nanoscience research is the understanding of the effect of size and its influence on the properties of nano-material.

With this rapid growth of nanotechnology, it is only natural that the next major wave of applications for silver would include nanoscale particles. However, the safety of nanosilver (AgNPs) in public health is a potential “Nano-Titanic” possibly preventing a sustainable nanosilver industry. As with macroscale silver, nanosilver effectively kills bacteria and is therefore biocidal, but many scientists are still uncertain of its safety.

At the nanoscale, materials have different properties as a function of size compared with the same materials at a larger size. The size range of greatest interest is typically from 100 nm down to approximately 0.2 nm, because in this size range properties of the materials become tunable (Sun, 2007; Lem et al., 2010). This tuneability requires a better understanding of effect of size of particles on public health.

Given the explosive growth in applications of nanosilver, certain authors have expressed misgivings about potential public health effects. Senjen and Illuminato (2007; 2009) of Friends of the Earth claimed that nanosilver was an extreme germ killer which presents a growing threat to public health. Chaloupka et al. (2010) discussed a number of medical uses of Ag and AgNPs in human prophylactic antibacterial effects such as bone cement, implants, and coating for neurosurgical shunts and catheters. In their literature citation, Wijnhoven et al. (2010) and Chao et al. (2010) found that AgNPs were toxic to rat and human cells. They further noted that these silver nanoparticles could enter the human skin via textile and dressing contact, via release from medical devices ingressing into the female genital tract, forming protein-silver complexes that can deposit in human vital organs such as the liver, lungs, and kidneys. Recently, silver has found use in everyday products such as antimicrobial products, consumer products, and electronic products.

Even with the urgent need to specify the nanotechnology that could be the most assist the developing world, Faunce & Watal (2010) reported that the role of AgNPs was not specifically mentioned in water purification due to their potential environmental toxicity. Very recently, Powers (2010) mentioned in her dissertation that her results showed positive that Ag<sup>+</sup> and AgNPs are developmental neurotoxicants in vitro and in vivo. Furthermore, the discharge, emission, and disposal of AgNPs and their products to the environment during their entire products life cycle are also a major concern (Rebitzera et al., 2004; Ross et al., 2002; Panyala et al., 2008; Hansen, 2009; Danscher & Loch, 2010; Nowack, 2010). In recent years, the uncertainty of safety has increasingly made nanosilver a concern of potential threats to public health. Despite the fact that silver and nanosilver has been used for many centuries in applications pertinent to our daily life because silver has an antiseptic effect. In ancient times, many Greeks used silver vessels for drinking water storage.

In contrast, Volpe (2010) and Height (2009) of The Silver Nanotechnology Working Group (SNWG) argued that AgNPs used in antimicrobial applications are identical to all the EPA-registered silver products that were used for decades. Very recently, Nowack et al. (2011) urged the policy regulators should not hastily declare nanosilver materials as new chemicals in their study on the 120+ years of nanosilver history. However, Schäfer et al. (2011) rebuked Nowack et al. (2011) by questioning the difference between the scientific definition of “colloid silver” and nanosilver. They further raised five pertinent questions regarding the safety of nanosilver in consumer products that need to be clarified:

1. Is the toxic potential of nanosilver identical to “classical” silver?
2. Since when has it been possible to analyze silver at the nanoscale?

3. Does nanosilver enter the body in the same way as “classical” silver?
4. Do we know enough about the environmental spread of silver resistance?
5. Is our current knowledge on nanosilver in consumer products sufficient to account for safe use?

In her exhaustive study, Powell (2011) clearly concluded that, “I propose that enough is known already about the toxicity of silver as a metal to begin taking strong steps to prevent human exposures and environmental releases now, rather than waiting till silver becomes the next mercury.”

Recently, the German Federal Institute for Risk Assessment (BfR) has conducted the Delphi study (Bartels, 2010) regarding nanoscale silver compounds in food products, cosmetics and every day products. To ensure that products are safe for consumer health, BfR recently recommended that German manufacturers not use nanoscale silver or nanoscale silver compounds in foods and everyday products until the data are available and comprehensive enough to allow a conclusive risk assessment (Bartels, 2010). Faunce & Watal (2010) noted further the uncertainty of the safety may be compounded by lack of toxicological data and lifecycle studies of acceptable environmental exposure limits.

## 6. A clinical medicine perspective of silver and nanosilver

In view of the many applications in Asian countries like Korea, the importance of a clinical medicine perspective of silver and nanosilver needs to be emphasized. Silver has long been used as an antimicrobial agent in medicine to keep wounds clean since the days of ancient Greece, Egypt, and Rome (Chen & Schluesener, 2008; Lansdown, 2010). This is because of the efficacy of thiol group reactions which inactivate bacterial enzymatic activity (Faunce & Watal, 2010). Colloidal silver was introduced as long ago as 1884 by German physician Dr. C.S.F. Crede, to prevent transmission of maternal gonorrhea to newborns and thus preventing blindness. This is still a practice used in nurseries today (Feder, 2005). Silver was used as a wound dressing and disinfectant during World War I until the advent of penicillin, but the combination of silver with the antibiotic sulfonamide into silver sulfadiazine cream is still the first-line treatment for burns (Atiyeh et al., 2007; Ahamed et al., 2008; Faunce & Watal, 2010).

Nanosilver, or nano-particle sized silver provide a greater surface area of silver and theoretically a more efficacious product. It has also been used extensively in medical applications, from the impregnation and coating of surgical mesh, indwelling catheters, ports, stents, tubes, scopes, and cuffs to other devices to prevent the growth of bacterial biofilms which can precipitate infection. (Faunce & Watal, 2010) Additionally, the use of nanosilver has extended into the public health arena, where it is being used to coat food and agricultural facilities in an effort to prevent bacterial outbreaks in the general population (Powell, 2011).

Despite the wide ranging applications of silver and nanosilver in medicine, it is not clear that enough regulation exists or that there is sufficient research on the potential toxicity of silver to the human body and environment at large. Not only is there evidence for the potential toxicity of nanosilver, there is evidence to suggest that nanosilver is uniquely harmful to the human body when compared to silver compounds because of its ability to generate reactive oxygen species (ROS). ROS, also known as free radicals, cause a



biochemical chain reaction which eventually leads to the destruction of cellular metabolism, structures, and DNA (Faunce & Watal, 2010). Oxidative stress can disrupt cell membranes or cell walls, leading to cell destruction (Powell, 2011). In vitro studies have shown that silver can increase the rate of cell death, inhibit cell growth, decrease DNA and protein synthesis, disrupt DNA replication, affect cell membrane ion transport and integrity, cause cell swelling and toxicity, cause cell death, inhibit neutrophil and lymphocyte activity, and decrease the body's cell count (Powell, 2011).

Environmental concerns surrounding nanosilver have also entered the public health arena (Yu, 2008). Nanosilver production can lead to bulk form release of silver and nanosilver into waste streams, which have previously led to major environmental toxicities (Faunce & Watal, 2010). Such pollution can lead to not only deleterious effects to the ecosystem as a whole, but also cause direct poisoning of humans and animals. In fact, ionic silver is considered to be the second most toxic metal after mercury, in part because of its efficacy in binding prokaryotic and non-mammalian organisms (Power, 2011).

One common condition linked to increased silver deposits in the skin is argyria, a permanent blue-gray discoloration of the skin, and the related argyrosis, a similar discoloration in the eye (Atiyeh et al., 2007; Powell, 2011). The presence of silver is thought to increase melanin production, therefore leading to the color change, particularly in the presence of sun exposure (Powell, 2011). Though long thought to be a harmless cosmetic change, the finding of argyria is a proxy for increased systemic contamination with silver and suggests deeper pathophysiological effects in the body.

Medically, well-documented effects have suggested that silver harms the renal and hepatological systems (Powell, 2011). Deposits of silver in the glomerular subunits of the kidney have led to its classification as a nephrotoxin (Powell, 2011). In the cardiovascular system, case reports have noted an association with arteriosclerosis, a precursor of coronary artery disease (Powell, 2011). The inhalation of silver in the respiratory system has also been linked to inflammation, emphysema, reduction of lung volume, and straining of the tissues in the lung (Powell, 2011). As a result, patients have complained of sometimes daily upper respiratory tract irritation, cough, wheezing, and chest tightness (Powell, 2011). Silver has also been used as an abortifacient and sterilizing agent, suggesting its intrinsic damage to the reproductive tract (Powell, 2011). In pregnant women, silver has also been shown to cross the placental barrier, allowing it to enter the fetus as well (Powell, 2011). One case-control study also suggested an association between the presence of silver in drinking water and developmental abnormalities (Powell, 2011).

Delayed wound healing and decreased white cell count has been found to be a result of silver-enhanced wound dressings (Powell, 2011). In patients with argyrosis, discoloration of the eyes with decreased night visual acuity has also been reported (Powell, 2011). Neurological effects include deposits in the central nervous system, glial changes, and cellular gliosis (Powell, 2011). Clinical manifestations may include seizures, vertigo, weakness, gait disturbance, and decreased sensation (Powell, 2011). Finally, studies in mouse embryonic stem cells have shown a rise in levels of p53, one of the main tumor suppressor proteins which help prevent cancer in the body, which inevitably leads to the question of whether nanosilver use can potentially contribute to greater likelihoods of cancer (Faunce & Watal, 2010). On the other hand, enhanced efficiency of wound healing has also been reported by application of AgNPs on skin wounds in mice (Liu X et al., 2010).

Novel research done recently by Powers (2010) has shown that monovalent silver impairs mechanisms of neuronal development in vitro, but also causes disruption of neurodevelopmental mechanisms in vivo, which persists as lasting changes in adult neurochemistry and behavior (Powers, 2010). Working with the model organism, zebrafish (*Danio rerio*), Powers was the first to show that while lower levels of silver ion did not affect morphology or embryonic viability, they do nevertheless negatively impact swimming performance and thus long-term mortality. Higher concentrations of ionic silver resulted in clear embryonic problems such as delayed hatching, decreased survival, and dysmorphology, suggesting a concentration-dependent effect (Powers, 2010). Powers also provides evidence for the teratogenic effect of silver nanoparticles and of note, shows that the toxicity of nanoparticles was through a distinct mechanism from ionic silver. Some of these biological effects can be explained through differing toxicokinetic and toxicodynamic effects, which elicited unique developmental and neurobehavioral pathologies (Powers, 2010).

Another study conducted by Seoul National University showed that nanosilver enhances platelet activation and procoagulant activity (Jun et al., 2009). Nanosilver worked synergistically with thrombin, a native blood protein which precipitates platelet activation and aggregation, to amplify thrombotic effects. Jun et al. (2009) found that nanosilver works in separate ways to enhance both the activation of platelets as well as facilitate platelet aggregation, or clumping. Intracellular calcium levels were increased by more than two fold in the presence of nanosilver, which is directly related to the activation of GPIIb/IIIa, a protein found on platelet surfaces which aids in platelet activation and binding to fibrinogen. By potentiating these platelet activation and aggregation pathways, nanosilver exposure can theoretically lead to increased thrombotic events. Thrombosis can lead to decreased blood flow or infarction in the circulatory system, particularly in individuals already predisposed to blood clots. Potential complications include venous thromboembolism, deep vein thrombosis, pulmonary embolism, stroke, and myocardial infarction, underscoring the importance of understanding the thrombotic effects of nanosilver (Jun et al., 2009)..

Despite the plethora of studies which suggest certain harmful effects of silver, the data are incomplete. The links between in vitro and animals studies to humans are in dispute, and the existing data on humans are largely through case reports, case-control studies, or retrospective analyses. There is a lack of high-quality, randomized controlled trials (RCTs) which can increase statistical power while minimizing biases. Obvious ethical concerns limit the amount and type research that can be done on human subjects, though longer-term, broader retrospective studies of patients exposed to silver may prove to be more helpful (Powell, 2011). In any event, the assumption that silver is benign to human beings or that health effects are relatively mild cannot be made without further research to confirm these views. The existence of previous studies show, if anything, that there are potentially very real and severe side-effects which must be addressed prior to increasing the use of silver and especially nanosilver in the health, consumer, and professional settings.

## 7. Concept of waste generation

Waste generation is a critical limitation for any sustainable industrial system (Evens et al., 2009). Waste is an important part of our life. Humans are not perfect and thus create wastes.



The actual performance is often lower than the theoretical because the efficiency is always less than 100% (Berglund and Snyder, 1990).

Elimination and minimization of waste have been making great progress in industries and businesses using advanced methodologies such as Lean Six Sigma (Curran et al., 2006; EPA, 2009). For instance, in polymer composite manufacturing, the total waste generated from these processes could be as high as 25% based on the theoretical yield of raw materials (Lem et al., 2006). Figure 6 gives a typical schematic of a materials processing value chain. The steps of the process include component selection, processing, structure, product, and performance. Each step can generate waste only if the waste cannot be recycle back to the start or inputs. Gutowski (2002) has examined the product induced material flows through the product manufacturing system, and has suggested several research strategies to reduce material related environmental loads. This can be accomplished by focusing on three key aspects of the manufacturing process: (a) resource productivity, (b) cleaning products, and (c) re-manufacturing, recycle, and compositing.

A simple mass balance of the net flow performance balance in Figure 6 can be described by Eqn 1.

$$\begin{aligned} \text{Performance} = &af \left( \text{critical component selection} - \text{its wastes} \right) + \\ &bf \left( \text{process} - \text{its wastes} \right) + cf \left( \text{structure} - \text{its wastes} \right) + \\ &df \left( \text{products} - \text{its wastes} \right) - \text{performance wastes} \end{aligned} \tag{1}$$

$$\begin{aligned} \text{Performance} = &af \left( \text{critical component selection} \right) + bf \left( \text{process} \right) + \\ &cf \left( \text{structure} \right) + df \left( \text{products} \right) - \sum (\text{wastes})_{\text{all sources}} \end{aligned} \tag{2}$$

Where a, b, c, d are constants. In term of a continuous flow process, we can rewrite Eqns 1 and 2 into Eqn 3

$$P(x) = \int \lambda_j V(x_j) dx_j - \int \omega_j W(x_j) dx \tag{3}$$

Where, P(x) is a value performance function, V(x<sub>j</sub>) is the value generating function at component x<sub>j</sub> stage or phase j, and W(x<sub>j</sub>) is the waste generating function at component x<sub>j</sub>, and λ<sub>j</sub>, and ω<sub>j</sub> are constants. ). The variation of V (x<sub>j</sub>), W(x<sub>j</sub>), λ<sub>j</sub>, and ω<sub>j</sub> greatly affects the value of P(x).

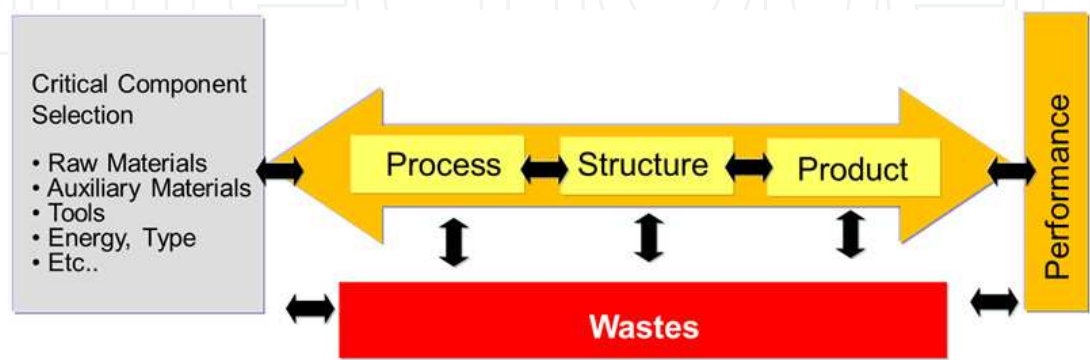


Fig. 6. Relationship of Component Selection–Processing–Structure–Product–Performance (Adopted from Lem et al., 2006)

The expression in Eqn 3 has found uses in many applications in science and engineering. An example of such is the tensile modulus of several ordered polymers (Lem et al., 2006) in Table 1, in which the actual value  $[P(x)]$  is substantially lower than the theoretical value  $[V(x)]$ .  $V(x_i)$  is not restricted with any limitations in Eqn 3 and it is valid to include the feedback loops (as in a recycling process) in Figure 6 except with different forms of  $V(x_i)$  and  $W(x_i)$ , and different values of  $\lambda_j$  and  $\omega_j$ .

#	Materials	Molecular Structure	Theoretical $[V(x)]$ [value generating function at component $x$ ]	Actual $[P(x)]$ [Value performance function]	Gap $[W(x)]$ [Waste Generating Function]	
			GPa	GPa	GPa	%
1	Poly(p-phenylene-2,6-benzo[1,2-d:45-d'] bisoxazole (PBO)	Cis	730-670	360	370 - 310	55 - 43
		Trans	707-620		347 - 260	60 - 37
2	Poly(p-phenylene-2,6-benzo[1,2-d:45-d'] bisthiazole (PBZT)	Cis	610-600	325	285 - 275	48 - 45
		Trans	605-525		280 - 200	53 - 33
3	Polyethylene		360 - 320	172 - 117	243 - 148	76 - 41
4	Graphite		1500	600 - 70	1430 - 900	95 - 60

Table 1. Tensile Modulus of Several Ordered Polymers (Adapted from Lem et al., 2006)

8. Waste minimization in flow of materials as a food metabolism process in a material life cycle

The quality of our life is improved by our industrial system, but the current system is creating unintended and serious consequences for the environment and public health at a global scale. For nanotechnology, to minimize these consequences, one must be able to transform all sources of waste and toxicity into “technical” or “biological nutrients”. We can then reuse them indefinitely without harm to living systems.

Senge and Carstedt (2001) offered a view of why industry produces waste and suggested that a synthetic process can emulate nature to reduce the waste using a cyclic industrial system. One example of this approach is recycling of nylon 6 carpets (Sifniades et al., 1999; Lem et al., 2001, 2002). This type of cyclic process has addressed and overcome the economic, technical, and logistical barriers to commercialize a closed loop recycling process and recover caprolactam from waste nylon 6 materials (Lem et al., 2010). Based on the exergy analysis by Dewulf et al. (2002-2007), in Figure 7, Lem et al. (2010; 2011) have shown that waste generation in a real process is more than just exergy loss (destroyed) in industrial metabolism. Waste generation is unavoidable so waste minimization becomes a fundamental requirement for economic feasibility. The energy and exergy concepts can be formulated in the laws of thermodynamics. Energy is motion or ability to produce motion. It is always conserved in a process (1<sup>st</sup> law). Exergy is work or ability to produce work. It is always conserved in a reversible process, but is always consumed in an irreversible process (2<sup>nd</sup> law, the law of exergy) (Wall, 1988; Sciubba & Wall, 2007))

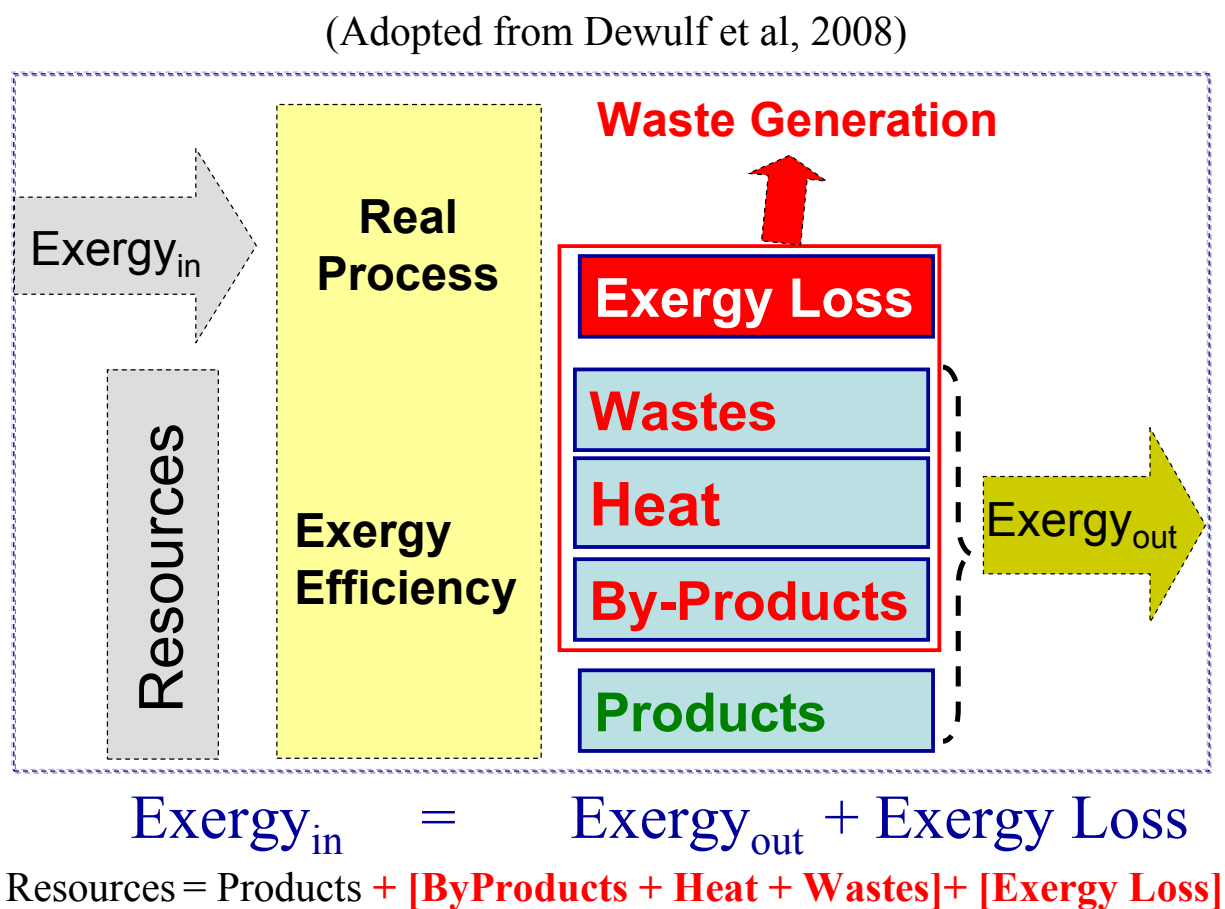


Fig. 7. Waste Generation and Exergy Loss (Dewulf et al., 2008, Lem et al., 2009, 2010)

9. Flow of Ag and AgNPs as a food metabolism process in material life cycle

Using a material flow analysis (MFA), Johnson et al. (2006) in their “anthropogenic cycling of silver in 1997” study have found that North America and Europe have the biggest share of use of silver products on a per capita basis. They found that global silver discards are approximately 57% of the silver mined and only 57% of the silver entering waste management globally is recycled. The amount of silver entering landfills globally is comparable to the amount found in silver mining tailings. Eckelman and Graedel (2007) reported that more than 13 Gg of silver are emitted annually to the environment globally. The tailings and landfills make up almost three-fourths of the total emission.

Figure 8 gives an overview of a silver/nanosilver product’s life cycle as food and waste in industrial metabolism. The metabolization of resources should be optimized with respect to exergy. Dewulfn and Van Langenhove (2002, 2004) have previously applied exergy analysis as a quantitative tool in the thermodynamic optimization of the life cycle of plastics.

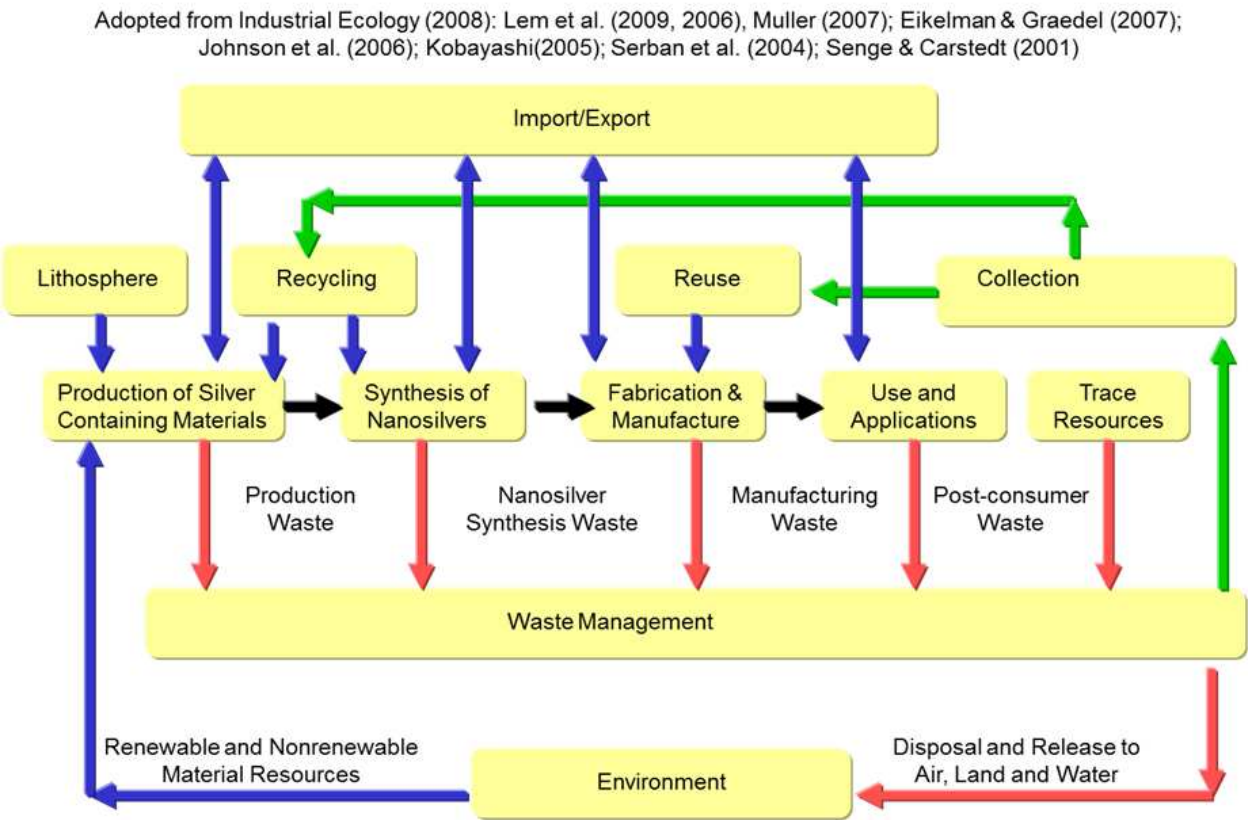


Fig. 8. A Silver/Nanosilver Product’s Life Cycle as Food and Waste in Industrial Metabolism (Adopted from Lem et al., 2010)

Once again as in Figure 6, a mass balance of each step in the life cycle in Figure 8 is equal to the food resource (in blue color arrows) available in each step minus the wastes (in red color arrows) at each step. Therefore, a summation of all the steps gives rise to the total value generated. Eqn 4 can be found

$$Total\ Value\ Performance = \sum (Food\ Resource\ in\ Each\ Step) - \sum (wastes)_{all\ sources} \tag{4}$$

For the continuous process we have the generalized Eqn. 3 (above)

$$P(x) = \int \lambda_j V(x_j) dx_j - \int \omega_j W(x_j) dx \tag{5}$$

Therefore, the main thrust in the waste minimization is to minimize the waste generation function  $W(x_j)$  at any step  $j$ .

10. Effect of size on functional materials (silver)

It is well established that the size of nanomaterials affects its properties (Sun, 2007). There is no exception in AgNPs, particularly as an antibacterial and anti-biofouling agent (Chaloupka et al., 2010; Liu H-L et al., 2010; Liu JG et al., 2010; Sotiriou & Pratsinis, 2010). Fundamental morphology, surface area, and property changes with smaller size have led to

size dependent material properties which are substantially different from their counterparts in bulk. The extent of valence electron delocalization can vary with the size of the particle or domain. Quantum effects become relevant for sizes less than 10 nm. Material properties become tunable by size (Sun, 2007); notably, coordination number imperfection, surface relaxation behavior, nanosolidification in physical properties, superplasticity in mechanical properties, melting and thermal diffusivity in thermal properties, acoustic phonon hardening and optical phonon softening behavior, quantum confinement effects in optical properties, work function and dielectric suppression in electrical properties, and magnetic modulation in magnetic properties. For example, the bandgap of semiconductors such as ZnO, CdS, and Si, changes with size. Magnetic materials such as Fe, Co, Ni, Fe<sub>3</sub>O<sub>4</sub>, etc., exhibit size dependent magnetic memory properties (Sun, 2007).

In spite of the significance in the size of nanosilver, patenting directly addressing size effects only started in 2006 as seen in Figure 9. It is growing every year and 19 patent publications mentioned the size of nanosilver in 2010.

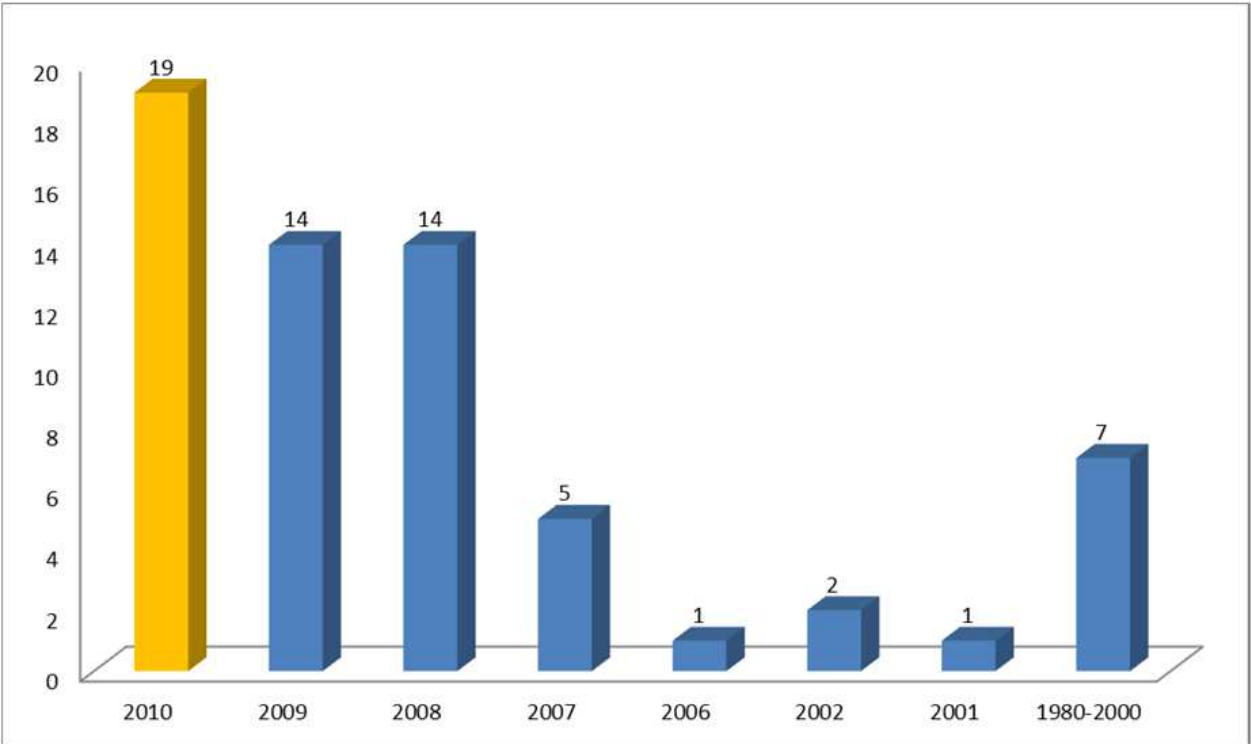


Fig. 9. Patents Describing Size of Nanosilver (Adopted from Lem et al., 2012)

As seen in Table 2, much effort has been employed to refine the type of stabilizers depending on the size of the nanosilver. For the larger diameters up to 400 nm, polyethylene glycol, poly (styrenesulfonate), cetyltrimethylammonium bromide have been used. For the medium diameters up to 100 nm, proteins, peptides, polyvinylpyrrolidone, human serum albumin and transferring have been reported in the IP publication to stabilize the nanosilver. For the very small diameter up to 15 nm, polyvinylpyrrolidone, (1-vinyl pyrrolidone)-acrylic acid copolymer, polyoxyethylene stearate, and 1-vinylpyrrolidone-vinyl acetic acid copolymer were used. Since most AgNPs require to be capped by stabilizers for dispersion, the cytotoxic effect from NP size may be mixed with that from stabilizers. A study employed physically produced AgNPs for examination of the size effect



(Liu H-L et al., 2010). Results revealed that AgNPs of smaller average size (among 3 nm, 6 nm or > 10 nm) had greater antibacterial activity as well as cytotoxicity. This study pointed out the critical role of NP size in their effect on human health and environment.

11. Waste minimization in eco-product design for public health

We have recommended earlier to use Design for Lean Six Sigma - Green (DFLSS-G) and TRIZ to design eco-products (Lem et al., 2009). Kobayashi (2005) has used a product life planning methodology based on a quality function deployment (QFD) and a software tool to establish an *eco*-design concept of a product and its life cycle in multigenerational eco-products development. Serban et al., (2004) have used a TRIZ approach to design for environment for over a product life cycle. We need to answer the following three hard questions in this design:

- 1. Do we have a complete understanding of AgNPs product life cycle?
- 2. Do we have a clear understanding on the unmet needs?
- 3. What can we do to minimize use of AgNPs with optimal effects?

Publication Number	Stabilizers/Important Components	Application Area/ End Product	Nanosilver Size
WO2010091529A1	Stabilizers: Proteins And/Or Peptides And/Or Polyvinylpyrrolidone: Human Serum Albumin And Transferrin;	Cosmetics And Personal Care / Hair Care	1-100 nm in diameter
US20100172997A1	Stabilizer : Agarose, Hydrogel, Paa (Poly Acrylic Acid), Pva (Poly Vinyl Alcohol), Chitosan, Pnipam (Poly-N-Isopropyl Acrylamide), Substituted Pnipam (Including Pnipam-Aa (Poly-N-Isopropyl Acrylamide-Acrylic Acid), Pnipam-Allylamine (Poly-N-Isopropyl Acrylamide-Allylamine), And Pnipam-Sh), Pamam (Polyamidoamine), Peg (Polyethylene Glycol), Alginate Acid and/or Hpc (Hydroxyl Propyl Cellulose)		
US20090326614A1	Stabilizer : Polyethylene Glycol (Peg), Poly(Styrenesulfonate), Cetyltrimethylammonium Bromide;		1-400 nm
CN101402757A	Stabilizer: Amine Light Stabilizer.	Packaging	
US20090011046A1	Stabilizer: Proteins And/Or Peptides: Human Serum Albumin or Transferrin		1-100 nm.
US20080248086A1	Stabilizer : Hydroquinone, Hydroquinone Monomethyl Ether, T-Butyl Paracresol And Hydroxy Methoxybenzophenone, A Pigment, Or A Beneficial Agent.	Medical - Implant	
KR2008083499A	Stabilizer: Polyvinylpyrrolidone, (1-Vinyl Pyrrolidone)-Acrylic Acid Copolymer, Polyoxyethylene Stearate, And 1-Vinylpyrrolidone-Vinyl Acetic Acid Copolymer.		1-15 nm
US20080181931A1	Stabilizer: Acrylic Acid, Polyacrylic Acid, Poly(Ethyleneimine), Polyvinylpyrrolidone		
KR2006026362A	Stabilizer: Glycerin, Polyethylene Glycol, Ethanol, Ethylene Glycol, Propylene Glycol, Sorbitan Fatty Acid Alkylester And Its Ethylene Oxide, Hydrogenated Caster Oil		
US20050013842A1	Stabilizer: Polyacrylic Acid (PAA), A Poly(Ethyleneimine) (PEI), A Poly(Vinylpyrrolidone) (PVP), A Copolymer of Acrylic Acid (AA) with a Vinylic Monomer, Acrylic Acid	Biomedical Device - Lense	

Table 2. Type of Stabilizers Used (Adopted from Lem et al., 2012)

We have started to answer the first question by examining each step of the material flow in a metabolism during the life cycle as discussed earlier. The value generated is equal to the food resource available in each step minus the wastes at each step (Lem et al., 2009). In the material flow model, we need to include probabilistic method as suggested by Gottschalk et al. (2010) that is commonly being used in Design for Six Sigma (DFSS, Curran et al., 2006). To answer the second and third question, we need to understand how the use of nanosilver can be minimized based on specific needs in release and apply the DFLSS and TRIZ to generate innovative ideas for the eco-products design. As an exercise, we will use a shoe pad as an example as illustrated as in Figure 10.



Fig. 10. Shoe Pads (Adopted from Lem et al., 2012)

The amount of AgNPs release depends on the mechanics of the release. To prevent and control these occurrences, it is necessary to use “right amount” of suitable biocides to control fowl and kill microbes. Using a TRIZ approach (Terninko et al., 1998; Rantanen & Dom., 2002) in Figure.11, such a concept is proposed to use water activity as a means to control the water content of  $\text{AgNO}_3$  in the nanofibers where these nanofibers have a shell and core structure. In addition to the controlled release of AgNPs, the use of the nanofibers is to produce a very high contact angle surface to prevent water absorption on the surface (i.e., the Lotus Leaf Effect).

AgNPs can be controlled release at least seven in ways:

1. Particle size,
2. Particle surface modification,
3. Oxidant availability,
4. Media composition,
5. Structured release materials (such as multilayer shell and core structured nanofibers),
6. Release device structure,
7. Locality.

The release can be by one, combination of several, or a combination of all. The first four have been demonstrated by Liu JG et al. (2010) experimentally that the release of AgNPs can be tuned. To understand better the mechanic of the release, we will extend the work by Schiesser (1992, 2011) to describe the release control (desorption and diffusion) in our model.

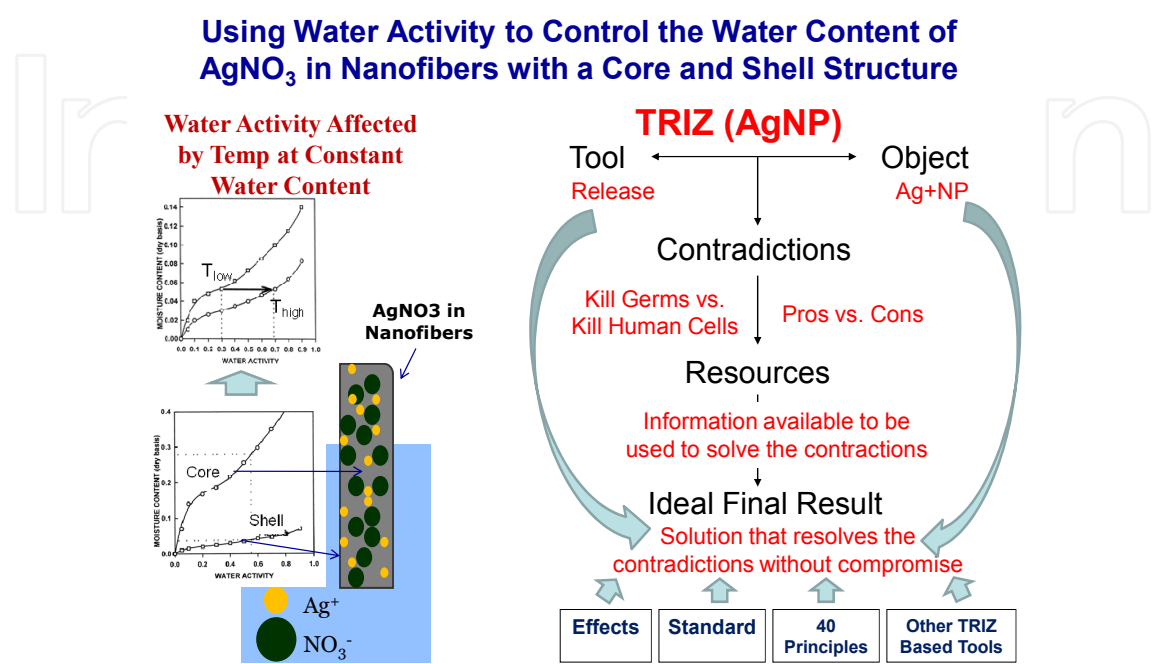


Fig. 11. The Proposed TRIZ Concept (Adopted from Lem et al., 2011)

11.1 DFLSS and TRIZ

A flow chart of the procedure to be used in our study is given in Figure 12 and a TRIZ approach in Design for Lean Six Sigma – Green for AgNPs products life cycle is given in Table 3. We are using the following four steps iterative approach:

**First:** determine the Voice of the Environment regarding the safety of the AgNPs products using two extreme sides of the debate between Friends of Earth/USEPA and Silver Nanotechnology Work Group (SNWG) to obtain a resolution regarding “Conflict”. We try to answer the question - could improving one technical characteristic to solve a problem cause other technical characteristics to worsen? Once the problem is defined, we need to define the system boundaries, quantify mass flows of AgNPs, and define several emission scenarios.

**Second:** search for previously well-solved problems by looking at the 39 engineering parameters/40 principles (Terninko et al., 1998; Rantanen & Dom., 2002). Antimicrobial nanoscale silver is typically embedded within substrates, mainly a a matrix such as a polymer, where any antimicrobial functionality is achieved via release of silver ions (Ag+).

The behavior of silver in environment will be reviewed, and a mass balance model applied to calculate predicted environmental concentrations. The uncertainty of the results is assessed and predicted concentrations are compared to experimental and empirical data (examine an example such as “Nanoparticle Silver Released into Water from Commercially Available Sock Fabrics” by Benn and Westerhoff, 2008).

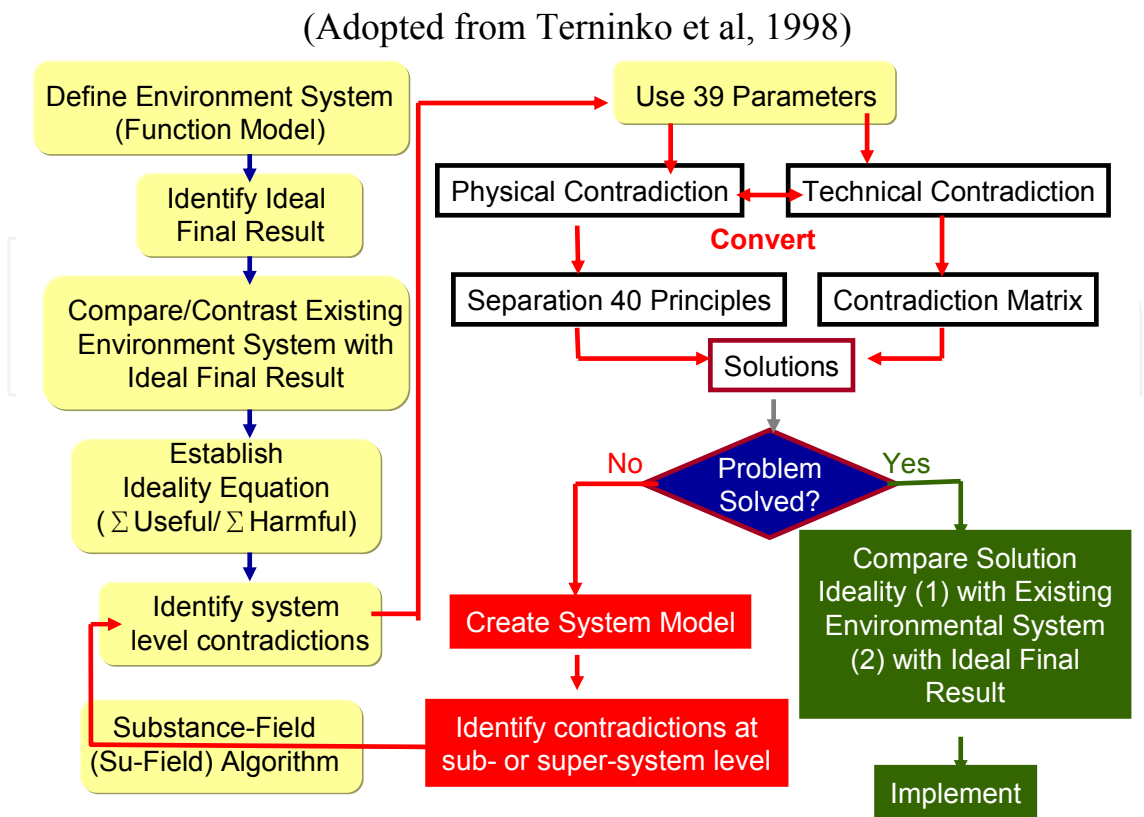


Fig. 12. Flow Chart for DFLSS-G with TRIZ (Adopted from Lem et al., 2010)

DFSS Phase	TRIZ Tools	Approach	Application to AgNP Product Life Cycle
Voice of the Customer	1. Conflict Resolution, 2. Ideal Final Result, 3. Development of Measurement Systems.	Identify the Problem	Step 1: Voice of the Environment (VOE) 1. Safety of AgNP Products. 2. Define Ideality Based QFD
Concept Development	All	1. Find The Principle that Needs to be Changed 2. Then Find the Principle that is an Undesired Secondary Effect.	Step 2: Conflict resolution 1. Example - Friends of Earth/USEPA vs. Silver Nanotechnology Work Group 2. Define Functionality/ Requirements
Detailed Design	All	1. Find the Principle that Needs to be Changed, 2. Then Find the Principle that is an Undesired Secondary Effect.	3. Use of Resources 4. Search for Previously Well-Solved Problems a. Examine 39 engineering parameters/40 principles. b. IP Landscaping
Optimize	1. Conflict Resolution, 2. Trimming, 3. Subversion Analysis, 4. Problem Solving	1. Look for Analogous Solutions 2. Adapt to the Potential Solution 3. Optimize – Ideality	Step 3: Review toxicity data for environmentally relevant silver compounds. Optimize wherever possible. Review earlier search for previously well-solved problems
Validate/ Implement	1. Conflict Resolution, 2. Trimming, 3. Problem Solving	Validate potential solution	Step 4: Gap Closing - Conflict resolution/Ideality Revisit

Table 3. TRIZ Approach in DFLSS-G for AgNPs Products Life Cycle (Adopted from Lem et al., 2010)

**Third:** compile and predict the toxicity data for environmentally relevant silver compounds for no effect concentrations. This material flow will be optimized based on a review of our earlier search for previously well-solved problems.

**Fourth:** evaluate and determine the potential for risk caused by the release of silver into environment using all available experimental data and literature data.

## 11.2 Release mechanics of AgNPs

As discussed earlier, the release of AgNPs can be controlled seven ways: (1) particle size, (2) particle surface modification, (3) oxidant availability, (4) media composition, (5) structured release materials, (6) structure of release device, and (7) locality. The release can be by one, combination of several, or a combination of all. The first four have been demonstrated by Liu JG et al. (2010) that the release of AgNPs can be tuned. The readers are referred to their excellent paper for details. In this section, we will focus our discussion on the last three methods.

### 11.2.1 Structured release material

One way to control the release of AgNPs is the control of the presence of water. Water activity ( $a_w$ ) is defined as  $a_w = p/p_o$  (where  $p$  and  $p_o$  are the partial pressures of water above a medium such as a food and a pure solution under identical conditions). It is a measure of how efficiently the “free” water vs. the “bound” water present can take part in a chemical and/or physical reaction. Water content as a function of water activity has played a critical role in the understanding of food processing science and technology (Cassini et al., 2009). Nadia et al. (2011) have suggested further use of the glass transition temperature ( $T_g$ ) of the material together with water activity in the material. This combination is a powerful tool for understanding the quantification of water mobility in foods and controlling the shelf-life of products. They reported that  $T_g$ , moisture content, and  $a_w$  are useful tools to quantify the water migration pattern in food precisely (Nadia et al., 2011).

The design of the structured release material must have an appropriate  $T_g$  and the desired concentration of total water content present in a medium strongly bound to specific sites. These sites can be the hydroxyl groups of polysaccharides, the carbonyl, amino groups of proteins or synthetic polymers like nylon, polyurethanes, and other polar polymers containing hydrogen bonds and ion-dipole bonds. The preferred structure of the release material can be either bilayer such as shell/core or multilayered where the availability of free water in the material containing  $\text{AgNO}_3$  can be controlled as needed (see Figure 13).

### 11.2.2 Structure of the release device

It has been known for many centuries that water forms spherical droplets on a leaf as seen in Figure 14, and it is more pronounced in the lotus leaf (Luzinov et al., 2006; Ramaratnam et al., 2008; Schilthuizen, 2009; Eichhoff, 2011). Lotus leaves are unusually water-repellent and keep themselves spotless, because on their surface there are countless miniature protrusions, coated with a water-repellant hydrophobic substance. Water cannot spread out on the leaves; so it acts as droplets, removing grime and soil as it moves. The rough surface inhibits wettability and reduces the contact area for dirt particles. Lotus effect has found many interesting applications in consumer products, surface coatings, electronic materials, and smart textile (Luzinov et al., 2006; Ramaratnam et al., 2008; Schilthuizen, 2009).



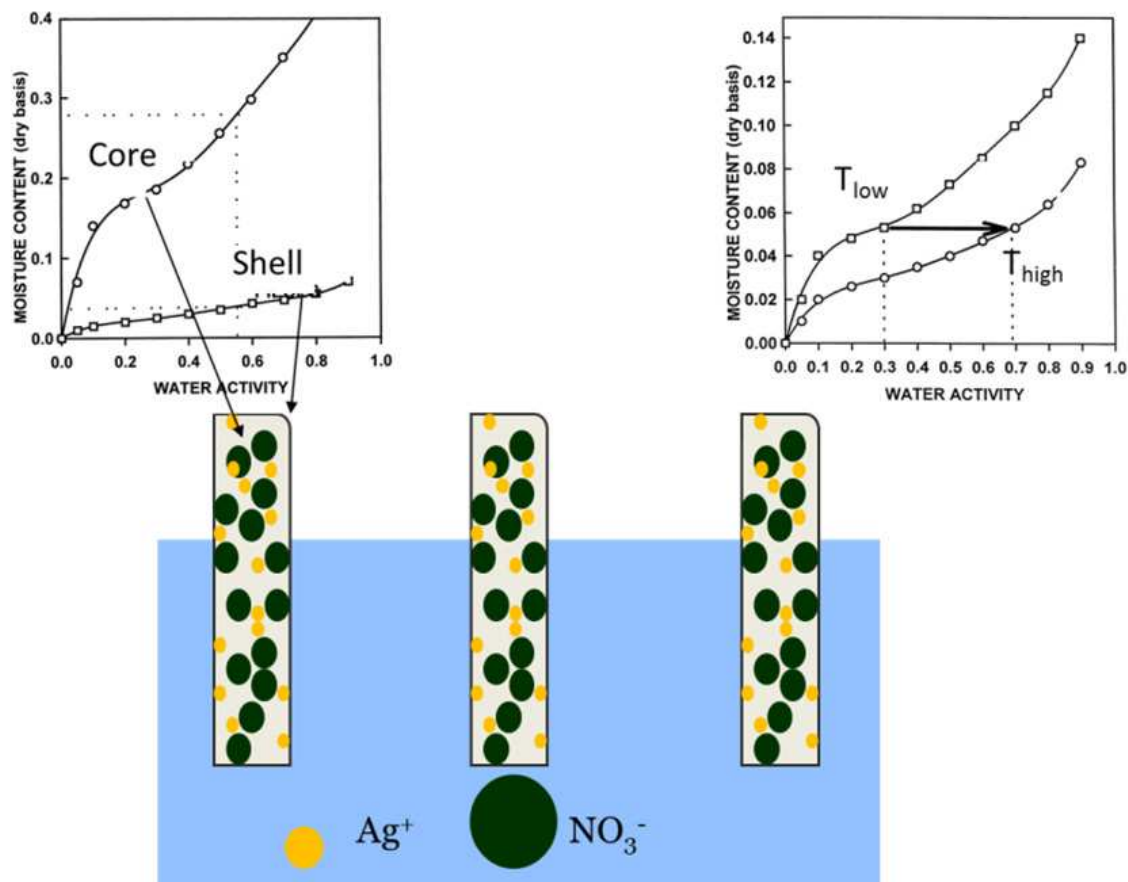


Fig. 13. The Proposed Structural Release Medium (Adopted from Lem et al., 2011)



Fig. 14. Water Droplets on a Leaf

Our goal is to control the wetting of water on the release device by using the concept advanced by Nano-Tex, LLC. Nano-Tex improves the water-repellent property of fabric using the so-called “Lotus Effect” by creating hydrocarbon nano-whiskers that are of 1/1000 of the size of a typical cotton fiber. The distance between the whiskers on the fabric is smaller than a typical drop of water and water thus remains on the top of the whiskers and above the surface of the fabric. (Eichhoff, 2011; Schneider, 2008; Wong et al., 2006; Lo, 2006).

A pictorial diagram of our proposed structure of the release device is shown in Figure 15. The materials used to make the release device have been suggested by KnollTextile (2010) and Wong et al. (2006).

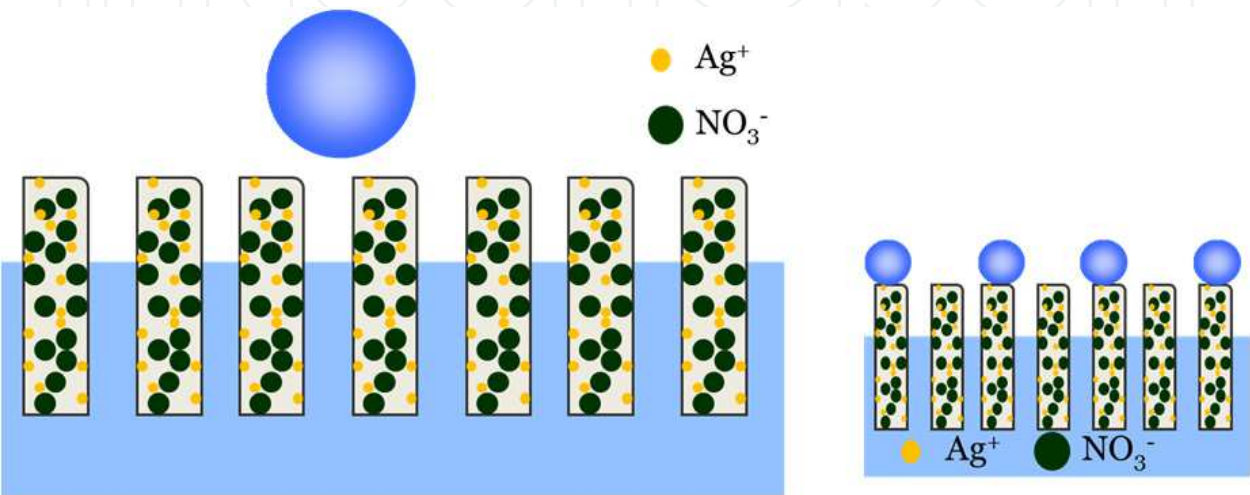


Fig. 15. Proposed Structure of Release Device (Adopted from Lem et al., 2011)

11.2.3 Locality

Bacterial fouling by humans has become a serious environmental and health issue. The existence of bacteria and its fouling in shoes and socks used/worn by human can lead to problems such as biofouling accumulation which leads to health problems. However, as seen in Figure 16, only certain areas in a shoe pad may require suitable biocides such as AgNPs for antifouling. Most sweat and frictional force occur in these areas indicated by the changing of the color of the pad.

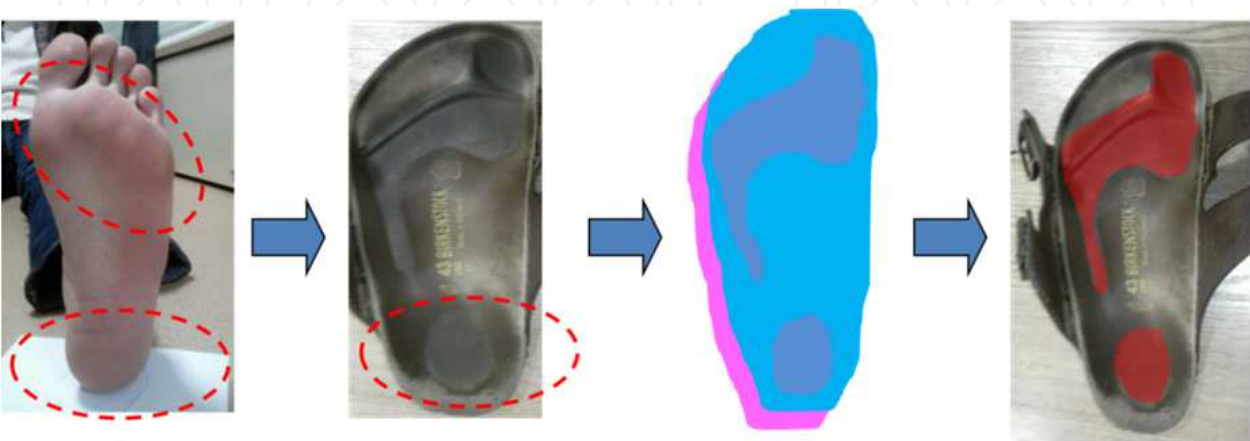


Fig. 16. Locality of Required Biocides for a Foot and a Shoe (Adopted from Yang et al., 2010)

## 12. Future study

In our Design for Lean Six Sigma based Waste Minimization research program, we have begun our journey to study the life cycle assessment of nanosilver starting with the use of product life cycle process mapping and Design for Lean Six Sigma with TRIZ. We are planning to have a more multidisciplinary and international interaction to the characterization of AgNPs products and their transformations in relevant biological and environmental media. A rigorous material flow analysis is needed to quantitatively assess the environmental impact of AgNPs emission. We have continued our study on waste minimization for the safe use of nanosilver in consumer products with particular attention paid to the eco-product design for public health. The data that have been generated from an IP search study help us design eco-products using Design for Lean Six Sigma - Green (DFLSS - G) and TRIZ (Curran et al., 2006; Lem et al., 2006; Terninko et al., 1998) as seen in Figure 17. In addition we need to verify the concept illustrated in Figure 17 experimentally. We will use Monte Carlo (Curran et al., 2006), artificial neural network modeling (Chayjan et al., 2011), and generic programming (Langdon, 2008) approach in the front-end of the innovative concept generation process to search for the best new generation design. To have a better understanding the mechanic of the release control, we will extend the work by Schiesser and his coworkers (Silebi & Schiesser, 1992; 2011) to describe the desorption and diffusion in a pore with Monte Carlo simulations (Gottschalk et al., 2010).

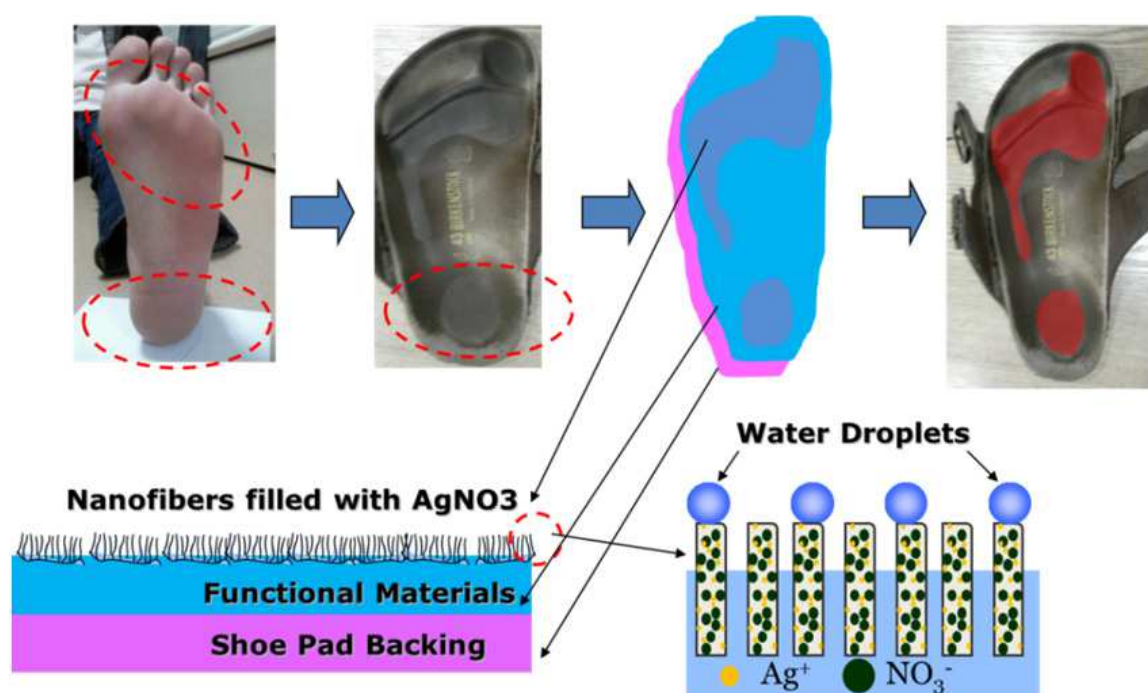


Fig. 17. Proposed Structure of an Eco-Product Required Biocides for a Shoe Pad (Adopted from Lem et al., 2011)

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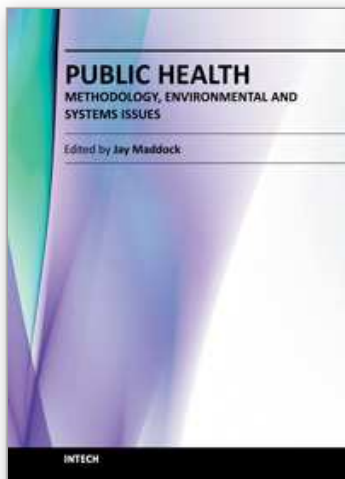
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Public health can be thought of as a series of complex systems. Many things that individual living in high income countries take for granted like the control of infectious disease, clean, potable water, low infant mortality rates require a high functioning systems comprised of numerous actors, locations and interactions to work. Many people only notice public health when that system fails. This book explores several systems in public health including aspects of the food system, health care system and emerging issues including waste minimization in nanosilver. Several chapters address global health concerns including non-communicable disease prevention, poverty and health-longevity medicine. The book also presents several novel methodologies for better modeling and assessment of essential public health issues.

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