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Silver in the product stream: From consumer goods to sludge and water ecosystems with a focus on stakeholder positions

Master's Thesis in the Master Degree Programme:
Geo and Water Engineering

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Department of Energy and Environment
Division of Environmental Systems Analysis
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Technical Report No: 2011:12

ISSN: 1404-8167

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Göteborg, Sweden, 2011.

Till Elisa, Noelle och Nea and my family far, far away

REPORT NO. 2011: 12

Silver in the product stream: From consumer goods to sludge and water ecosystems with focus on stakeholder positions

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Abstract

One of Sweden's 16 national environmental objectives includes a sub-objective that 60% of phosphorus will be recycled from wastewater to agriculture by 2015. The use of sludge as a medium in which to return phosphorus to agriculture is seen as the best solution. There is however a societal and regulatory demand that the sludge be of a certain quality and silver is one toxin of focus. Until recently, many Swedish wastewater treatment plants have seen a rapid decrease in silver concentrations. Why the decrease has halted is unknown but emerging consumer products is considered to be a potential source. The Swedish Water and Wastewater Association (Svenskt Vatten) oversees the sludge certification system (REVAQ) and is interested in the use of silver and stakeholder positions and activities.

This study documents niche markets, current research and regulatory trends and stakeholder positions surrounding this issue. Literature review was conducted, interviews and correspondence with stakeholders were executed and a consumer survey was administered to gather information. Silver-treated (anti-odor) textiles and hygiene products, which have received some attention in Sweden and are of most focus for this study, are shown by research to represent a minor but diffuse portion of total silver pollution. Research regarding degree of risk associated with silver is not conclusive but regulatory action is oncoming with the EU Biocide Directive, for which the Swedish Chemical Agency (KemI) is responsible for silver-related recommendations.

Some non-industry stakeholders are concerned about dispersive use of silver, accumulation in soils, and market expansion. Consumers appear to value the anti-odor function to a certain degree and are willing to pay for it, at least when not specifically made aware of potential risks. When aware of potential risks, reception to the function is considerably less favorable. Pro-silver industry stakeholders see silver treatments as the best available technology, as representing a miniscule amount of silver, and as something environmentally beneficial from the life-cycle point of view. Fashion industry stakeholders do not see such treatments as relevant. Other industry stakeholders appear generally cautious and almost all industry stakeholders report looking for improvements and alternatives, of which there are a few. This precaution and search for alternatives, along with cost limitations and past changes in the anti-odor market indicate rapid evolution and a silver-treated product market that is limited in time and scope.

Keywords: *Silver, biocide, anti-odor, textiles, Biocide Directive, REVAQ, KemI, sludge, phosphorus*

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Abbreviations

Ag – Silver

KemI – Swedish Chemical Agency (Kemikalieinspektionen)

KO – Swedish Consumer Agency (Konsumentverket)

LRF – Swedish Farmer's Federation (Lantbrukarnas Riksförbund)

MPA – Swedish Medical Products Agency (Läkemedelsverket)

SEPA – Swedish Environmental Protection Agency (Naturvårdsverket)

SNF – Swedish Society for Nature Conservation (Naturskyddsföreningen)

REVAQ – Swedish (non-governmental) sludge certification system which includes involvement by SWWA, LRF and others

SLV – Swedish National Food Administration (Livsmedelsverket)

SWWA – Swedish Water and Wastewater Association (Svenskt Vatten)

USEPA – United States Environmental Protection Agency

I. Background

One of Sweden's 16 national environmental objectives includes a sub-objective that 60% of phosphorus will be recycled from wastewater to agriculture by 2015, which can be compared to a 2000 estimate of 21% (SEPA 2002). The use of sludge as a medium in which to return phosphorus to agriculture is one method currently used.

Sludge use in Sweden's agriculture was more common a short time ago. Fifty to sixty thousand tonnes of sludge were estimated to be used per year in the 70s and early 80s, compared to only twenty thousand during the 2000s (SEPA 2002). The 90s saw the percentage rise from around 20% to 30% but fall after a 1999 recommendation by LRF to not use sludge as fertilizer due to pollution-related concerns (SEPA 2002). In 2008, 26% of sludge (214,000 tonnes) was used in agriculture (LRF 2010). There is however a societal and regulatory demand that the sludge be of a certain quality and concentration and application recommendations have been made by SEPA.

Although the amount of silver in sludge from Swedish wastewater treatment plants is usually well below the SEPA-recommended value of 8 mg/kg TS sludge (SEPA 2010), the estimated accumulation in soils exceeds the Swedish sludge certification system REVAQs target of 0.2% per year (Gryaab 2011). The movement to digital photography and less use in some medical and dental applications are a couple of the socio-technical trends that have been attributed to the reduction of silver in sludge over the past years. Silver levels in Göteborg's treatment plant, Ryaverket's sludge, for example, have declined 15% over the past decade but the decline seems to have slowed if not halted altogether (Gryaab 2011). With a growing market of over 600 products containing nanosilver and other silver forms, the number of sources to wastewater is increasing (WERF 2011).

Silver occurs naturally and is even present in food between 10-100 ug/kg (World Health Organization. 1998) without obvious repercussions. However, in addition to its relevance to sludge certification, silver in ion form is recognized as being one of the most toxic metals (Svenson et. al 2008)and the full extent of environmental risk associated with a market surge is debated and unknown. This work focuses on silver in products and related stakeholder positions and actions and is part of a larger upstream effort motivated by REVAQ and lead by the Swedish Water and Wastewater Association (SWWA). See concept illustration displaying the general situation and motivations related to REVAQ and silver in the environment in Appendix A (cover).

II. Aim and Objective

Although some of silver's effects are understood and documented to potentially pose a risk to the environment, there are some questions left to be answered and ownership of the issue is diffuse. This challenge can currently only be addressed in the open market and with related stakeholders. The **aim** (strategic target) of this work is: *to establish a better understanding of the silver as a biocide market, related activities (research, legislation) and stakeholder actions.*

Establishing an improved understanding of the topic required obtaining increased knowledge of the topic. A basic way to gain knowledge is by collecting information about the topic from many sources and organizing that information to create a coherent understanding. Thus, the **objective** (what to do to fulfill the aim) is *to document and describe the current situation surrounding the non-bulk silver market to include descriptions and documentations of:*

1. *the current market: to include silver uses, products available, and silver quantities related to different uses,*
2. *research activity and trends: reflecting current scientific positions about associated risk,*
3. *legislative-regulatory activity: to include existing regulation, pending reviews and legislation and*
4. *stakeholder positions: their actions and positions.*

Considering this objective, important questions were:

1) Current market: How is non-bulk silver currently used? What types of silver are being used in the market and in what quantities? What are alternatives?
2) Research activity and trends: What are important considerations when considering risk of silver? What potential risks related to silver have been noted? What are known and estimated silver sources to wastewater and the environment? What else has research demonstrated involving the topic?
3) Legislative-regulatory activity: What legislation and regulations are relevant to this market? What are authorities doing related to silver?
4) Stakeholder positions: What are different stakeholders' positions and activities related to the issue? Do stakeholders feel that silver-treated products and their function are beneficial and good in general? How do stakeholders weigh benefits with risks and how do they justify their actions?

III. Method

A general method with steps, assumptions and boundaries is discussed here. In addition, a more in-depth explanation of the data collection for the stakeholder section is included. The specific methods for this section were considered more complex than data collection and analysis for the other areas of interest.

a. Steps

In order to complete the objective described above, the study was conducted following these steps:

1. Conduct literature and media review: document current market trends, risk perceptions, regulatory climate, and stakeholders relevant to the study.
2. Determine relevant questions, design and conduct interviews: Decide what information is important to the study and design questions accordingly.
3. Identify and contact stakeholders: determine relevant authorities, special interest groups, trade organizations, manufacturers and retailers. Send information and interview requests via email and follow-up via telephone when possible. Identify other research activity related to the topic.

4. Design and administer consumer surveys: Determine what areas consumer awareness and opinions are important to the study and question accordingly.
5. Host a workshop on the topic: Organize a workshop (at Chalmers) with focus on gathering further stakeholder positions, data and arguments. The author also attended a seminar (at Lund's University) regarding a silver-treatment product launch and gathered input there.
6. Evaluate positions documented during stakeholder correspondence and interviews: Review interviews and other correspondence documenting and comparing stakeholder positions and noting trends.
7. Conduct quantitative analysis with survey results: Analyze survey results and note statistical trends.

b. Objective foci- boundaries

As the objective of this study was to document a broad spectrum of silver in products, some efforts were made to narrow it with consideration to the original motivation of the study, *REVAQ and silver pollution sources upstream*.

Generally, pollution to include silver can be considered to occur due to processes and products occurring in society. The current market contains these processes and products and is the landscape used to describe where the potential pollutant of interest (silver) appears. Knowledge gained about the current market (based on the description below) was used to focus the remaining three sections: research activity, regulatory activity, and stakeholder positions.

Boundaries for each of the four objective interests were defined as seen below.

Current market: The current market was defined as the Swedish non-bulk silver (diffuse use of silver, silver in nano, salt, colloidal or ion exchanger bound) market with a sampling of international compliments. For the purposes of this study, the term non-bulk silver is used to represent all silver that does not appear in bulk metallic forms seen with silverware, jewelry, coinage and electronics. Market is used in the broad sense of open market: "a market which is widely accessible to all investors and consumers" (InvestorWords 2011).

In addition, a special consideration was given to the textile and apparel industry because:

1) It has been already identified by the SWWA as an area of interest and efforts have been made already to add caution to the use of silver in this market. The current market and its stakeholders are thought to perhaps reveal indications if these efforts have had an effect or not.
2) Silver in this market is used diffusely and the anti-odor function is perceived to be especially polarizing. The use in medical products for anti-infection is considered acceptable but the use to reduce odor – Is this actually necessary?
3) Since household pollution is considered crucial to the goal, consumers are considered to be a stakeholder of interest. The textile (apparel) market is considered to be more consumer-driven compared to others such as building materials, pigments and preservatives which makes it a better topic for use in consumer evaluation.

Research activity and trends: Searchable (by English, Swedish) research and that referred to by other media was considered. Google Scholar was primarily used and a sampling of those found and deemed most relevant by the author was used.
Legislative-regulatory activities: An attempt was made to understand the relevant legislative activities surrounding this topic in Sweden first. International perspective was gained through journal articles mostly with referral to the European Union (EU) and USEPA activities. Activities were then further reviewed via EU and USEPA websites. No other legislative activity was noted nor was it specifically sought.
Stakeholder positions: Although silver is used in many ways and applications, the stakeholders in the textile market were deemed as the subjects of interest. This segment of stakeholders had been already identified in the motivation of the study due to their appearance in the consumer market (vs. bulk and industrial uses). No information obtained during the "current-market" study revealed that this was unjustified.

An attempt was made to obtain an understanding of Swedish stakeholders first and foremost. International perspective was gained by identifying stakeholders in primarily the U.S. market as well is in the EU market. Stakeholders were considered as those that have interest in or that could affect or be affected by the market: special interest and industrial groups, manufacturers and retailers, experts and consumers.

c. Objective foci- assumptions

In accordance with the four objective focus areas, the following assumptions were determined.
Current market: Products found via media and search functions are representative of what is available to consumers on the open market. It is assumed that those chosen for further investigation are representative of the market.
Research activity and trends: Google-scholar (and others) searchable research by use of English, Swedish languages is representative of current knowledge. Research found is representative of current scientific trends and opinions. Those deemed most relevant by the author are assumed to properly represent research activity.
Legislative-regulatory activities: Official and publicly available data is representative of actual public and non-public (behind the scenes) activity. Swedish, EU and U.S. legislation are assumed to be most relevant to the Swedish legislative environment and relevant market.
Stakeholder positions: Stakeholders chosen (and those with which correspondence was gained) are assumed to be the most important to the market as those that have the largest bearing on the market's trajectory. Individuals represent their affiliations, whether it is an organization or a demographic characteristic. Stakeholder positions collected are assumed to represent stakeholders (of that type) in general. Unresponsive entities are assumed to be properly represented by other stakeholders. Despite it being difficult for the author not to label non-responders as monsters lurking in the shadows, the author perceived resistance from many stakeholders (responders, non-responders) due to administrative structures and practices that protect in-house expertise from students and other inquisitive persons. Therefore, the author assumes that most non-response was due to that protection mechanism and not the other more insidious one that involves hiding dirty secrets.

d. Method: Stakeholder study

In order to properly document stakeholder positions and activity, the need presented itself to first determine what a relevant stakeholder was and then identify stakeholders for data collection. Second, the author determined a manner in which to collect and analyze data from the identified (and responsive) stakeholders. These two sub-steps are described here.

1.Identifying stakeholders

For the intent of this study, a stakeholder is defined as any entity having an influence on the market of interest. Many other entities could have been considered but in the interest of simplicity and time, the data gathering was limited.

Important stakeholders were identified as entities active in the production, sales, marketing, consumption and regulation or opposition of products of interest. The below is a list of stakeholder groups from which some type of information was included in the study. Also included is a quick description of the group and an explanation for why the particular stakeholder group was targeted for information, i.e. how they influence the market.

1) Authorities: This group is assumed to, by appointment of their government and people, communicate and enforce the regulations of their jurisdiction as well as recommend legislation based on current knowledge and trends.
2) Industry and Market: This group is assumed to include manufacturers, resellers, retailers, and marketers and industry groups. The group is assumed to collectively identify and provide the products and services that are deemed attractive by consumers or deemed marketable by industry actors themselves. They are also assumed to largely act in order to best ensure their success on the market but with consideration to public opinion, which is built via and by the other stakeholders.
3) Consumers: Those who make purchases and ultimately decide whether a product or service is attractive and worth the price (and associated benefits, risks) are in this group.
4) Non-governmental organizations: These groups are for-profit or non-profit organizations that act in the interest of their members and influence (or attempt to influence) other stakeholders' opinions and behaviors in order to complete their organizational goals. (Note: Industrial organizations are included as an industry actor).
5) Experts: This group made up of researchers who have focused on the topic or related topics is assumed to produce scientific opinions with which, in combination with research, all opinions are considered to be tightly or loosely affiliated. Other stakeholders are assumed to use these opinions to support or disprove their and others' opinions and actions.
6) Certifying entities: These entities are assumed to afford some type of quality assurance to the market (processes, products) and act as a signal to other stakeholders. They are, however, not assumed to be without fault but only represent some form of external review of industrial activities and products.

2.Data collection and analysis

Data was gathered from important market actors by use of literature review, official website messaging and other publication, interviews, email correspondence and consumer surveys. Quantitative data analysis was used to a small degree for some survey results.

Literature review and documentation involved the search and reading of website material, published documents and reading available information. Relevant data gathered was used as supporting documentation and cited. Websites were found by basic internet search functions.

Interviews and other personal communications were gained in-person, by phone or email contact. Discussions and interviews were recorded besides in the case of impromptu mobile-phone calls and the like, in which cases notes were taken. Notations were made during and post interview. Notations that were to be potentially published or cited were sent to the interviewer for review and approval. Information and opinions gained from the discussion were documented. A similar approach was taken with information gathered at the workshop and the attended seminar (Chalmers and Lund).

Customer surveys were sent to both target and non-target groups by way of email and facebook. All data gathering sought to get a general picture of each market actor's knowledge, perceptions, opinions and activities related to the topic: silver in the product chain.

The interviewed and the surveyed

The biggest challenge can be finding entities and individuals that are willing to be interviewed or surveyed in the first place, especially when it comes to industrial stakeholders. In order to find willing stakeholders, emails were sent to companies and industry groups seeking interview opportunities.

Finding large groups of consumers to survey electronically was also challenging. Many groups protect members from solicitation (nor does Chalmers have a method for allowing such distribution) and therefore, personal contacts became a main avenue for gaining potential survey responders.

Questions and interviews

Stakeholders were first approached with emails stating the general aim of the study as well as the reason for interest in gaining information from them. During interviews, an attempt was made to only gain answers to identified questions. But as stated in Miles, "An interview will be a 'co-elaborated' act on the part of both parties, not a gathering of information by one party." (Miles and Huberman 1994). This takes into account that both parties determine the tone of the interview of discussion, which has direct bearing on information gained and the manner in which it is delivered.

Seven basic questions were constructed to form a basic guideline for interviews and surveys (more questions seen in Appendix B).

1) Are stakeholders aware that some products contain silver?

2) What do stakeholders think about silver-containing products, related function and risks?
3) Do they understand the capabilities and limitations of wastewater treatment?
4) Are they aware of the use of sludge for the recirculation of phosphorus?
5) Are stakeholders aware of the potential negative consequences related to silver-treated products?
6) How do they weigh the potential negatives versus beneficial function (and market demand)?
7) How is this segment of the market expected to grow or develop? Do consumers display demand for related products?

IV. Results

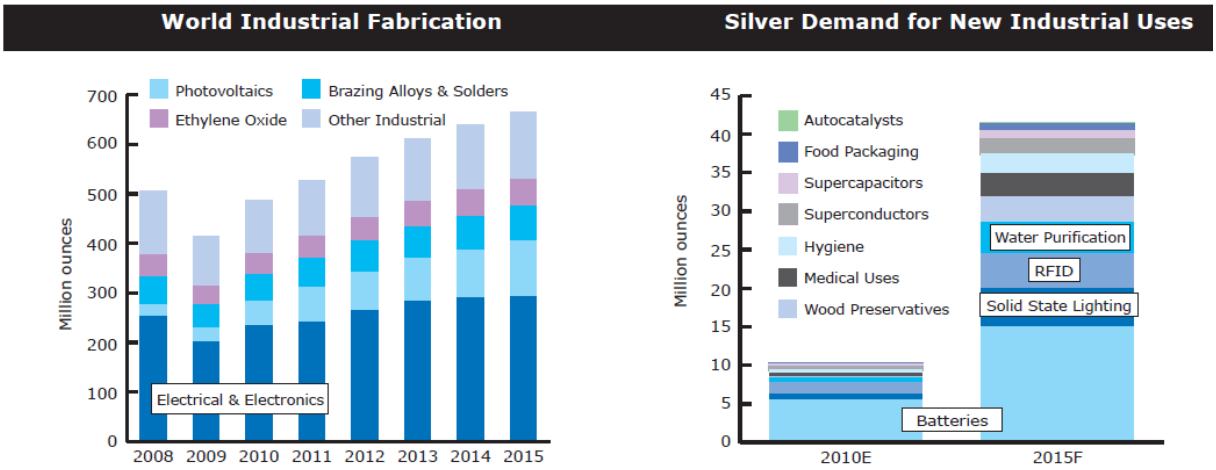
Results from interviews were used in conjunction with literature and other references to complete objectives. Therefore, all forms of data are presented combined in the remainder of the report. However, the stakeholder section is where the majority of information gathered during interviews is used and is relevant. The current market, research and legislative sections depended more on static sources of information.

a. The Current Market

How is non-bulk silver currently used?
What types of silver are being used in the market and in what quantities?

Non-consumer uses of non-bulk silver include for photography development, in municipal water treatment and purification processes as well as an array of industrial processes. Figure 1 (below) from the Silver Institute puts the subject at hand in context. Industrial use represents about 50% of total global silver use and accounts for 14,175 tonnes (500 million ounces) of the 28,325 tonnes (1000 million ounce) total. Of these 14,175 tonnes, less than 300 tonnes are thought to be used in emerging industrial uses, such as medical, hygiene, textile use and others (GFMS 2011). This means that the primary interests of this study represent less than 2% of industrial use of silver.

Figure 1: World Industrial Uses of Silver with Emerging Use Insight (GFMS 2011)



Although emerging industrial uses are small in amount of silver, uses are diffuse and growing. Silver is increasingly used in consumer products because it is a versatile biocide. It's effectiveness in killing bacteria is proven and undeniable. It has thereby been incorporated into just about anything that at some point will come in contact with moisture (GFMS 2011). It is present on the consumer market in an array of marketable forms – nanosilver, silver salts, colloidal silver, silver ions (and ion exchangers), and silver fibers to name the most common. In this somewhat loose regulatory environment, a large number of silver-containing products have emerged under the radar partially due to the lack of research and knowledge around the topic (Luoma 2008). Silver now appears in or on various toothpastes, health supplements, cosmetics, shower nozzles, and clothing articles (Jacobsson 2008).

Based on a data collection done by the Project on Emerging Nanotechnologies, nanosilver is likely the most common nanomaterial present today in consumer products (Luoma 2008). According to the inventory focused on nanomaterial-based consumer products, 24% of the products were listed as containing nanosilver and from March 2006 to March 2011, the number of products increased 10-fold , from 212 to 1,300 (PEN 2011).

Estimations of silver (non-bulk) quantities used vary. A study conducted for the Silver Institute (Trade organization representing silver industry) in the year 2000 estimated that 155 tonnes was used in drinking water purification and that the amount would double in the coming decade (SI 2009). However, the same source later reported an estimate of 56 tonnes for the year 2010 indicating uncertainty in the forecasts. A German silver biocide study reported an estimated 8 tonnes total used in Germany with the majority used in water treatment and 0.5 tonnes respective 0.4 tonnes for textile and polymer sectors (Hund-Rinke et. al. 2007).

One manufacturer (HeiQ, Switzerland) estimated the European market for silver-containing products (non-bulk) would reach 100-230 tonnes silver by 2010 and stabilize by 2015 (Blaser et al. 2008). However, a more recent estimate from HeiQ estimated a current EU market of less than 25 tonnes (Height 2011).

Regarding the global market, another source estimated that the amount of nanosilver currently produced and used globally (however use is not specified) is estimated to be approximately 290 tonnes per year (Nowack et al. 2011) These estimates are further clouded by a projected estimate by the Silver Institute that the "hygiene" market including textile, surface use, coatings and biocidal paints (excluding photography) would not exceed 85 tonnes by 2015 (GFMS 2011).

On the company level, Polygiene, a known company offering anti-odor function (via silver salts) in the textile industry, estimated a 10-15 kg Ag/year in Sweden and 120 kg Ag/ globally (mainly EU and U.S. market) (von Uthmann 2011).

As mentioned here, estimates and the parameters used to derive them vary greatly. Estimates are done with different geographical focus, use classification, and silver form (nanosilver or other). These variations demonstrate the potential unpredictability as well as the difficulty in establishing a reliable estimate.

The following section provides a brief description of niche silver uses. A brief description of silver mining and certain industrial uses is contained in Appendix C.

1. Textiles and surface materials

As mentioned earlier, the total hygiene market including silver-use in textiles, bedding, appliances, and surface coatings is expected to reach no more than 85 tonnes in the next five years (GFMS 2011). This can be compared to an estimate of less than 25 tonnes for the EU market (Height 2011).

Clothing, flooring, appliances, and surface materials are all available in silver-treated varieties in order to prevent and reduce growth of bacteria, fungi and algae (GFMS 2011). Silver-impregnated plastics have appeared and been used in and on everything from telephone receivers to toys (Scheringer, Blaser et al. 2008). Building materials are also considered a potential product segment that could be offered treated with an anti-growth agent such as silver and one silver treatment manufacturer, Agion, has a long list of building material clients (Agion 2011). Polygiene is used in at least one flooring product called Flowcrete, which is self-referred to the number 1 choice in hygienic flooring touts Polygiene as "effective against bacteria including E.Coli, Staphylococcus Aureus, MRSA, Salmonella Typhi, Streptococcus Pyogenes and SARS." (FBR 2008).

In the textile market, silver-treated variants of clothing such as socks, underwear, first-layer sporting garments, and shoe insoles are available to the consumer, these being items that have high likelihood of sweat collection and related bacterial growth (von Uthmann 2011)

2. Water treatment and disinfection

As mentioned earlier, a variation between 56 tonnes for the year 2010 (GFMS 2011) and 155 tonnes for 2000 by the Silver Institute (SI 2009) was estimated to be used in drinking water purification.

Silver has been used for ages in water treatment and it is used in small scale drinking water treatment, such as in hospitals or on cruise ships. Silver is ineffective as an anti-virus (Finnson 2011), but its other qualities make it considered a preferred replacement to harsher chemicals such as chlorine and bromine for swimming pool treatment (SI 2009). Some of the consumer water filtration company Brita's home water filtration systems utilize silver in activated carbon (Blaser et al. 2008). Also, various nanosilver products have been used in swimming pools as an anti-algal agent for decades (Nowack et al. 2011).

According to a list of approved U.S. suppliers of silver-based Water Purification Systems, twelve suppliers of Drinking Water Purification Systems are USEPA Registered, Food and Drug Administration (FDA) approved, National Science Foundation (NSF) listed, Drug Administration (USDA) approved as well as seven suppliers of Swimming Pool, Spa, and Cooling Tower Systems (USEPA approved, NSF listed), and one supplier of Fluid Sanitation Systems (SI 2010). In addition, Polygiene (silver treatment manufacturer

reported that one of their applications is USEPA approved but not currently utilized in such systems (von Uthmann 2011).

Some food packaging utilizes biocidal properties of silver, sometimes applied as part of a coating or embedded in a polymer. These and other food hygiene uses are estimated at considerably less than 28 tonnes (1 million ounces) Ag per year (GFMS 2011). Also, silver-laced gelatin is sold in a few countries for the purpose of cleaning and disinfecting vegetables (Silver 2003) .

Finally, an excerpt from the Washington Post reveals one silver-containing disinfectant available in the U.S. and presents it as environmentally preferred:

> *"However, some smaller companies offer products that meet EPA standards without resorting to ingredients some environmentalists find troubling, such as sodium hypochlorite, phenols and quaternary amines, or "quats." PureGreen24, for example, uses an active ingredient composed of* ***silver ions*** *and citric acid, and the company claims the manufacturing process produces no waste or byproducts."* (Rastogi 2009)

This is notable in that it can be said to demonstrate an example in which an ingredient targeted as a toxin by one party can be proclaimed as an environmentally-preferred ingredient by another.

3.Medical, Dental, Health Uses

Silver has a long history of medical use. Its effectiveness as an antibacterial is known. It is currently used in topical antimicrobial agents for burns- cream, bandages for trauma and diabetic wounds, silver coated catheters and medical devices, dental amalgams and as a homeopathic remedy or supplement. In addition, toothpastes and ointment creams are also available in varieties containing silver (SI 2011).

Non-prescription products and supplements (often colloidal silver) are offered widely in supermarkets and health shops around the world – a web search reveals a long list of products (Silver 2003). These products have been a subject of debate both in Sweden (Jacobsson 2008) and abroad (Silver 2003). See a further description in Appendix D.

4.Cosmetics and beauty products

In a Japanese study, nanosilver is identified to be a good preservative alternative to other preservatives for use in cosmetics (and possibly pharmaceuticals) due to its antimicrobial properties and limited response to UV radiation (Kokura, Handa et al. 2010). There is at least one such preservative sold by Johnson Matthey Chemicals (UK) for the use in cosmetics and toiletries (Silver 2003). Silver-containing deodorants were available in Sweden but were removed from the market (Holmer 2011) after criticism from authorities, researchers and consumers (Guzikowski 2011) but are available at least via online-retail, such as Amazon (Amazon.com 2011). However, silver is not present in cosmetics in Sweden according to the industry group Chemical Technical

Group, a branch organization that support the cosmetic industry in Sweden (Holmer 2011).

On the world market, various beauty products enhanced with nanosilver are marketed online and into include a product-line called Nanover, manufactured in South Korea and Simengdi Phyto Silver Cream (MadeInChina 2011).

5.Photography

In photography, silver (fabricated as silver nitrate) is used in the form of silver halide, which is very light sensitive, and is suspended on film. When developing film, chemicals are used to transfer the negative images revealed by silver halide crystals onto paper. One ounce (28 grams) Ag can yield about 5,000 color photographs (SI 2011).

Although use of silver halide in photography has declined in recent years with the dispersion of digital photography, use is still prevalent in x-ray photography and in the motion picture industry due to its cost effectiveness and preferred quality (SI 2011)

Although use of silver in photo development is decreasing, it still represents one of the largest non-bulk, non-industrial uses. The total global use of silver in photography is estimated (2010) at just over 2000 tonnes (Klapwijk 2011).

6.Paints, Preservatives and Pigments

Silver is used in some paints and pigments (Svenson et. al 2008). Silver has been tested in paints as an added biocide for use on surfaces in water treatment systems. In one study, a silver treated surface reduced biofouling and the presence of legionella pneumphila much better than a similar surface, but only for two weeks (Rogers et al. 1995). Another study presented household paint synthesized with nanosilver as an environmental friendly alternative and as effective in reducing both gram-positive and negative microbial growth (John et al. 2008). However, this use of silver for these purposes is expected to remain marginal (GFMS 2011).

The Silver Institute reports a small (5.7 tonnes) but increasing use of silver in wood preservations in their March 2011 report (GFMS 2011). In 2003, a U.S. Senate Subcommittee held a hearing on the potential replacement of copper based wood preservatives by silver-based preservatives. The silver-based alternatives were considered to possibly be an environmentally-preferred alternative to the already-proven hazard chromated copper arsenate (CCA) (SI 2011). However, since an agreement was established to phase out CCA, silver alternatives, which are almost triple the price of other alternatives, have only gained a fraction of the market and only utilize an estimated 5.7 tonnes Ag per year (GFMS 2011).

Radio Frequency Identification (RFID) technology, which can be used as an alternative to static barcodes, relies on the use of silver ink (in silver nitrate form) and is estimated to utilize 1 to 2 million ounces of silver per year globally (GFMS 2011). In addition, silver was deemed to be a suitable pigment for use in water-based ink jet printing applications

(Magdassi et al. 2003) and nanosilver has appeared in some commercial inks (GFMS 2011).

7.Alternative biocides and anti-odor

Triclosan and triclocarban are chemical biocides known to be hazards to the environment (and to human health for triclosan) and are used to a certain degree on the current market (Adolfsson-Erici 2007). Four tonnes of triclosan was reportedly used in Sweden yearly, with two tons attributed to toothpaste and 0.3 tonnes in cosmetics and deodorants and documented use in textiles (Adolfsson-Erici 2007). Microban, one patented antibacterial function that sometimes contains triclosan as an active ingredient, has been documented as offered in a number of products on the Swedish market. Triclocarban is reportedly used in 85% of antibacterial soaps in the U.S. and also appears in some textiles (Adolfsson-Erici 2007).

Positively charged polymers can act as mechanical biocides, but current use appears to be limited. Charged polymers are reported as only in the experimental and development stages in a recent Swedish magazine, *Ny Teknik* (Karlsson-Ottosson 2011). However, Adidas reportedly offers products that utilize a technology sold under the name, AEGIS (Meister 2011) available at microbeshield.com.

There are also sprays that offer the function by self-application. Besides Polygiene's silver spray, there are others such as Stink-free spray that has other ingredients (Benzalkonium Chloride, Cetrimonium Bromide, Propylene Glycol) (2toms 2011).

There are also some non-biocide alternatives that mitigate the conditions that cause substantial biota growth. For textiles, the 'wicking-effect' refers to the spreading of moisture in order to reduce growth. Bamboo, coconut and hemp forms are known to have these properties (von Uthmann 2011). In addition, a recent magazine (Ny Teknik) highlights the use of a nano-silicon coating used to ease surface cleaning (von Schultz 2011).

b. Research determinations and risk

What are important considerations when considering risk of silver?
What potential risks related to silver have been noted?
What are known and estimated silver sources to wastewater and the environment?
What else has research demonstrated involving the topic?

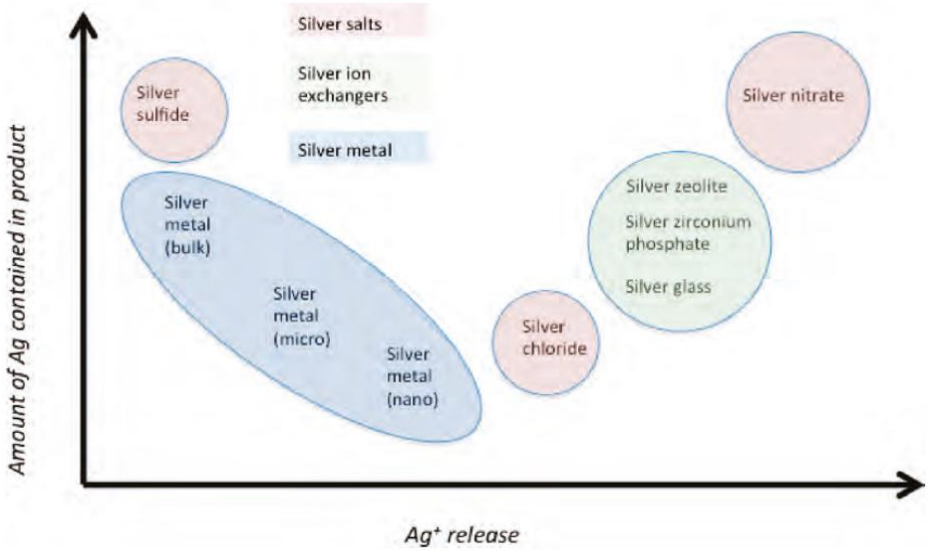
Through use of each of the uses mentioned above, silver substances are washed out and end up in wastewater sludge and the environment, causing some known and other less understood consequences. Risk of silver to human health and the environment is based on a number of factors to include: speciation, quantities and sources, and silver's inherent toxicity. These considerations are discussed in this section based on noted research on the topic. Noted themes related to silver-associated risk are also discussed.

1. Speciation and toxicity

Although it is convenient to group all forms of non-bulk silver into one category, speciation is considered critical to potential risk (see Figure 2, below). A silver ion is an atom that is less one electron, making it Ag^+. Nanosilver is Ag particles of less than 100 nanometers (Luoma 2008). Colloidal silver includes both nanosilver and non-nanosilver and is considered as silver particles of (<1000nm) (Luoma 2008). Silver salts are salt-silver compounds, usually present as silver chloride, nitrates, sulfides display varying levels of ion release. Silver can also be utilized in ion exchangers, which act as a surface area from which to dispense ions or in fiber form, which is simply metallic silver processed into the shape of very small threads (Nowack et al. 2011).

A general illustration of amounts of ion release related to amounts of total Ag for various silver formulations is seen below. As seen in the figure, nanosilver is thought to release high amounts of ions per amount. Ion release of salts varies greatly from minimal for silver sulfide to substantial for silver nitrate.

Figure 2: Silver release and amount of silver required in products for different biocidal silver formulations. (Nowack et al. 2011)



Nanosilver is generally considered to be the most harmful as it creates more surface area for the release of silver ions (Ag^+). It is still not determined whether the nanosilver in itself is toxic as well as released ions (Nowack et al. 2009). Nanosilver has shown to be present even in silver fibers and larger sized colloidal silver applications (Benn et. al. 2008).

In laboratory testing, ionic silver has been shown to be one of the most toxic metals to aquatic organisms (Svenson et. al 2008). This establishes the foundation of theoretical ecotoxicity (toxicity in ecosystem) of silver but these tests are done to assess the toxicity of ions, not of ions in real environmental conditions.

The real question lies in what actual effect silver has in the environment. It has been documented that water and sediment contaminated with silver corresponds greatly with ecological damage to the environment. In the 1970s and 80s, some species

disappeared from mudflats in the San Francisco Bay at the same time that industrial emissions resulted in very high concentrations of copper and silver. At that time, silver levels were 100 times the concentration in open waters. After stricter regulations were imposed and the concentrations lessened, the species reestablished themselves in the bay (SD 2005).

Despite the case of potential chronic effects in San Francisco Bay, ecotoxicity of silver has been determined mostly by testing acute (short-term) toxicity of silver to organisms, which is limited to short exposure durations, limited species testing, and a dismissal of dietary exposure (Luoma 2008). Since the testing of true chronic toxicity requires much more resources and are not as easy to quantify (counting deaths vs. assessing sub-lethal effects), chronic toxicity results are limited (Luoma 2008). Considering that some zooplankton's reproduction is inhibited when they consume food contaminated by 50-100 ng/L silver and that traditional acute tests have revealed a toxic threshold for dissolved silver of 10,000-40,000 ng/L, current levels of allowed contamination are debatable (Luoma 2008). Nanosilver has also been shown to "cause changes in gene expression and to cause oxidative damage to proteins in earthworms exposed at relatively low concentrations in soil" (Unrine 2010).

However, some studies partially discount even the risk related to ions, concluding that most particles are bound by sulfides (forming silver sulfide salts) both in wastewater treatment and in the environment rendering them virtually harmless (Nowack et al. 2011). Another study concludes the same tendency, noting that an initiated batch experiment resulted in silver nanoparticles transforming to silver sulfide within two hours (Kaegi et al. 2011). Nowack concludes that if a majority of silver is removed from wastewater at a 90% rate as reported by Kim et. al. and if it occurs mostly in the form of Ag_2S (silver sulfide), the nanosilver currently on the consumer market could be deemed to be no less harmful than other uses of silver (Nowack et al. 2011).

Although risk associated with silver in normal environmental conditions is generally considered to be minimal, silver ions in a test tube are known to be another story and some recommend proceeding with precaution. Luoma notes that it was observations made in nature, not toxicity tests, that provided the first evidence of adverse effects by pesticides, DDT and PCBs (Luoma 2008).

2. Specific areas of risk

Silver is considered to pose a potential risk in various ways, including those referred to in the previous section. Beyond the cautiousness towards silver nanoparticles, silver's presence in biosolids used in agriculture, its tendency to bioaccumulate in organisms, effects in wastewater treatment and the potential to cause resistant bacteria are commonly discussed risks.

Bioaccumulation (and nanoparticles)

Bioaccumulation is considered one of the most contributing factors related to risk of mercury, DDT and PCBs in the environment and is considered an important factor in assessing risk of some metals as well.

Silver bioaccumulates faster than any other trace metal and diet accounts for between 40-95% of the silver bioaccumulation of some organisms (Luoma 2008). Chun-Mei Zhao and Wen-Xiong Wang concluded that over 70% of accumulation of nanosilver in Daphnia magna was via consumption of algae. Bianchini and Wood determined a 20% mortality of silver-exposed Daphnia compared with 0% of the control from a 2001 experiment (Luoma 2008).

Use of contaminated sludge

Although human health risks are unlikely to occur due to silver in agriculture, the consequences of drastically heightened levels of silver in the terrestrial environment are unknown. This being said, silver accumulation is an unwanted condition, at least for those in the Swedish agricultural community and some informed consumers (Finnson, 2011). This study is partially motivated by this risk and it is apparent elsewhere too. Studies have been done showing the bioaccumulation of organisms when exposed to metals to include copper and gold What if any effects this accumulation will have is unknown and motivates such work as that associated with REVAQ (Finnson 2011).

Effects in Wastewater

Choi and Hu report a tendency of nanosilver, especially that of a size of 5 nm or smaller, to inhibit nitrifying organisms (Choi et. al. 2008). It should be noted, however, that most silver ions released are thought to be larger than this size. Benn et. al. (2008) noted also an inhibiting factor of nanosilver at concentrations as low as 0.14 ug/l (Benn et.al. 2008).

In addition, recent studies concluded that silver binds to form silver sulfides in wastewater treatment plants, and this can be considered to largely reduce inherent risk to nitrifying bacteria (Kim et al. 2010). Even so, another recent study confirmed that silver does have an effect on nitrifying bacteria at higher concentrations (WERF 2011).

Bacterial and antibiotic resistance

The first documentation of bacteria resistant to silver was reported in 1969 (SBU 2010). Later studies have shown resistance to silver in both bacteria in contact with humans and those in nature. One study revealed that 10 percent of studied intestine bacteria carried silver-resistance genes. Silver et.al. reported that 10 of 70 bacteria samples from a hospital (from catheters and other silver-exposed sites) displayed recognizable silver (sil) genes, i.e. they had been genetically modified by silver (Silver 2003). Resistance to silver-treated burn bandages have also been reported (Luoma 2008).

Bacterial resistance to silver is proven but is not in itself alarming as bacteria have demonstrated resistance to many substances. The question of most interest is whether documented resistance to silver can be directly related to antibiotic resistance. Silver resistance genes and antibiotic resistance are known to be located on the same plasmid (mini-chromosome) and exchange of genetic material promoting resistance is theoretically possible. In addition, resistance to disinfectants has been linked to resistance to antibiotics so a similar relationship between silver resistance and resistance to antibiotics is thought to be possible (Silver 2003). However, this relationship has not yet been proven (SBU 2010).

Risk to human health
Two potential risks (beyond those indirect risks related to the above) to human health were noted: effects on genetic material and argyria. Investigation on how nanosilver may affect genetic material is minimal (Yang et al. 2009) and effects on DNA are theoretical, argyria is the only documented direct impact on human beings. It is a very rare irreversible condition that results in a victim's skin turning bluish gray when silver droplets are precipitated in the dermis (Svenson et. al 2008). It´s been only documented to affect those who have consumed extreme amounts of silver, usually in the form of colloidal silver (Svenson et. al 2008).

Regarding direct impacts from silver antibacterial during skin contact, one study in particular focused on the effect of silver-treated garments on skin conditions and skin-surface organic life (bacteria, etc.) and concluded no impact (HI 2011).

3. Sources to the environment

Silver is released from a number of products during use and many industrial processes both in water and air pollution. The highest concentrations ever noted in open ocean were noted off the coast of the Pacific Northwest, U.S., and are thought to be linked to air pollution from China (Science Daily 2005). A similar type of air-bound diffusion to land and stormwater was mentioned in a publication by the SEPA in 1997 (SEPA 2002).

Waterbound releases are thought to result primarily from photography development, water treatment, and from dental amalgams. These sources are thought to be on the decrease but should not be excluded from consideration. One study from 2001 revealed that silver concentrations in black water were greater than in grey-water, possibly pointing to dental amalgams as a significant source (SEPA 2002). In addition, Gryaab manager, Ann Mattson mentioned that old pipes from former medical and dental facilities are considered a potential source to the treatment plant (Mattsson 2011).

Nanosilver itself has gotten much attention. Mueller and Nowack modeled potential pollution by various sources of nanosilver based on a crude estimate (referred to as a best guess) that the world nanosilver production is 500 tonnes per year (Nowack et. al. 2008). Table 1 summarizes some results and shows that paints (35%) and cosmetics (25%) represent the highest portions of total nanosilver release. However, type of release must also be considered. For example, 50% of the paints are released in disposal, which could be considered more favorable than that of other sources such as cosmetics and textiles which allow silver to exit the system into wastewater and the environment.

Amount of nano-particle (to include silver) release depends on many factors to include initial quantity used in or on an item, how the nano-particle is manufactured and applied, the item´s life time, and the use of the item (Nowack et. al. 2008). Table 1 presents modeled path and characteristics of release. The model estimated that the main product of interest, textiles, releases 85% of silver via dissolution in ionic form which can be important in determining final effects (Nowack et. al. 2008).

Table 1: Estimated nanosilver releases and manner of release for various products (Nowack et. al. 2008)*

NP	product category	% of total amount	release	%	release
nano-Ag	textiles	10	abrasion during use	5	air
			abrasion during washing	5	STP
			disposal (WIP)	2.5	WIP
			recycling	0.5	leaving system
			export	2	leaving system
			dissolution	85	leaving system
	cosmetics	25	application	95	STP
			disposal	5	WIP
	sprays, cleaning agents	15	application	95	air (10%), STP (85%), soil (5%)
			disposal	5	WIP
	metal products	5	abrasion	5	STP
			recycling	47.5	leaving system
			disposal	2.5	WIP
			dissolution	45	leaving system
	plastics	10	abrasion	5	STP
			disposal	50	WIP
			dissolution	45	leaving system
	paint	35	run off	5	soil (50%), STP (50%)
			dissolution	45	leaving system
			disposal	50	disposal site

*Sewage Treatment Plants (STP), Waste Incineration Plants (WIP)

Another study focused on silver in general is somewhat consistent to these results. Blaser estimated that biocidal plastics and textiles account for between 0.3% and 15% of total silver emitted to water in Europe in 2010 (Blaser et al. 2008). A table representing these results appears in Appendix E.

While other studies have estimated current silver emissions, one modeling effort at Chalmers included estimating future emissions. The study, conducted by Arvidsson at Chalmers, projected textiles as potentially causing the most emissions of Ag nanoparticles in the future (Arvidsson et. al. 2010).

Textiles as a source

The subject of textiles as a source has indeed been a hot one. At least a few studies have specifically focused on silver in textiles and their rate and manner of leaking silver. Benn and Westerhoff conducted a study focused on sock fabrics and nanosilver release. They produced the table below which reveals amounts of silver in socks as well as exactly how much a representative sock can be expected to release (Benn et. al. 2008). Results show that amounts (Table 2) and rate of release (wash by wash comparison appears in Appendix E) of silver vary greatly from sock to sock.

Table 2: Estimated silver content and wash release (Benn et. al. 2008)

TABLE 1. Sock ID/Characterization and Silver Content

				acid digestion analysis			wash analysis
sample ID	sock company	description (color)	price per pair	mass of silver per mass of sock (μg Ag/g sock)	average sock mass (g)	total silver in sock (μg)	cumulative silver released after 4 24-h washings (μg)
1a	Sharper Image	lounge sock (green)	$2.47	25.8	29.3	756	836
1b	Sharper Image	lounge sock (blue)	$2.47	57.8	27.3	1578	1845
2	Sharper Image	athletic (white)	$1.65	2.1	28.6	60	bdl
3	Fox River (Xstatic)	casual (black)	$13	1358.3	23.0	31,241	165
4	Arctic Shield (E47)	over-the-calf boot sock (green)	$14	35.9	58.6	2104	bdl
5	Zensah	basketball (black)	$13	bdl	24.2	bdl	bdl
6	AgActive London	casual (black)	£6.99	0.9	21.9	20	19

In another study conducted by Nowack et. al, nine different fabrics were tested with different wash conditions, namely at pHs of 7 and 10 and with or without added oxidizers. The fabrics were found to release silver at largely different rates and proportions (based on Ag-particle size). Between 1.3 to 35% of the silver was released during the first wash and although the percentage amount was favorable for X-static, the actual quantity was significant compared to other fabrics (Nowack et al. 2009) . Results for Ag released from socks (0.3-377 µg/g) were higher than for Benn and Westerhoff (1-68 µg/g), and this was denoted to that Benn and Westerhoff experimented with distilled water and gentle agitation. All fabrics released less silver during the second wash. It was found that, contrary to expectations, oxidants (bleaches and other surfactants) had little effect on Ag-size classes (particle size) nor on Ag release (Nowack et al. 2009). Furthermore, they found that most silver released during wash cycles was in the particulate form (>450nm). One important conclusion from the study is that manufacturing processes, the way silver is applied, is critical to the end result and related risk (Nowack et al. 2009).

Another laundry experiment was presented in a 2009 report by SWEREA IVF distributed by Göteborg Office of Environment. It reported the loss of silver from 4 garments during 10 washes. One sock (Falke Family) apparently went from 2.9 mg/kg to 0.01 mg/kg Ag, representing a loss of over 99% Ag. The least percentage leakage was 8% observed for SilverNODOR X-socks, having contained 1310 mg/kg to 1210 mg/kg Ag (Hjärtnäs 2009).

The estimations presented above reveal two things: not all silver-treated products are alike and that most silver released from the products are in particulate form considered to be less toxic to organisms.

Natural occurrences

One final consideration pertaining to sources to the environment is a study released in 2011 that determines that nanosilver may be produced in the environment in the presence of humic acids via reduction of silver ions. This implies that not all nanosilver observed in aquatic environments is of anthropogenic origins (Akaighe et al. 2011).

4. Research summary

In summary, the risk related to silver in the environment is not completely understood and is debated. A couple of models estimate that silver use in textiles and hygiene uses accounts for only a small amount of pollution but as the Mueller-Nowack model reveals, it likely results in the most diffuse pollution.

In addition, the literature review revealed some consistencies and some differences in published results and scientific opinions. The following are points that research generally agrees on:

1) More studies should be done in order to determine true risk
2) Silver ions do have anti-bacterial characteristics
3) Nanosilver may require additional caution
4) Silver-resistant bacteria do exist
5) Silver ions have the potential to adversely affect other living creatures
6) Silver has been used for many years as an anti-bacterial agent

7) Direct risk to humans is minimal (although effects to DNA are not fully explored). Argyria is very rare.

Research **disagrees** on the following statements:

1) Silver is not a risk to wastewater treatment processes nor to the environment because it is bound in wastewater treatment as silver sulfide, which is very stable.
2) Existing research does demonstrate a present or imminent tangible risk to ecosystems
3) Silver resistance can realistically lead to antibiotic resistance (and should be considered a tangible risk)

c. Regulatory Climate

What legislation and regulations are relevant to this market?
What are authorities doing related to silver?

Although this study focuses on the issue in the Swedish context, having an understanding of how the issue is handled in other jurisdictions is also important. Since the success and promulgation of consumer products (especially emerging ones) often requires on a broad market (possibly global) and environmental regulation can be considered contagious, this is relevant. Some relevant regulatory action that was found during the study from the U.S. and Europe is noted.

Outside Sweden

The USEPA listed silver on the priority pollutant list in 1977 in conjunction with the Clean Water Act which established the inherent requirement for release into aquatic environments to be regulated (Luoma 2008). The USEPA has authority also because antimicrobials are considered pesticides and therefore fall under the Federal Insecticide, Fungicide & Rodenticide Act (FIFRA). Silver is therefore to be registered and regulated as a pesticide (USEPA 1993).

Luoma notes that it is difficult to know to what extent the USEPA will use FIFRA to regulate nanosilver and noted that the EPA ruled that the Samsung Silver Wash washing machine were devices not pesticides, but did reverse the decision that the machine must be registered as a pesticide (Luoma, 2008). This precedent may demonstrate a tendency to label pesticide-treated items as pesticides themselves.

Most current water criteria are primarily based on acute toxicity of silver to organisms. Water quality levels for chronic exposure have not even been proposed by the USEPA (Luoma 2008). Nonetheless, the USEPA has established water quality criteria that allow for silver concentrations (1,920-3,200 ng/L) to exceed even the highest levels of contamination ever documented even though one USEPA document from 1993 states that “acute toxicity data indicate that silver is highly toxic to fish, aquatic invertebrates and estuarine organisms.” (USEPA 1993). In addition, the European Union does not list silver among its 33 “priority hazardous pollutants” (Luoma 2008) nor does the EU biosolid directive (EG direktiv 86/278/EEC) include limits for silver (SEPA 2002).

However, regulatory agencies have taken notice to the expanding market and to potential risks associated with silver. The USEPA has increased its focus on silver and initiated such investigations as the *Nanomaterial Case Study: Nanoscale Silver in Disinfectant Spray*, of which results are currently only released as an external review draft and thus cannot be cited but were reviewed by the author.

More importantly, the EU issued the Biocide Directive which requires all biocides to be screened and approved by May 14, 2014 (EC 2007). Of the substances, the following silver substances are some of the listed and Sweden's KemI has been given responsibility as reporting entity for them: Disilver oxide, silver chloride, silver nitrate, silver zeolite A, Silver-zinc-aluminium-boronphosphateglass/Glass oxide, silver- and zinc containing, Silver sodium hydrogen zirconium phosphate, Silver sodium hydrogen zirconium phosphate, and Aluminium sodium silicate-silver complex/Silver zeolite (EC 2007). More regarding the KemI's responsibility is discussed in the "Stakeholder" section. It should be noted that if a substance and use is regulated by the Biocide Directive, REACH does not apply (Steptoe Johnson 2009).

Possibly related to this impending "judgment", the German Federal Institute of Risk Assessment (BfR) has recommended manufacturers to refrain from use of nanosilver in consumer products until the risk is defined to its fullest extent (Nichol 2010).

There has also been specific focus on cosmetics. Starting in 2013, the EU will require all manufacturers to declare use of nanomaterials in cosmetics (Nichol 2010). Other regulatory actions taken related to cosmetics in Canada and the U.S. are documented in Appendix F.

Finally, an EU directive focused on health supplements requires that such supplements be tested and proven to be beneficial in order to be sold as supplements (EC 2002). Similar regulations exist in the United States. This regulation has resulted in colloidal silver retailers selling their products as water disinfection agents, which in Sweden are regulated by KemI (Sultan 2011).

Sweden

Although all EU regulatory activity mentioned above applies also to Sweden, there is one activity that is of extreme importance in Sweden: a commitment to recycle phosphorus to agriculture. There is thereby an interest to apply treated sludge to agricultural land while at the same time minimizing and monitoring related pollution.

The SEPA has recommended limits for pollutant concentrations in sludge lower than those stated in the EU Biosolids Directive (1986, does not include silver). The REVAQ certification was established by SWWA, LRF (Swedish Farmer's Federation) and others, and has since adopted recommendations established by the SEPA and the SEPA developed an action plan for the recycling of phosphorus in 2002 (SEPA 2002). Before the 2002 plan, no Ag-limits were even recommended by SEPA (SEPA 2002).

The REVAQ system is directly motivated by two of the sixteen Swedish Environmental Objectives: "A non-toxic environment" and "a good built environment." The first goal mentioned here points specifically to a number of activities, to include improving the transparency of environmental characteristics in the supply chain (SEPA 2004). The

second goal includes a specification that 60% of phosphorus from wastewater will be recycled to agriculture (This can be compared to a 2000 estimate of 21% (SEPA 2002)).

Understanding that the current method of returning phosphorus to agriculture (required by the 60% goal) is the use of sludge which contains phosphorus and contaminants (addressed by the toxin-free environment objective), SEPA has recommended a 500-year accumulation limit that is to be achieved for all substances by 2025. Those substances that are estimated to double in concentration faster than 500 years (Ag included) are recommended to be regulated or monitored (SEPA 2002). As such, SEPA suggests continually reducing the allowed concentrations of Ag in sludge (and allowed amounts of applied Ag per land area per year) until the 500 year limit is reached (SEPA 2002).

In summary, regulator focus in both the EU and the U.S. has increased for silver in recent years. The EU Biocide Directive is probably the most relevant ongoing legislative activity and it could have strong implications to silver in the textile and hygiene market. The USEPA has identified silver as a focus element in ongoing biosolids safety assessment, but unlike in Sweden, no action has been taken. In addition, nanotechnologies (to include nanosilver) are receiving focus by agencies in both the EU and the U.S.

Various Swedish authorities and their positions related to this issue are discussed in the "Stakeholder" section.

d. Stakeholder positions

What are different stakeholders' positions and activities related to the issue?
Do stakeholders feel that silver-treated products and their function are beneficial?
How do stakeholders weigh benefits with risks and how do they justify their actions?

The fourth and final section of this study involved identifying stakeholders and gathering their impressions on this topic. Five groups were targeted: authorities-regulators, non-government organizations (NGOs), industrial actors to include industrial groups, experts and consumers.

1.Authorities

Information via email and or interviews was received from the Swedish Chemical Agency (KemI), the Swedish Consumer Agency (KO), the Swedish National Food Administration (SLV), the Medical Products Agency (MPA), the SEPA and the Göteborg Office of the Environment (GOE) and combined with information available through public websites and publications. Consistencies were seen in that no individual of any agency ventured outside the bounds of their affiliated organizations public goals and policies. The following areas of concern similar amongst these organizations were:

1) *to protect the consumers from unsafe products or false claims of product function or otherwise and*
2) *to work towards environmental goals*

KO's prime objective and mission statement include this first idea. The marketing law (marknadsföringslagen) acts as the legal vehicle by which the agency can protect consumers from false claims (Suserud 2011). However, the agency acts mostly in response to consumer (or other entity) claims so that it is possible that many products are marketed outside the bounds of the products' proven characteristics.

One interesting example is a product called "Ionsil", which is a colloidal silver tablet formally sold as a supplement. Like mentioned earlier, supplements not explicitly proven to fulfill the functions claimed are to no longer be sold as supplements. Ionsil is one such product that is no longer officially sold as a supplement, but as a "water disinfection agent." However, on the Ionsilver (manufacturer of Ionsil) website, the product description includes that the product is now (due to unreasonable EU directive) a water disinfection agent, but is the same product that was sold as a supplement for years. When asked, the KO's representative and legal expert, Martin Suserud, responded that that type of marketing falls in grey area and that it would require further review to make a determination (Suserud 2011).

Regarding general product claims, Suserud also substantiated that manufacturers and marketers hold also the burden of proof when it comes to claims of environmental-friendliness or similar (Suserud 2011). Complaints related to suspect labeling have been filed. One complaint (KO anmälan) filed by the Swedish Cosmetic, Toiletry, and Detergent Association (KTF) referred to a non-Swedish manufacturer's suspect labeling of some biocides and the unfair advantage it affords the offender (Melvås 2010). In addition, the SWWA and the Swedish Society for Nature Conservation (SNF, Naturskyddsföreningen) filed a complaint in 2010 regarding one of manufacturer Polygiene's silver biocidal products. In the complaint, plaintiffs referred to Polygiene and misleading marketing (Karlsson 2010). These are just a couple of relevant examples.

Moving on, the SLV's and MPA's primary focus is the protection of consumers by ensuring that product manufacturers are able to provide proof of safety and effectiveness (SLV 2011) (MPA 2011). Both the SLV and the MPA have been involved in scrutiny of the silver market to include both silver-treated medical products and colloidal silver (formerly sold as a supplement). The SLV website includes an explanation of the organization's reasons for recommending against use of Ionsil and other colloidal silver products. Their reasons include lack of evidence that the products provide benefit and discussion of antibiotic resistance (SLV 2011). The MPA had criticized the marketing of Ionsil, which presented it as demonstrating medicinal qualities against different ailments and diseases (Jacobsson 2008).

The only other relevant product noted to be relevant within the food and drug sector was silver used in confections. A representative of the SLV confirmed that the traditional use of silver in confections utilized usually as a decoration is not regulated. To his knowledge, no attempt has been made to limit silver's use in this context however, it is considered to be a minimal amount and in the metallic form (Ilbäck 2011).

The SEPA and the GOE are responsible for driving environmental initiatives in their perspective areas of responsibility. The SEPA has responsibility for the oversight of national environmental objectives. In regards specifically to the 60% goal and with consideration to the REVAQ certification, the agency has recommended reduced allowed

concentrations of silver (and other contaminants) for sludge used in land application (SEPA 2010) .

One potential conflict amongst the environmental objectives is ironically that although use of sludge as fertilizer is a great way to recycle phosphorus, the use of sludge can be said to be a conflict with a "non-toxic environment" due to pollutants. However, Martin Holm of SEPA explained that this is not a direct conflict and that the 60% phosphorus goal could be met without use of sludge. He mentioned that burning of sludge and retrieval of phosphorus from ashes is also possible. Therefore, theoretically one can be both against the use of sludge and for the 60% phosphorus goal (Holm 2011).

Victoria Lind Magnusson, a representative from the GOE who works primarily towards the aim "Toxin-free Göteborg" (Giftfritt Göteborg), indicated that efforts are focused on the general use and dispersion of a long list of toxins and mostly not towards any toxin in particular (Magnusson 2011). However, the GOE did release a report called "Analysis of Chemicals in Goods" (Analyser av kemikalier i varor, R2009:8), as part of their "Toxin-free Göteborg" project (Magnusson 2011). This report includes a section on silver that refers to the SWEREA IVF investigation on silver in textiles (GOE 2009).

The agency that perhaps has most influence related to the topic *silver as a biocide* is the Swedish Chemical Agency (KemI). A more thorough documentation is included here that includes insights obtained during an interview with Ulrike Frank of KemI.

The agency is of the Swedish Competent Authority (CA) for REACH and for the biocides directive (98/8/EC) established by the EU. The biocides directive will come into full effect 2014 (KemI 2011). REACH generally excludes substances which are already effectively regulated under another legislation. However, some dual-use biocides can be covered by both REACH and the biocide directive (Steptoe and Johnson, 2009).

The agency has been given responsibility by the European Community as rapporteur for several silver compounds under the existing substances review program of the biocides directive (KemI 2011). This responsibility includes assessing the risk to human health and the environment related to biocidal products that contain silver substances in order to display an antimicrobial effect. More specifically, it includes review of a dossier which includes applications from various manufacturers of silver biocides. The agency must review products and applications and must:

1) Evaluate risks related to the active substance in question;
2) Evaluate risks related to the biocidal product, which contains the active substance;
3) Produce an assessment report which will include recommendations whether the active substance shall be included on Annex 1 (active substances). Is a specific silver compound authorized as an active substance in biocidal products? The Agency's assessment and recommendations will be used by the European Commission to make final decisions. If a given compound is selected for inclusion in Annex 1, the biocides containing the compound as an active ingredient will require approval before being placed on the market. The authorization granted can be a maximum of 10 years (Frank 2011)

Currently, only chemical substances that have biocidal properties, not articles (such as a clothing item) that have biocidal function, are regarded as biocidal products in Sweden, and therefore, shall not be regulated as such. The European Member States are not in agreement on this point (Frank 2011). However, the use of a biocidal product in a treated article is quite decisive for the risk assessment. A review of the biocides directive is ongoing. One of the intentions is to regulate the use of biocides in treated articles more clearly (Frank 2011). As said on the website, "The environmental impact related to, for example, silver-treated textiles through regular washing is certainly higher than by a refrigerator, which gets wiped only seldom and with far less amount of water" (KemI 2011). Furthermore, circumstances associated with (for example) application on an outdoor bench may be quite different than those related to a shoe insole (Frank 2011).

Until the European evaluation process (for the active substance) is complete, most biocidal products that are already used as disinfectants or preservatives may be marketed in Sweden without authorization (Frank 2011; KemI 2011). Once the inclusion decision is made on compounds, decisions are made nationally on each individual product or application (on a case by case basis). However, countries can adopt other countries' authorization once it has been completed in that first EU member country (Frank 2011).

The biocide directive will likely have an effect on the biocide market, at least as it relates to smaller manufacturers. For the purposes of thoroughness, the application process is resource intensive, and could thus affect a smaller, less-financially strong entity (Booker 2008; Frank 2011). However, some cooperation occurs between companies, and this cooperation is thought to achieve some resource savings (Frank 2011), albeit perhaps mostly for larger conglomerates (Booker 2008).

It is noted by the agency that some treated articles that use silver as an active substance are not transparent in labeling (especially unclear on which biocide or active substance is used) and that some are marketed with "environmental-friendly" even though the marketer has no proof of the product's "friendliness." (KemI 2011)

There is an acknowledging that the silver as a biocide topic is more active in Sweden than at least in Southern Europe. Frank noted that non-inclusion could possibly be heavily debated by some non-Swedish stakeholders, but that the agency takes no consideration to such politics when executing this review (Frank 2011).

Finally, the methodology used for risk assessment of these compounds is considered by Frank as limited in that it does not allow for the consideration of certain long term risks. This is considered the most limiting factor in KemI's task. It is unknown exactly when KemI will be prepared to deliver their recommendations to the EU Community but the end of September is thought of as a target (Frank 2011).

Summary

In summary, the Swedish Chemical Agency has been assigned the most important task related to the topic *silver as a biocide*. It should be noted that all organizations note a commitment to the national environmental goals and have initiatives related to them. The following are points that all regulators agree on:

1) Manufacturers must be transparent to consumers about product content
2) Manufacturers are responsible to prove that a product fulfills its claims, not vice versa.
3) Sweden's environmental goals are important and all agencies must work together to achieve them.

All agencies are inherently in support of the 16 national environmental goals. Therefore, all are by default supporters of the 60% phosphorus recycling goal, as long as it does not clearly interfere with other goals. However, as Martin Holm of SEPA mentioned, although the recirculation of sludge and phosphorus are two different things, the use of sludge in pursuit of the 60% phosphorus goal has been debated to a small degree as being in conflict with the "non-toxic environment" objective (Holm 2011).

2.Non-governmental organizations

The following non-industry organizations were interviewed and/or corresponded with: The Swedish Water and Wastewater Association (Svenskt Vatten), Swedish Society for Nature Conservation (Naturskyddsföreningen), Farmer's Association (Lantbrukarnas Riksförbund), Swedish Retailers (Svensk Dagligvaruhandel), The Natural Step- Sweden, Greenpeace and the World Wildlife Federation (WWF) (email : Greenpeace, WWF).

Swedish Water and Wastewater Association (SWWA)
SWWA and member insights were gathered from a telephone discussion with Anders Finnson and meetings (to include a workshop) with Gryaab's (member plant) Ann Mattsson and Lars Nordén. SWWA and its members are the drivers of upstream studies like these and SWWA places silver on its priority list. The decline of silver in wastewater has slowed down if not halted all together. To reach an estimated 0.2% accumulation rate is the goal by 2025 (Mattsson 2011).

Point sources of silver have been identified and mitigated to a high degree and therefore, diffuse uses are considered a worthy target. Whether the anti-odor function is something that people actually want or need is debatable and silver in textiles is considered a source of interest (Finnson 2011). According to a Gryaab´s (Göteborg Wastewater Treatment- Ryaverket) Ann Mattsson, the source of silver responsible for the halted decline is not known for sure. Old pipes, especially those coming from dental and medical facilities are considered to possibly contain residual silver from years past (MattssonA 2011) or photographic development facilities (Finnson 2011).

The only new, diffuse silver sources noted are silver in textiles and other consumer products. This segment is thereby a focus SWWA (Mattsson 2011). Silver per person per year targets have been set for 17 mg Ag per year (MattssonA 2011) and therefore, releases from individual silver-treated garments are considered significant versus when one considers the whole system perspective (Finnson 2011), which make individual releases look miniscule. A simple calculation putting releases into an individual perspective was performed by SWWA member, Gryaab (Ryaverkets management), using information obtained from Haglöfs (apparel) and Polygiene (silver treatment). A release was estimated (for 5 washes of 5 Polygiene-treated garments) to be 1.6 mg Ag/year per person, representing 9% of yearly allowance (MattssonA 2011).

Finnson mentions that the large system perspective can be dangerous. If only a few people drive cars with V8 engines and low fuel efficiency, related emissions may not make a big difference compared to the total emissions. Does this justify the sale and use of such a vehicle?(Finnson 2011)

Finnson also cautions against the idea of tackling climate and energy goals by increasing other aspects of environmental risk. He believes that all goals must be addressed at once, not just one or two at a time. In response to the idea of using biocides to reduce laundering and water use, he mentions that water as plentiful here in Sweden and that there are other ways towards water stewardship without using toxins (Finnson 2011).

When asked about how a water-poor country would view the possibility of their citizens reducing laundering due to silver-treated clothing. Finnson said that with water shortage, one should be even more sensitive to this issue and that one wouldn't want to save water while contaminating the little water one has (Finnson 2011).

Even reduction in cleaning agents such as detergents is seen as not worth the risk. According to Finnson, detergent is very degradable and much more effective than some years ago. Most detergents are environmentally certified by Svanen, Bra Miljöval or another certification and thus must be effective and degradable (Finnson 2011).

Two other potential uses of silver were also discussed – surface treatments and swimming pool disinfection. Surface treatments on outdoor surfaces pose the threat of direct contamination to waterways as many stormwater systems release direct without treatment. Silver for pool disinfection is thought to be uncommon in Sweden and the Social Authority (Socialstyrelsen) has actually advised against the use of it as it is not effective against viruses. SWWA recommends instead other traditional pool disinfectants and the slow release of pool water to the surrounding area to allow some natural filtration and treatment (Finnson 2011).

Regarding the anti-odor function, Finnson sees the challenge as reducing the need for the function and refers to merino wool as a fabric that has lesser tendency to odor. He also refers to an example – to prevent the spread of disease, wash your hands instead of coating society with antimicrobial agents. In addition, he sees the anti-odor function as something that people perhaps didn't know they needed until marketing told them so (Finnson 2011).

In response to a question about still existing point sources that may represent high amounts of silver contamination, he mentions that point sources such as single factories are easy to target and that law and procedures are well-established to address them. On the other hand, addressing hundreds of thousands of "point sources" (households) is another matter (Finnson 2011).

Regarding the fact that Swedish sludge meets the 8 mg Ag/kg sludge guideline recommended by SEPA, Finnson says that the agricultural community is not comfortable with the current suggested silver levels and foreseen accumulation levels. Lower concentrations of silver are required to meet the 500 year accumulation goal (as recommended by SEPA) – this goal requires a 0.2% estimated accumulation per year which can be compared to Ryaverket's 0.8% per year (Finnson 2011).

Sister organizations in the European Union are more and more focused on this issue but citizen-support for environmental work may not be as strong. When Samsung Silver wash machines were taken off the Swedish market, they were taken and sold in Hungary. Regarding broad European support, EUREAU, which is the European equivalent of SWWA is very committed to upstream work focused on toxins (Finnson 2011).

In regards to future regulation related to the issue, the EU Biocide Directive is seen as very important. In addition, the Swedish environmental department is currently reviewing SEPA recommendations which may result in stronger regulations (Finnson 2011).

SWWA has been an active part in the silver debate in Sweden. The SWWA and Swedish Society for Nature Conservation (Naturskyddsföreningen, SNF) sent one letter directly disputing one silver treatment manufacturer, Polygiene's position that the sulfide state was harmless and final (This was after they had filed an official complaint with the Swedish Consumer Agency). Lena Söderberg (SWWA) and Mikael Karlsson (SNF) stated the below in a response to Polygiene's statements (von Uthmann 2010) that were made in an August 2010 release by Dagens Nyheter news outlet:

"Polygiene claims that their product is converted to silver sulfide and that the environmental problems are thus void. This is not true. First, there will always be a certain amount of silver ions. Second, silver sulfides can be converted over time to other forms of silver. The effects of biological activity and changes in pH result in, for example, lake-bottom sediments continuing to pose an environmental risk. " (translated from Swedish). (Söderberg 2010)

Members are aware that their viewpoint on this issue may not be consistent with other similar entities in Europe, but the 60% goal and REVAQ make the landscape surrounding this issue different in Sweden (Mattsson 2011). Beyond the water toxicity issue, this is a customer matter. Agriculture wants less-contaminated sludge and SWWA aims to give it to them (Finnson 2011). Swedish Water is motivated to help achieve the 60% goal via continued REVAQ certification. Finally, Finnson points out that SWWA observes the precautionary principle and that the lesser one knows, the greater level precaution must be (Finnson 2011).

Environmental groups

The Swedish Society for Nature Conservation (SNF) is highly focused on creating more aware consumers and one of their focus areas is environmental impacts related to fashion items and clothing. They have assisted with making consumers aware of the silver issue in the past (see letter excerpt above). Silver is one of a myriad of substances in consumer products and although SNF does not have resources dedicated specifically to the silver issue, Eiderström sees anti-odor use as a questionable use of a limited resource (Eiderström 2011).

According to email correspondence, Greenpeace and WWF both see silver in products as a relevant issue but not one to which they have currently allotted resources (Albertsen 2011; Tham 2011).

Farmer's Association
Sunita Hallgren of the Farmer's Association sees silver as one of many current agricultural issues, and perceives heavy metals in general and pharmaceutical products as its members largest concern (but not silver in particular). This is reflected in a 2-page document called – *Spreading of sludge in Agriculture- What LRF thinks on the topic* (Spridning av avloppsslam i jordbruket– så här ser LRF på frågan) where only cadmium is the only metal mentioned specifically (LRF 2010).

Its members are considered to be very sensitive to consumer views. Since LRF members are responsible for providing customers with safe food goods, sludge quality is of highest importance. If there is suddenly a high perceived risk, the use of biosolids could be halted again, as it was in 1989 and 1999 (Hallgren 2011). These biosolid bans are seen by the Association as necessary but destructive to progress towards more sustainable agriculture (Hallgren 2011).

The group is thereby committed to assisting progress in relation to the REVAQ certification (LRF 2010; Hallgren 2011).

Swedish Retailers Association (Svensk dagligvaruhandel)
Although this group could be considered as "part of industry", the Swedish Retailers Association was included in this group due to their focus in the grocery market and their involvement in REVAQ. Insights were gained from Per Baummann of SRA. SRA members represent approximately 90% of food and grocery market. The group has three reasons to be involved with REVAQ (Baummann 2011):

1) Confidence in REVAQ: It sees the REVAQ system as a good system of quality control with promise for future improvements. It is much better than former informal cooperation. It sees that Swedish Water and its members are taking great efforts in upstream work.
2) Leadership in biosolids use and quality control: Biosolids quality standards are not as high in other European countries and the group promotes revision of the EU biosolids directive, which was crafted in 1986.
3) Taking interest in potential product-related pollutants: Each of the products that the group's members sell is used in society and is disposed of or dispersed elsewhere. The group sees a responsibility in ensuring that the products it sells are not causing environmental or health issues. REVAQ is a system that not only fulfills its function of certifying sludge, it also helps monitor pollution in society. (Baummann 2011)

Baummann also mentioned the importance of assessing risk of a substance, not just presence in sludge (Baummann 2011). One example was demonstrated in the case of substance LAS, which was first hyped in Denmark based on high presence in sludge and lack of degradability in anaerobic environments, such as sludge. It later showed itself to be quite degradable in aerobic soils, which lessened related risk substantially. This demonstrated that presence is not always representative of actual risk, especially when involving presence in a temporary medium, such as sludge. The group hopes that the EU will revise the biosolids directive and evolve from presence-based approach to a more risk-based approach (Baummann 2011).

The Natural Step Sweden

Richard Blume, of The Natural Step Sweden provided insights on The Natural Step, its foundations and perspective. The Natural Step is based on 4 system conditions, and can be translated to four sustainability principles which are considered how to proceed towards a sustainable society. As stated on their website, "In a sustainable society, nature is not subject to systematically increasing: concentrations of substances extracted from the earth's crust, concentrations of substances produced by society, degradation by physical means and, in that society, people are not subject to conditions that systemically undermine their capacity to meet their needs."(TheNaturalStep 2011)

These four conditions are considered the mechanisms by which humans degrade the system that humans are dependent on (how not to proceed) (Blume 2011). Comparing man-made flows with natural flows of materials is thought to give a basic idea on whether the activity is consistent with progress towards a more sustainable society. Silver, like other heavy metals, is considered to accumulate more rapidly than for example, aluminum, which flows naturally very quickly through the system. Accumulation in itself is considered to be a violation of the sustainability principles (Blume 2011).

Summary

In summary, the NGOs agreed on a couple things:

1) Observe the precautionary principle. We should be careful about widespread silver-use
2) Don't replace one environmental impact with another. In this case, increasing garment use-life and reducing laundering (reduced water, chemical use, and textile manufacturing) would be replaced with the impact of diffuse silver release.

Other unique views they mentioned are the below. The last two are considered very relevant in the debate about silver as a toxin and silver-treated textiles from a life-cycle perspective.

1) Maintains a focus on toxics, not silver in particular (SNF, Greenpeace, WWF)
2) Focus on Ag per person (SWWA)
3) Expresses caution about assuming that silver sulfide is completely stable and therefore, harmless (SWWA, SNF- letter).
4) The four system conditions are the basis of which to assess impacts. Human activities that create imbalance, such as accumulation of elements in soils is considered a violation of sustainability principles. (The Natural Step)
5) A life-cycle assessment is a convenient tool but depending on how it is designed and conducted, it may not include long-term considerations, such as accumulation of compounds in the environment and associated future consequences. (The Natural Step)

3.Industry

Industrial stakeholders were sought after and documented under the following sub-categories of interest.

1) Silver product or function manufacturers: those that offer silver treatments and the like on the market.
2) Companies: Primarily those that manufacture and sell apparel.
3) Certification entities

3i. Silver product manufacturers

Silver product developers and manufacturers can be considered to be at the heart of the debate as they are the ones promoting the use of the silver-containing products or functions. Three established companies associated with this category were contacted: Polygiene, HeiQ, and Ionsilver (colloidal silver).

From their perspective, there is not currently strong enough evidence that silver products are an inherent risk. Quite the contrary, their view is that when comparing to already long-existing silver market (photography, industrial processes) environmental risk, the risk is negligible. In addition, they mention that silver in many forms is a naturally occurring element. The amount of silver in these products is considered by them negligible and that the benefits of their products outweigh any potential risk. Finally, they see their markets as niche markets with slow and limited growth.

These general opinions are conveyed by a letter from the Silver Nanotechnology Working Group (SNWG, works for and represents silver industry) to the USEPA urging the agency not to consider nanosilver as a "new substance" (Volpe 2010). Another statement by SNWG also refuted statements made by the German Federal Institute for Risk Assessment (BfR), who published an opinion advising against use of nanosilver in food and everyday products (SNWG 2011).

Another product in launching phase is represented by Agsol. They along with Polygiene and HeiQ consider the life-cycle perspective to be a defining argument for their products' function. The reduction of cleaning, laundering and product wear is considered to reduce environmental impacts during product use phase and increase product life (Hedlund 2011).

Polygiene (silver salts) and HeiQ (metallic silver) also mention that silver has replaced to some degree triclosan, which requires a much higher dosing to achieve the same effect. They are also quick to point out that their products are not nanosilver and that only a minimal amount of silver is washed out during laundering. Polygiene also points out that silver as a biocide has evolved from using metallic fibers to higher tech, higher effectiveness forms such as silver salts (von Uthmann 2011).

There is also a feeling that the focus on silver in Sweden is greater than elsewhere. HeiQ (Switzerland) mentioned an opinion that the debate in Sweden is less factual than it is emotional and that if all goes according to scientific standards, silver will be allowed even after the EU Biocide Directive is in full force (Skantze, 2011).

Regarding REVAQ and related targets, von Uthmann points out that sludge currently meets SEPA-recommended limits (8 mg Ag/kg sludge) by wide margins and that even a halving of that would be met easily. Furthermore, he and Ohlsson mention that the accumulation estimates are based on continual application- year after year – and that if sludge was spread more strategically (over time and area) the accumulation would not be as great (UthmannC 2011).

Another theme noted was the perspective of relativity: how silver compares with other pollutants. Referring to recent evidence that nanosilver may be produced in the presence of humic acids, Ionsilver representative Anders Sultan mentioned that silver is a natural occurring substance and that:

"We should instead concentrate on reducing man made substances that nature does not know how to handle. I am talking about 100.000 + manmade chemicals and probably as many Big Pharma medical substances that now leak right into our environment."(Sultan 2011)

As mentioned earlier, Ionsil has been the subject of scrutiny in media. Ionsilver has been rather active to retain legitimacy. The company sued SLV and MPA for "spreading false information" about their products on an investigative journalistic program in 2007. No damages were awarded the company in the case (Justitiekanslern 2010).

The commitment to silver is not total according to at least one of the interviewed. Polygiene claimed that the anti-odor (anti-microbial) function was what their company offered and that silver is the best technological solution currently. They continue to look for improvements (in function and process) and alternatives that could either replace or enhance (think hybrid) the function (von Uthmann 2011).

Polygiene also defended the anti-odor function believes that consumer demand is proven. Polygiene does not see the anti-odor market as just something that has been pushed on consumers, but displays group study results that demonstrate that over 50% of customers are willing to pay more for odor-free garments, that 90% of people said that odor reduces their self confidence, and that 30% of people have discarded a garment due to odor after washing (von Uthmann 2011).

Partially related to this is consumers' general demand for antibacterial function (not specifically pointed out by silver product manufacturers interviewed but found elsewhere). Antibacterial function company, Microban, refers to a 2008 Gallup poll (societal survey entity) that 75% of consumers prefer a product with antibacterial function (Microban 2008).

Polygiene also reports that anecdotal evidence from consumers attests to the anti-odor function and that washing less is possible. These messages are echoed by AgIon (via their website), an U.S. –based company that offers free T-shirts with the challenge to test the limits of the anti-odor technology. Using the slogan, "Try everything, stink at nothing," AgIon promotes their anti-odor technology and has accumulated hundreds of customer responses documenting the performance as an anti-odor (StinkAtNothing 2011).

In order to allow realization of less laundering, Polygiene has made an effort to improve awareness of the function and how to realize the wash-less benefit both on hang tags attached to garments and via the internet (von Uthmann 2011).

Finally, Polygiene representatives mentioned confidence in their product and quality control efforts, that they utilized recycled silver, and that their product has been certified and approved by various entities. In addition, companies with high environmental reputation like Patagonia utilize their product. There is a belief that the EU Biocide Directive may even be beneficial to them as it may make it difficult for newcomers and lesser proven products (von Uthmann 2011).

In summary, manufacturers see their products as very low-risk, with low amounts of silver, and as providing a function that consumers want. All stakeholders (besides Ionsilver, the issue is not as relevant for colloidal silver and was not specifically discussed) see the life-cycle perspective as something to consider.

3ii. Retail companies

Retailers were emailed and more than a dozen responses were received. Most companies targeted were from the clothing industry but some others were included to including two non-clothing textile companies, one footwear company, one from building material industry, and one from food packaging. Representatives from apparel companies Adidas, Haglöfs and sports outfitter Stadium were also interviewed.

For those companies that manufacture biocide-treated products, many positions were similar to those revealed by the silver manufacturers. Haglöfs sustainability director, Lennart Ekberg mentioned that amounts of silver in their clothing articles is minimal (Haglöfs uses Polygiene) and that when considering the life cycle of a clothing article, the function is beneficial. In addition, Ekberg mentioned that it is perceived to be difficult to sell a synthetic sport undergarment that is not treated with an antimicrobial and that most articles in this category are treated with something. According to him, this may not always be made known to the consumer (Ekberg 2011).

According to Adidas representative, Phillip Meister, Adidas strives to always give the customer the best functioning sportswear while considering known and perceived risks. Adidas does not use triclosan or nanosilver treatments due to potential health risks, but does offer Agion (ion exchanger) treated shoes and X-Static (silver fiber) in a few articles (Meister, 2011) and according to one study, triclocarban in ClimaLite apparel (73). Use in shoes is considered a different risk scenario as they are not laundered as often. X-Static fibers are also considered a differentiator because it offers a visible anti-odor (Meister 2011).

Customer choice is important to Adidas and an increase in demand for anti-odor products has been observed. Meister also mentioned anecdotal evidence of people discarding clothing after washing due to odor (Meister 2011) which is consistent with study results reported by Polygiene.

Meister also reported the use of alternatives Aegis (antibacterial polymer) and coconut coal-treated (moisture management) polyester. It should be mentioned that each of

these treatments (both silver and alternatives) are used in a very minimal segment of the Adidas line and that the anti-odor market is expected to remain a small one (Meister 2011).

Both Meister (Adidas) and Ekberg (Haglöfs) mentioned their continued pursuit of improvements and better alternatives (Ekberg 2011; Meister 2011). Many "opponents" reported using or considering the use of moisture management function instead of antibacterial- biocidal function. Cross stopped use of silver –one of their formerly offered undergarments reportedly lost 25% Ag over 10 washes (Hjärtnäs 2009)– and will introduce a few products treated with bamboo charcoal in 2012 (Ulvsgärd 2011). Fjällräven utilizes natural-wicking hemp and bamboo fibers in a few clothing articles (Linné 2011). Didrikssons does not reportedly use biocidal agents and is continually looking for safe alternatives (Westbom 2011). An interview with Dennis Baktemann of Stadium revealed that although Stadium did formerly sell a shoe with bamboo-fibers, the effectiveness is debatable and they no longer sell the product (Baktemann 2011).

Patagonia, which is a company widely respected for its environmental stewardship mentioned the below on their website, referring to customer demand and their use of anti-odor.

> *"There was a time when body odor was considered a natural byproduct of exertion, something to be expected, even celebrated, but those days are gone for most people. Odor control has become de rigueur for technical knits in the outdoor clothing marketplace. Gladiodor garment odor control is our solution."(Patagonia 2011)*

With this idea in mind, Patagonia also utilizes Polygiene silver treatment (von Uthmann 2011)).

Not all companies are willing to take the risk associated with utilizing biocides. Nike's John Frazier reported that Nike has placed both silver and triclosan and any other anti-odor technology that leaches in order to function on their restricted substance list (Frazier 2011). This is confirmed by the *Nike Corporate Odor Management, Antimicrobial, and Scented Material Guidelines* which include a couple of principles that may be considered beyond business as usual:

> *Scented materials or Odor control technologies must:*
> • ***Not leach or release chemicals in order to be effective*** *ABC*
> • *Meet legislative standards (globally)*
> • *Be registered under the EU Biocide Directive (applies to antimicrobial technologies)*
> • ***Pass a corporate toxicity review (conducted thru the Nike Considered Chemistry team)***
> • *Be proven effective (for our product types)*
> • *Comply with the Nike Corporate RSL (Restricted Substances List)* (Nike 2010)

Regarding triclosan, L.L. Bean (U.S.-based apparel company) revealed use in at least one article and the sale of a Teva sandle treated with triclosan (Microban) (LLBean 2011). Haglöfs and Adidas reported excluding use of triclosan long ago (Ekberg 2011; Meister 2011). Varner (parent company to Dressmann, among others) reported the listed of both triclosan and silver in their supplier manual's no-contain list (Lefebure 2011). No other mention of triclosan was noted in correspondence with the apparel companies.

Baktemann also revealed that Stadium does not sell anti-odor clothing in its own line, but it sells a number of products from other manufacturers to include Peak Performance apparel treated with Polygiene. He also mentioned the use of an Öko-tex approved treatment for purposes of moisture management during transport (Baktemann 2011). Interestingly enough, Haglöfs Ekberg mentioned also that the beginnings of biocides in the apparel market was due to the need to combat growth (mold, etc.) during long distance transport (Ekberg 2011).

Regarding the potential expansion of the anti-odor market, fashion retailers, Varner (Dressmann), H&M and Lindex revealed no intent to utilize anti-odor function (H&M 2011; Lefebure 2011; Lyckdal 2011). Both Varner and H&M mentioned the lack of relevance for their sector (H&M 2011; Lefebure 2011).

Outside the apparel industry, Life Sleep Center reported that sales of their silver-treated mattress were minimal with no signs of increasing (Gencer 2011). From the building material industry, St. Eriks Concrete will not use silver and biocides in the near future as it is considered not worth the environmental risk and not what customers currently want (Sten 2011).

Viking footwear's Terje Moland indicates that Viking is offering treated products on a trial basis. Moland foresees that Viking will probably offer treated products in the future referring to it as a "marketing issue." (Moland 2011)

Thorbjörn Andersson, of food packaging company Tetra Pak, says that the use of silver in packaging is not a possibility due to regulation and health concerns. Tetra Pak has reviewed the potential of using silver for application on in-factory machines. One interesting concern (not known whether the concern is founded or just a theory) is that the mere application of such a treatment could lead to lackluster cleaning habits by employees, leading to lesser hygienic conditions (Andersson 2011).

In summary, the companies corresponded with are generally cautious. This has been substantiated in Sweden in the past by manufactures such as Cross (mentioned above) and a few retailers, who removed products from inventory after media scrutiny. One instance of this occurred when the SWEREA IVF silver-releasing garments report was released (mentioned earlier). Åhlens and three other resellers removed products from their shelves soon after the study's release (GOE 2009). This sensitivity to public pressure indicates that public scrutiny in Sweden is a functioning deterrent.

It might not be just Swedish goods that are affected by such initiatives. According to a GOE publication, the branch organization Swedish Textile Importers' Association (not reached for this study) recommends against the use of biocidal agents in goods (GOE 2009)

Beyond their general sensitivity to public pressures, companies see human health of high importance, but see customer choice as important (The author is not inclined to determine which elements is more important. The phrase: *Customer First, Safety Always* comes to mind.). The companies that utilize biocides see the biocides they use as safe alternatives. The companies that do not utilize biocides observe the precautionary

principle and may offer moisture management function instead. All seek improvements and better alternatives. Each of three fashion retailers did not see the biocidal function as something beneficial to their products, possibly indicating a ceiling for the biocidal clothing market. Finally, one of the largest sports apparel companies in the world, Nike, has established what one might consider progressive standards for odor-control, essentially banning use of chemical biocides in its products.

3iii. Industrial certifications

One other area of interest is certification entities, which play a role in assessing products and processes with varying sets of criteria. This section is meant to provide a mere glimpse into certifications that were noted when evaluating the silver manufacturers mentioned earlier (selection of certifications was performed by merely noting certifications associated with products and companies reviewed). This discussion in no way represents the entire field of certifications and related foci.

One internationally-known textile certification standard is Germany-based Oeko-tex. Oeko-tex "provides the textile and clothing industry with a globally uniform standard for the objective assessment of harmful substances." (Oeko-tex 2011)

Each entity has a logo that is often used in product marking – this may be considered to act as a signal to the consumer related to quality or safety. Foci for the certifications vary. For Oeko-tex, "the tests for harmful substances comprise substances which are prohibited or regulated by law, chemicals which are known to be harmful to health, and parameters which are included as a precautionary measure to safeguard health." (Oeko-tex 2011) Therefore, human health appear to be the focus of the certification and environmental risks are at most secondary.

However, as seen in the excerpt below from an online health product website (Magnolia Health), Polygiene's Oeko-tex certification is mentioned under the "Environmentally friendly" heading, not under the "Safe next to your skin" heading which might be considered more applicable. This could be an indication of confusion on the market related to certifications and "eco-labels."

> ***Safe next to your skin***
> *Thanks to its roots in the healthcare sector, Polygiene meets the highest standards for skin safety and hygiene. Hard at work only on the fabric surface, Polygiene does not affect the friendly bacteria on your skin.*
> ***Environmentally friendly***
> *Polygiene is on the list of Oeko-Tex approved products. Safe and eco-friendly, it uses extremely low concentrations of silver salt made from recycled silver. Plus with odour-free clothing, you do less laundry, which is also good for the environment.*
> (Magnoliahealth.com 2011)

Polygiene and AgIon as well as a number of other antibacterial treatments are certified by Oeko-tex (Polygiene 2011). Polygiene is also certified by a Japan-based textile certification, EcoCircle, which is described as the first closed-loop recycling system for polyester (EcoCircle 2011), and approved by Switzerland-based textile certification, Bluesign (Polygiene 2011).

According to a brochure available on the website for describing Bluesign criteria for textile manufacturers, resource productivity, consumer safety, air emissions, water emissions, and occupational health and safety are the five principles of the certification (Bluesign 2011). Bluesign-certified products have even been given a "highly-recommended" stamp of approval by Greenpeace-Germany (von Uthmann 2010).

The Bluesign-certification is beneficial for Polygiene in the competition for at least one customer, Patagonia. Patagonia is a respected American outdoor apparel company, known for their environmental commitment and allows the use of Bluesign-certified antibacterial treatments (Patagonia 2011). (Note: There are indications that Patagonia's decision was not completely without internal debate as one Business School – Darden, UVA— even used their decision as a case study in corporate ethics (Byrne 2011).)

AgIon is certified by Cradle to Cradle, an U.S.-based industry-wide, life-cycle and eco-design focused certification (MBDC 2011). Described on the website as "unlike single attribute eco-labels, Cradle to Cradle certification involves the assessment of each product "in five categories: Material Health, Material Reutilization, Renewable Energy Use, Water Stewardship, and Social Responsibility."(MBDC 2011)

One Sweden-based certification is Svanen, which has an industry-wide focus. Svanen aims to give Nordic consumers a chance to choose the most environmentally friendly products. Svanen assesses products via a life cycle assessment with such focus categories as (but not limited to) energy use, water use, toxicity, and waste. Everything from hotels to retail shops and cleaning supplies are afforded the Svanen label (Svanen 2011). In correspondence with Svanen, representative Ulf Eriksson said that Svanen was unlikely to certify silver-biocide treated textiles (Eriksson 2011).

In summary, the certifications noted during this study have varying objectives and scopes. Whereas one certification entity may solely focus on whether a treatment or product allows recyclability, another may focus on safety of human exposure, another only on the product cycle through manufacturing, and yet another on the entire life cycle. Considering this along with the fact that a submission for certification must be actively made by the manufacturer, it is not surprising that different certifications are seen associated with different products, and that while one certification sees a product fit for certifying, another may not. Therefore, although certifications may be considered to send (positive) signals to consumers, these signals cannot be considered to be completely clear. However, it must be mentioned again that this was nothing more than a glimpse into certification.

3iv. Industry summary

Two consistencies that were mentioned by most industrial actors are that 1) they respond to their customers' demands and 2) they are relatively cautious and continuously on the search for improvements and better technologies. This demonstrates that customers do have the power in their hands (when informed – being informed even in regards to common certifications cannot be considered an easy task) and that commitment to any one anti-odor treatment may not be very strong. In addition, it reveals another perhaps not-so-surprising idea – that a change in society's

position on silver as a relatively safe biocide or the advent of a better technology could cause rapid shift from it as a common biocide.

4. Experts

Mainly with consideration to the varying research indications and other opinions, the author sought views from experts noted during the study. The author received three responses regarding the question from experts, two by those who are directly involved with the topic and a third who is not directly associated with the silver topic.

Dr. Stephen Luoma is an Emeritus at the U. S. Geological Survey and the author for *Silver Nanotechnology and the Environment: Old Problems or New Challenges* (among other publications). Dr. Bernd Nowack has been active in silver (especially nanoAg) research and has published many papers on the topic to include modeling of silver pollution scenarios mentioned in this work. Dr. Julian Atwood has not focused on silver but was a co-author of the work *"Well Dressed? The present and future sustainability of clothing and textiles in the United Kingdom"* and is on staff at Cambridge and joint editor-in-chief of the Journal of Materials Processing Technology. Their responses are seen below and depict three views on the topic:

1) Cautious – Silver is a toxin that should be mitigated specifically

"While I have great respect of Nowack's models and his papers, I think he was premature in his assertion. In fact, increasingly it is looking like the Ag nanoparticle can enter cells and perhaps by releasing silver there can accentuate problems. He was just being too simplistic I think." (Luoma 2011)

Dr. Samuel Luoma (USGS) – On recent study by Swiss scientist that largely downplays risks associated with nanosilver.

2) Less cautious: Silver is another biocide

"It is very important to realize that nano-silver (where the current discussion is focused on) is only responsible for a small part of the total silver load to the environment. This is determined by industrial uses of Ag and not by biocidal uses. It is also important so realized that Ag is non-toxic to humans and that it is present in the environment in non-bioavailable forms (very low risk - most tox-studies have been done with free Ag+ which does almost not exist at all in a natural system). There might be formation of resistance to Ag but I would expect much less than for organic biocides (which are used in much higher amounts). Not using Ag means that other biocides will be used (in much higher concentrations in the product). It is of course questionable if a non-renewable resource like Ag should be used in a dispersive way. And also if we really need biocidal properties in so many products. We would need to regulate ALL biocides and not single out Ag." (NowackB 2011)

Dr. Bernd Nowack, Swiss Federal Laboratories for Materials Science and Technology. Author of a few studies cited in this paper.

3) Lack of awareness of the specific issue

“I'm sorry. I don't know anything about this issue.” (Allwood 2011)
Dr. Julian Allwood (Cambridge professor, author of “Well Dressed? The present and future sustainability of clothing and textiles in the United Kingdom”), in response to questions about biocides and textiles

The first two views epitomize the debate amongst researchers while the last demonstrates how this issue is just one of many issues of which many in the world (to include the scientific world) do not know. This can be considered to be a very specialized topic – if one is not involved in it directly, one may not be aware of it at all.

5. Consumers

In order to get an impression of consumer opinion and activities, three studies were considered:

1) the author’s survey focused on consumer awareness,
2) a Borås survey (Josefin Damm) focused on consumer opinions and behavior
3) the Polygiene group study focused on consumer demand (mentioned earlier)
4) a Borås experiment (J. Damm) on consumer perception of odor-free function.

The author’s survey revealed a general lack of awareness of silver used as a biocide. Out of 64 surveyed, 32 (50%) were not aware if they had purchased a product that was silver treated. Five responded that they had purchased such a product, and none indicated having purchased the product for its anti-odor function.

Although impressions were generally negative towards the silver being used in consumer products, eight (25%) responded that they would purchase or would consider purchasing a clothing item treated with silver or another biocide. Only one of sixty-four (1.5%) responded that the function was worth the potential consequences. Twelve (19%) considered antibacterial function to be beneficial but most indicated that it depended on the use. The Borås survey, which was conducted by Josefin Damm at Borås Textile University and yielded 306 responders, revealed comparable results: only 7.5% thought the antibacterial function was an important function for a garment (Damm 2011).

The Borås survey considered consumer opinions as well as consumer’s washing of sports clothing. Twenty-nine (9.5%) of responders (compared to 7.8% for the author’s survey) owned a biocide-treated garment and 43% did not know if they owned such a garment compared to 50% for the author’s survey. The biggest reason for washing athletic wear was due to odor (40%), indicating that the anti-microbial function (assuming that the function is actually fulfilled) could be considered as something that would reduce washing. In addition, 47% wash at temperatures in accordance with the instructions on the tag and an additional 16% chose wash temperatures in order to reduce wear or shrinking of garments (Damm 2011). Since silver-treated clothing is to be washed at lower temperatures to reduce release of silver (von Uthmann 2011), this can be important to understanding risk related to consumer behavior.

The Polygiene group study results demonstrate (mentioned earlier) that over 50% of customers are willing to pay more for odor-free garment (PolygieneStayFresh 2011),

which can be said to contradict some of the consumer positions represented by the author's and Borås survey (only 19% respectively 7.5% saw the function as important). The Polygiene study also depicted a consumer that is very sensitive to odor as 90% of people said that odor reduces their self confidence, and 30% of people have discarded a garment due to odor after washing (PolygieneStayFresh 2011). These statistics can be said to strengthen the justification for anti-odor clothing.

Finally, the Borås odor experiment was conducted also by Josefin Damm and attempted to answer the question, "Do consumers perceive a difference between odor-free treated and non-treated garments?" The experiment was performed by first initiating wear of stitched garments –one half treated and the other half non- treated—by a number of individuals. A sniff test was performed by a panel after various time intervals (in days) to assess odor. Results showed no definitive difference in perception of odor for the treated and non-treated garments (Damm 2011).

Indications given by these consumer surveys are the following:

1) ***Consumer awareness*** – According to the author's survey, many consumers are not aware if they own such products. This may not indicate much. Asking someone if they own a product that has an invisible function may be like asking someone if a specific chemical was used in the manufacture of something they own. Most people will not be sure. The only thing this may indicate is that they did not specifically seek and purchase a product with that function.
2) ***Consumer opinions*** – The author's survey reveals that consumers are negative towards the need of the anti-odor function as well as if it was worth the potential risk *at least when informed of the potential risks*. Many consumers are cautious to such functions. However, as the respondents were essentially being made aware of potential risks while assessing the value of a function, the results only indicate cautiousness in a state of data symmetry, which is almost definitely not the case in reality. Furthermore, the Polygiene study demonstrated a true demand – half of consumers are said to be willing to pay more for odor-free garments, which can be considered a rather positive position on the function (Polygiene).
3) ***Consumer washing behavior*** – According to the Borås survey, a significant amount of consumers actually wash based on odor or soiling. In addition, many wash in accordance with garment wash instructions or choose temperature based on lengthening the garment's life. These two habits indicate that a well-functioning anti-odor garment could reduce washing to a degree and that many consumers wash silver-treated garments in accordance with instructions. Whether or not the other consumers' behavior can be altered is another question. In addition, as the Polygiene study revealed, people actually discard garments after washing due to odor.
4) ***Consumer function perception*** – According to the Borås experiment, the odor-free function tested did not demonstrate a definitive benefit. This is contradictory however to anecdotal evidence from tens (if not hundreds) of others from AgIon's customer website (StinkAtNothing 2011).

In summary, consumers revealed that they are not extremely aware of what products they buy and that they are cautious about certain products when made aware, at least, for short periods of time, i.e. during the survey. The Borås survey showed that, however a minority, many people do follow wash instructions and that perhaps not all consumers

are wash-crazy as 40% wash based on odor not just because they had worn the garment. The Polygiene study demonstrated a rather significant consumer demand. The Borås experiment attacked a question related to the silver debate – do these functions really work and are they perceived to fulfill the anti-odor function by individuals? The experiment results said no.

Results should not be considered as absolute representation of consumers today. But they are considered to give an impression of some of consumers' thoughts and actions in relation to the topic.

6. Workshop summary

This serves as a short account of two group meetings, one seminar in Lund and a workshop at Chalmers. The author attended one seminar at Lund Innovation Center that involved the presentation of a patented nanosilver product called AGSOL. Various stakeholders were in attendance to include AGSOLs inventor and business development team, and experts in various areas to include water and sanitation, medicine and risk, food packaging, paints and pigments, and nanotechnology. Although primary focus of the meeting was for the AGSOL team to assess potential business opportunities in different sectors, discussion gravitated towards risk related to the product. Stakeholders in attendance were generally not very receptive to the idea but the AGSOL team was able to engage a few individuals in constructive discussion. Overall, the author perceived a general discomfort amongst stakeholders and some of the time set aside for discussing potential product use was used instead to discuss environmental and health risks. However, a couple months later, the team had succeeded in gaining investors and established the company Prebona AB, which was to offer nanotechnology solutions in the building materials market (Hedlund 2011).

The author also hosted a workshop at Chalmers with the idea of gathering new insights from stakeholders. Although nearly all stakeholders were invited, unfortunately, only three outside academia were represented – Polygiene and Gryaab, Kungsbacka Wastewater Treatment. During this workshop, the following individuals presented related material:

1) The author presented a summary of work compiled thus far,
2) Josefin Damm of Borås Textilhögskolan presented results regarding consumer behavior and silver-treatment function (mentioned earlier)
3) Christian von Uthmann of Polygiene presented material demonstrating consumer demand for anti-odor technology and
4) Richard Arvidsson of Chalmers presented a summary of work focused on assessing risk related to silver use and
5) Ann Mattsson of Gryaab presented an update on REVAQ upstream work with a focus on silver.

According to stakeholders who have been at the forefront of the debate (Gryaab, Polygiene), the discussion was much of the same. Fortunately, the author did gain some insights from the workshop and a summary of discussion was sent by the author in an email to participants (email summary seen in Appendix G).

7. Stakeholder summary

As expected, stakeholders can be said to reveal positions that are consistent with their own interests. Silver product manufacturers think that their product is great and that risk related to them is beyond reproach. Industry generally wants to be able to meet customer desire and will do so often by offering best available technologies, which are merely best available and not always flawless. Organizations strive to meet their goals and satisfy their members. Authorities focus on their assigned responsibilities and established goals. Consumers are thousands and thousands of individual entities many of whom are considered to like the idea of hygiene, dislike odor and to be sensitive to environmental risks when informed.

Regarding awareness (p. 10, question 1: Are stakeholders aware that some products contain silver?), no non-consumer stakeholder revealed their lack of awareness related to the issue. The author's perception is that all non-consumer entities were aware based on their answers – this is a known issue. However, this is not conclusive as stakeholders were approached with an introduction explaining the study, precluding non-awareness.

V. Discussion

First, one can ask if the biocidal (anti-odor) function is actually something that consumers need or want. One perspective is that anti-odor clothing and other antibacterial offerings are neither necessary nor is it something consumers want.

In addition, there is a feeling that the use of silver as a supplement or biocide is unnecessary, and irresponsible, considering the risk of bacterial resistance to antibiotics. This opinion is attributed to at least Åsa Mellhus, Doctor at Uppsala Academic Hospital (Jacobsson 2008). Another person in attendance at the Lund seminar attended by the author referred to the rhetorical question about silver (which is a power antibiotic in itself and sometimes functions when others do not) – Why use the silver bullet (silver) to reduce odor in socks when it may be needed to save someone's life?

The concern related to consumers and anti-odor products is that consumers will get interested in and used to a potentially risky function that they didn't even know they wanted a short-time before. This is consistent with certain stakeholders' consideration to technology diffusion and lock-in. One researcher with interest in the topic mentioned that "it is easier to stop a stream than to combat a deluge." (Sandén 2011). Since silver is somewhat new in some of these biocide functions (textiles, surfaces, etc.), now can be considered a crucial time to act. It is perhaps considered too late with many other toxins that have already reached the magnitude of a deluge. Could a few companies pave the way for an influx of biocides (to include silver concoctions)? It is possible, but this influx is likely to be hindered by the Biocide Directive and the cost of silver.

Also, the anti-odor/ moisture management segment of the apparel market is evolving rapidly, with textile and other manufacturers seeking the best available technology without the hassle of political and societal intervention. One silver product manufacturer revealed that their clients have plenty of other issues to worry about and that they expect it (the silver product manufacturer) to take care of their own

authorization and certification. This is just one function of a many-function textile market. If silver is banned tomorrow, manufacturers will just find an alternative.

Just in the biocidal apparel market, there has been some evolution in the last 15 years. In that time, this segment that was once dominated by chemical substances (such as triclosan), has seen the emergence of silver fibers, and later by small particle metallics and silver salts. These newest can be considered the second or third generation in silver treatments as they require less silver are more effective, and release less during use (von Uthmann 2011). Even some silver treatment manufacturers are looking for other technologies to fulfill the same function. This problem may be a short-term one when replaced by another technology.

The issue of compromise must be considered. In this case of silver as an emerging biocide, there is little compromise seen from the two opposite poles of opinion (for example, Polygiene and SWWA). This is interesting in that there seems to be much more of a propensity to compromise in many cases of environmental risk (however on more of a system-wide perspective). Use of alternative energies cause addition resource demands and wind-power in particular can be directly linked to increased bird death and other ecosystem degradation. Hybrid vehicles increase the use of coal-power in the short-term and the use of elements needed in battery manufacture. Some commercialized biofuels are said to be not sustainably produced. Each of these 'solutions' by themselves are not considered sustainable in themselves- i.e. if all current technology were to be replaced by these alternatives alone without any other technological or social changes. Of course, each of these examples contains also polarized parties who either staunchly support or oppose such technologies. Therefore, this instance of silver as a biocide is not unique.

Accumulation is undeniably one of the key themes of the silver topic in Sweden. As other silver-related parameters have been met, accumulation is the documented reason for REVAQ-related focus on silver. Consequences related to accumulation are not entirely known and precaution is observed by many parties. Accumulation may be what sets silver and some other metals apart from other less-accumulating toxins.

The resource issue can be considered. Although some of these applications involve the use of recycled silver, the silver is lost during use and disposal. As mentioned by Nowack, who to some degree dismissed the severity of risk related to silver, "It is of course, questionable if a non-renewable resource like Ag should be used in a dispersive way." (Arvidsson 2011) This is seconded by three researchers from Chalmers who recommended that consumers not to buy silver-treated products and that retailers remove the products from their stores. They mentioned that silver is needed for electronics and photovoltaic mirrors, media from which silver can be recycled (Arvidsson 2011).

There are also indications of socio-political landscape differences. In the U.S., Patagonia, a company respected for environmental stewardship utilizes Bluesign-approved anti-odor technologies, such as Polygiene. In addition, one of Polygiene's competitors, AgIon, has been certified by Cradle to Cradle, an eco-certification that is at least moderately respected in the sustainability community. In addition, the product has received praise via the media as an eco-product. In Sweden, on the other hand, Polygiene has been

publically scrutinized in media channels and various organizations have advised against using any product treated with the product.

Of course, the landscape in Sweden is different. The Swedish Environmental Objectives and REVAQ demand rather progressive action towards reducing pollution and recycling phosphorus. As mentioned by SEPA's Holm, recycling of phosphorus can be done without the use of sludge. However, the alternative of burning sludge and recovering phosphorus from the ashes may be considered rather inefficient in itself and involves the loss of many valuable minerals and compounds. In the current state of affairs, sludge is the available medium of phosphorus delivery and there are customers (Agriculture) that want it only if it is of very high quality. That is the current reality.

Finally, a consideration should be made to the superficial aspect of this study. As noted in assumptions, the information seen by the author is considered to be representative of reality. A relatively small number of sources and stakeholders were considered but are thought to be representative by the author. The Swedish domestic market was best represented with many of the foremost outdoor apparel companies considered as well as a few fashion heavyweights. The international apparel market was represented by trend-setters Adidas and Nike and the clothing fashion market by H&M. Silver product manufacturers were represented by three independent leaders in the market. Three different consumer surveys of different sources were used and compared to a degree with anecdotal and internet-available information.

All sources were considered to be given equal weight and there were no indications that the representation by the author of the current market, research trends, regulatory actions and stakeholder positions differs from reality.

VI. Summary

A summary can be made with consideration to the study objective, which was *to document the current situation to include the current market, research activity and trends, regulatory activity, and stakeholder opinions and actions.*

Current Market
In the textile and hygiene market, silver does appear in many different forms and applications. The hygiene and textile market can be seen as a growing but small market when considering silver use. Based on all estimates, which vary greatly in method, scope, and focus, this market can be said to represent less than a percent (perhaps a fraction of a percent) of total silver use. One estimate is a future use (2015) of 85 tonnes for silver in hygiene (surfaces, appliances, textiles, coatings). This can be compared to current use of 2,000 tonnes for photography.

However, many of these emerging uses present more diffuse sources of silver and many new consumer sources of silver. Just the amount of products claiming nanosilver content has increased tenfold just in the last 5 years. Silver is increasingly used in hygiene and textiles but this market should not be considered the only emerging source.

With silver´s position in many industrial processes, uses in cosmetics and health products, and emerging uses such as in wood preservation and in RFIDs (Radio

Frequency Information Devices) and building materials, one should be aware of other sources, not just hygiene and textiles.

Research trends

Research revealed a mix of results but the silver ion is known as one of the most toxic metal ions. Silver is also known to bioaccumulate possibly affecting some functions to include reproduction. Speciation is undeniably important and nanosilver is generally perceived as the most risky form. However, speciation at different phases and times is also relevant. Silver is known to be often bound as silver sulfides in wastewater treatment and the environment, therefore, although a silver may start off in a product in one form (such as nanosilver), it may end in another. Risk models reveal that textile and hygiene applications make up a very small part of initial source but silver's pathway from these products is different. Whereas bulk silver is generally thought to be disposed of or recycled, hygiene and textile applications are thought to be dispersed via washing and dissociation, allowing a greater chance that silver ends up in wastewater, sludge and the environment.

Legislative and regulatory activity

Legislation and regulatory focus on silver has been minimal compared to other toxins and any limits have been based on health risks for drinking water standards and acute tests for environmental protection. More strict guidelines appear to be on the way. The EU Biocide Directive will likely involve some type of restrictions on silver compounds used as biocides and is probably the most important regulatory initiative relevant to the Swedish market. The USEPA has identified silver as a pollutant of interest related to biosolids use and in the larger context of nanotechnology. It also deemed that a silver-enhanced washing machine would be regulated as a pesticide, potentially setting a precedent in perceiving biocidal function as defining for a product. Workgroups focused on nanotechnologies and potential environmental implications have also sprung up in the last few years in both the U.S. and the EU.

Sweden's environmental objectives and REVAQ sludge certification system create a different landscape in Sweden, indicating one of the reasons for silver focus. SEPA has recommended limits for silver (mg Ag/ kg sludge- Ag/ hectare), a 500-year doubling minimum, and has referred to a continual reduction to the silver allowance levels.

Stakeholder positions

A review of stakeholders revealed some expected results and some more interesting. Not surprisingly, most entities hold opinions and act in accordance to their best interests. For those that have an official policy or goal related to silver, silver in these new markets must be stopped – It is easier to stop a stream than to wait for a deluge. For some, silver is one of many toxins and deserves focus but perhaps in magnitude of focus on other biocides.

For those in the textile industry who sell silver-treated products, silver is something (a product or function) that customers want and it is actually beneficial when considering the life-cycle perspective (less laundering). Industry stakeholders as a whole, especially those who have chosen not to utilize such treatments, are quite cautious about utilizing them. One stakeholder even mentioned the possibility that the mere presence of a biocidal surface could result in reduced cleaning efforts by employees.

VII. Conclusions

Although silver appears to be growing in this market, its presence may be limited in time and scope. Silver treatments are considered as just one feature or function of a greater product and because of cost and that a biocide function is not considered to be valuable in all products, they are expected to remain only in niche roles, such as in sporting apparel. Industry stakeholders are also perceptive to public discussion and trends and almost all report continually looking for improvements and better alternatives. Some companies that utilized chemical biocides in the past have ceased and most notably, apparel giant Nike has created a progressive standard, essentially banning any leaching biocide. Regarding alternatives, moisture management yielded by natural fibers such as merino wool, bamboo and others are thought to yield at least some function without chemical biocide-related toxicity. Charged polymers that offer mechanical biocide function are thought to be another alternative.

Despite the availability of these alternatives, silver-treatments are thought by many to be the best available (and least toxic) proven technology for anti-odor function. Consumers appear to want such a function to a certain degree and are willing to pay for it (as demonstrated by consumer studies and open market success) at least when not specifically made aware of potential risks. When aware of potential risks, as in the author's and Borås study presented here, reception to the function is considerably less favorable.

Accumulation in the environment is considered by some stakeholders to be something that differentiates risk related to silver (and some other metals) from other toxins, such as degradable substances seen in detergents, medical products, and organic substances. Silver was estimated to double in Swedish sludge-treated lands in approximately 40 years. There is an interest to extend that doubling to 500 years – what consequences (if any) the doubling will have on ecosystems, agriculture, and human health is unknown.

With time, increased focus on silver in Sweden may be proven as the right choice. Although risk related to silver is not conclusive, other pollutants were deemed equally safe and harmless in the past only to be later revealed as having a significant impact.

Actions by Swedish Water Organization and its members may be perceived as alarmist by some but their actions reflect their need to dispose responsibly of sludge and the dedication to a national objective for which they feel responsible. Swedish agriculture demands sludge with low levels of contaminants. SWWA aims to provide quality sludge, if not for Sweden's interests then most definitely for their own.

Regardless, sustainability does involve looking beyond immediately apparent impacts and attempting to forecast long-term consequences to society and the environment. As long as there is no evidence that precaution will result in another equal hazard, precaution is just the kind of thinking that should be respected.

Whether that type of thinking about silver is consistent in scope and magnitude with approaches to the other myriad of other proven impacts is another question for another study. However, if we were to make decisions by comparing new, unknown or seemingly

minimal environmental risks (such as silver in garments) to existing environmental sins (such as expansive chemical use in textiles), would we ever make the right choice?

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Appendix A: Conceptual illustration

Silver is sold on the market and used in society. There are three relevant products for this study: 1) the sale of silver-containing products on the market, 2) the sale of food from agriculture to society, 3) the sale of treated sludge from wastewater treatment municipalities to agriculture – the key ingredient here is phosphorus. There are quality control concerns for each of these markets.

From these products, silver is subsequently released to ecosystem and wastewater treatment systems. Wastewater treatment captures most silver in sludge. Treated sludge (with the ever important phosphorus) is applied on land and its components are taken up by organisms and released elsewhere in the ecosystem. Plants, to include food crops, intake biosolid components (phosphorus and contaminants including Ag) and other organisms, to include humans, consume the plants and release components to the ecosystem and wastewater treatment.

Appendix B: Interview guideline

These questions are translated from Swedish and were used as a guideline for interviews. Questions were chosen based on who is being interviewed. Some may not be relevant for some interviewees. Questions are used to generate answers and further questions. Therefore, some questions were never formerly asked but answered nonetheless.

□ Can I record the interview?
□ How long have you worked at_____
□ What is your role at_____?
□ What are your organization's purpose? Target?
□ What is your attitude to silver-treated products such as in anti-odor garments?
□ What do you want to happen when it comes to marketing and sale of silver treated products?
□ In your eyes, what is an appropriate way to market, sell, and consume the silver treated products?
□ What is your role to ensure that the silver treated products are marketed, sold and consumed in an appropriate manner?
□ What do you say to certain arguments that product life is longer that you do not wash as often, and that the amount of silver is nothing compared with many other things?
□ Do you think that the marketing of these products fit certain requirements, ethical, and others?
□ How do you prioritize this issue? Low, High?
□ Have you conducted studies on environmental impact ? ... Silver leaching from products?
□ Have you carried out risk assessment, LCA, or the like on them?
□ Have you planned to do an LCA or similar?
□ How much silver is in the product? In what form?
□ How much is released during the lifetime?
□ Where is the accountability in this topic? Politicians, industry, consumers, you?
□ How do suppliers and customers of a potential risk?
□ What is your attitude regarding environment risk associated with products with silver?
□ What do you know about sewage treatment and the current processes?
□ Do you know if REVAQ and Sweden's 16 environmental objectives?
□ Do you know about Sweden's goal to return 60% of phosphorus from sewage by 2015?
□ What is your approach in terms of silver in the sludge and the sludge possibly cannot be returned because of Silver in the mud?
□ Would evidence that your products release silver that ends up in sludge change your attitude? What are your thoughts on this?
□ According to some studies, the silver a high potential for bioaccumulation and also affect some aquatic organisms over a longer period, particularly with respect to its reproduction. What are your thoughts on this?

Interview to be completed with specific questions about the information on websites and the like ...

Appendix C: Ag mining & industrial use

In 2010, 736 million ounces Ag were mined (21,000 tonnes). This makes up around 70% of the world's yearly use (1035 Moz, 30000 tonnes) (GFMS 2011).

Silver occurs and is most often mined in the following silver minerals: tetrahedrite (Cu,Fe,Zn,Ag12Sb4S13), freibergite (tetrahedrite with up to 30% Ag), pyragyrite (Ag3SbS3), argentite (Ag2S), proustite (Ag3AsS3), and ceragyrite (AgCl). Some is also produced via Gold and Copper mining as well as via the lead mineral Galena. The largest producers of silver are Mexico, Peru, U.S. and Australia and Australia is known to have the largest economic reserves (Australianminesatlas.gov 2011).

Mining is performed by drilling and blasting ore, crushing and grinding it and submitting it to flotation processes. This involves the use of intense aeration, which allows wanted particles to attach to air bubbles while rocks and unwanted particles (tailings) sink to the bottom. The froth is skimmed off the top and in the case of the galena mineral, the resulting silver lead sulphate concentrate can yield between up to 1 kg silver per tonne of concentrate. The concentrate is partially melted (sintered) to allow some of the metal particles to coagulate and sulfur to be release as sulfur dioxide. It is then smelted and drossed (some impurities removal) which yields as crude lead which contains up to 2 kg silver per tonne. The crude lead is then poured into a kettle and through a top layer of zinc, which allows for the formation of zinc-silver-copper-gold alloy. The zinc layer is skimmed off and smelted yielding a silver-copper-gold (dore) which can be cast into plates for electrolytic removal of copper and yield of high purity gold and silver (Australianminesatlas.gov 2011).

Between 40 and 50% of total silver is used in industrial applications (GFMS 2011). Silver is used in many industrial applications to include:

1) as a catalyst in the production of formaldehyde, which is in turn used for the production of other organic materials and plastics
2) in brazing alloys (soldering of metals at temperatures above 600 C) (100, 12).
3) as silver oxide used as a catalyst in the production of ethylene oxide, a major component of polyester and epoxy resins.(GFMS 2011)

Appendix D: Medical and health uses

Silver has a long history of medical use. The following are some of the most common modern uses in medicine and health.

- Topical antimicrobial agent for burns- cream that contains 1% silver sulfadiazine (Silver 2003).
- Bandages for trauma and diabetic wounds. Some studies indicate faster healing with Ag but this is disputed (Silver 2003). The estimated use of silver for this purpose is around 0.5 million ounces (GFMS 2011)
- Silver coated catheters and medical devices- To include heart valves to prevent biofilm growth as well as in thread used to stitch tissue. Even 1.5% silver nitrate was administered in the eyes of newborns in some medical jurisdictions according to law (Silver 2003).
- Dental amalgams (silver fillings) contain 35% Ag (0) and 50% Hg(0) but no evidence exists that this Ag is oxidized to become Ag(l) to allow for antimicrobial activity.
- Homeopathy and colloidal silver as supplement.
- Silver ointment creams: Lotions are sold for use on humans and animals in Sweden (Svenskhalsokost.se 2011)

Another source, dental amalgams (silver fillings), contain 35% Ag (0) and 50% Hg(0) but no evidence exists that this Ag is oxidized to become Ag(l) to allow for antimicrobial activity. Whereas silver in this instance has been disregarded as a risk, Hg (II), which is derived when a common bacterial enzyme oxidizes Hg(0), has shown tendencies to be biocidal. Thus, studies have been performed on Hg in urban water and has been estimated that Hg from dental offices accounts for 60% of mercury in municipal waste waters. It is considered reasonable to believe that a similar proportions of Ag are released during the same dental procedures. It is also considered reasonable to think that Ag(0) is oxidized in a similar fashion resulting in biocidal Ag(l). However, author Silver concludes that this release of silver from dental settings should not be a concern in regards to impacts to aquatic environments. Regardless, it has been estimated that 4 tonnes of Ag and Hg from amalgams is released into the New York Harbor yearly (Silver 2003).

Appendix E: Silver source modeling

Table 2 – Silver (I) mass flows in tonnes per year for the three emission scenarios

Parameter	Explanation	Minimum	Intermediate	Maximum
$Ag_{WW,\ biocidal}$	Silver released into wastewater from biocidal products	0.5	50	60
$Ag_{WW,\ other}$	Silver in wastewater originating from sources other than biocidal products	190	270	350
Ag_{WW}	Silver in wastewater	190	320	410
$Ag_{WW,\ untreated}$	Silver in untreated wastewater	20	50	80
$Ag_{WW,\ STP}$	Silver entering STPs	170	270	330
$Ag_{STP\ effluent}$	Silver in STP effluents	1	15	50
$Ag_{water,\ input}$	Silver reaching natural waters	20	65	130
Ag_{SS}	Silver in sewage sludge	170	255	280
$Ag_{SS,\ agriculture}$	Silver in sewage sludge used in agriculture	80	140	190
$Ag_{SS,\ TWT}$	Silver in sewage sludge undergoing TWT	50	60	60
$Ag_{SS,\ SWL}$	Silver in sewage sludge deposited on solid waste landfills	40	50	40
$Ag_{waste,\ other}$	Silver in solid waste originating from sources other than biocidal products	700	1200	1700
Ag_{SWL} [a]	Silver deposited in solid waste landfills	800	1250	1800
Ag_{TWT} [b]	Silver directed into TWT plants	800	1260	1700
Ag_{slag} [b]	Silver ending up in slag	600	1000	1300
$Ag_{fly\ ashes}$ [b]	Silver directed into fly ashes	160	270	370
Ag_{air} [b]	Silver emitted to atmosphere	8	13	17

[a] Amount based on the assumption that 100% of solid waste is deposited in solid waste landfills.
[b] Amount based on the assumption that 100% of solid waste is incinerated.

(Blaser et al. 2008)

		WF "article"	WF "weight"	product of WFs	scaled (%)	rounded (%)	amount per category (RE- scenario) (*t*)	amount per category (HE- scenario) (*t*)
nano-Ag	textiles	0.17	0.018	0.0030	11	10	0.37	0.91
	cosmetics/ supplements	0.16	0.044	0.0069	24	25	0.84	2.06
	sprays/ cleaning agent	0.11	0.044	0.0049	17	15	0.60	1.47
	metal products	0.17	0.0044	0.0008	3	5	0.09	0.23
	plastics	0.38	0.0088	0.0033	12	10	0.41	1.00
	paint/ sealings	0.01	0.88	0.0098	34	35	1.20	2.94

(Nowack et.al. 2008)

Appendix F:

Silver in cosmetics has also received special attention listed in the table below.

Government, industry, academic studies and classifications

government/industry list/academic study	appears on list as	classification(s)
Canada - Prohibited and Restricted Cosmetics Ingredients	SILVER	•Use is restricted in Canadian cosmetics
CHE Toxicant and Disease Database	SILVER	•Limited evidence in humans: renal system toxicity; Condition: chronic renal disease; Organs/tissues affected: kidney
EPA Clean Water Act - Priority Pollutants	SILVER	•Priority water pollutant under the Clean Water Act
Environment Canada Domestic Substance List	SULFURIC ACID, DISILVER(1++) SALT	•This chemical was flagged for further attention by CEPA due to suspected aquatic toxicity and persistence.
EPA Integrated Risk Information System (IRIS)	SILVER	•Group D: Not classifiable as to human carcinogenicity (EPA classification)
Canada PBTs - Accelerated Reduction/Elimination of Toxics (ARET)	SILVER COMPOUNDS	•Persistent toxicant under Canada's Accelerated Reduction/Elimination of Toxics program - targeted for elimination or reduction
EPA Toxic Release Inventory PBTs	SILVER COMPOUNDS	•Toxic, U.S. Environmental Protection Agency Toxics Release Inventory programs

(Cosmeticsdatabase.com 2011)

Appendix G: Workshop summary email

Thank you for your participation in yesterday's workshop!

It was beneficial to my work - I hope you all benefited as well. A few successes that I noted:

1) **Knowledge related to consumer behavior:** Achieved increased understanding for consumer behavior related to biocide-related functions.
2) **Gryabb strategy update:** An insight to Gryabb's upstream work related to sludge and heavy metals (not just silver).
3) **Data sharing for risk analysis**: An agreement to share data between Polygiene and Rickard (Chalmers) contributing to risk analysis.

A few discussion points:

1) **All silver applications are not the same:** There is a big difference in risk when looking at varying silver biocides and application processes. Whether the function itself is needed or not is another discussion.
2) **Work must continue to identify silver sources and their magnitudes.** Do current sources include amalgam? biocides? wastewater pipes?
3) **Silver in niche markets:** Silver appears in many niche markets, not just in the textile market.
4) **Two potential but opposite effects:** Biocide treated clothing could potentially have two effects on consumer behavior.
   a) Positive: Teach wash-only-when-needed behavior
   b) Negative: Condition consumers to be even more sensitive to smells and potential bacteria presence
5) **Two market extremes noted:**
   a) A small biocide-treated textile market with little resulting silver release but little washing benefits (from system perspective).
   b) A large biocide-treated textile market with larger resulting silver release and potential washing benefits.
6) **Sludge and contaminant limits:** Naturvårdverkets limits are pragmatic limits established with consideration to probable attainability but to encourage progress. Limits will be continually reduced to meet this aim.
7) **Sweden and silver:** The 60% goal and REVAQ certification creates a more sensitive situation than observed in many other countries.

Thanks again for your contributions.

Derek