ObservatoryNANO

Economical Assessment / Textile Sector

Final report

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Executive Summary

Despite being considered a traditional sector, the textile industry has been one of the pioneers in commercializing products incorporating nanotechnology.

During the last decade the European textile industry has been continuously searching for new products and enhanced functionalities, aiming to implement new technologies, capable of customizing textiles, thus offering costumers high added-value products.

One of the technologies, which has got more media attention in the last years, has been nanotechnology.

This growing interest of the textile industry in nanotechnology has lead to the development of several new applications/products for textiles. However, only few of these applications have already reached the market. This low penetration (less than 1%), differs significantly from previous released forecast, which predicted an exponential growth of nanotechnology's during this decade.

However and despite the current situation, there is still the perception that in the coming years an increasing number of textiles products using nanotechnology will reach the market.

Nevertheless, this opinion is not shared by all stakeholders involved in the textile commercialization process, several voices inside the textile industry consider that nanotechnology added-value does not yet compensate the high costs associated to the use of nano-enabling finishing treatments compared to the traditional ones.

Even for the technical textiles sector, where performance is prioritized over cost, issues such as possibility of obtaining long lasting effects, reproducibility and environmental and health hazards are limiting the implementation of nanotechnology.

If we add to these facts the present economic situation it can be expected that nanotechnology growth will be significantly smaller than previously foreseen.

It seems clear that in order to achieve the expected impact of nanotechnology future R&D efforts should focus on achieving long-lasting effects, reproducibility etc. as well as textile specialties (structure, composition etc).

In this report the different challenges nanotechnology has to overcome in order to become one of the leading textile technologies are discussed. Issues such as up-scaling of production processes, high production cost associated, achievement of long lasting effects, etc, which are currently limiting the further implementation of nanotechnology in the market are analysed.

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1.1 Definitions and Methodology

1.1.1 What's nanotechnology?

ObservatoryNANO defines nanotechnology as:

1. Products with a functional component with controlled geometry size below 100 nanometres in at least one dimension, and innovative characteristics caused by this critical dimension.

2. Equipment for analytical or manipulatory purposes that allows controlled fabrication, movement or measurement resolution with a precision below 100 nanometres.

Obviously, only in few cases such a product consists of nanoscale building blocks alone, without any macroscopic element. Since the value of the nanotechnology contribution to such a product is difficult to estimate, the market price value of the end product will be considered.

Therefore, the smallest unit that can be commercially sold in the marketplace is defined as a "nanotechnology product". Consequently, the market figures in this study are based on the market price of the smallest commercially available units with functional nanotechnology components.

1.1.2 Methodology for preparing the report

The market figures for the nanotechnology world market, as covered in this report, were predicted on the basis of available market data from press releases, company reports and Internet websites including so far unpublished market research studies. Market estimations of the authors are clearly marked in the text. However, it should be taken into account that the reported market figures are only estimates.

Companies were identified via various databases, conferences and Internet researches.

For an analysis of the present status, future visions and economic perspectives of nanotechnology, expert interviews either personally or via on-line questionnaires were carried out.

The answers to the future predictions and future products are at least regarded as a good indicator of future developments from the present point of view. The results were crosschecked with experts.

Furthermore, the interviews and questionnaires included some open questions concerning the most important products and main innovation barriers. Naturally, the answers to this type of questions resulted in dispersed opinions that clearly reflect the difficulties to predict future developments.

1.2 General market description

The world textile & clothing trade (According to the world trade organization) reached in 2006 the US$ 530 billion.

The importance of the textile sector as part of the European manufacturing industry is reflected by its turnover in 2007, which was over €210 billion. According to the European Commission, this volume was produced by roughly 145,000 enterprises employing more than 2,5 million people. This means that small and medium sized companies represent the larger part of the sector. According to Eurostat, more than 80% of the companies have 1-9 employees. To give an indication, the textiles sector created 3.5% of the total added value of the EU 27 manufacturing sector in 2004.

The following table presents some of the most relevant figures from the European textile sector in 2007.

Table 1 - Highlights EU 27 Textile/clothing Industry 2007 *Source: Euratex*

	2006 revised	2007 interim	Yearly Change
Turnover - 1000 million € *(interim)*	209,1	211,3	1,0%
Employment - 1000 pers. interim	2.644.268	2.474.932	-6,4%
Added value - 1000 Million € - estimate	63,2	63,7	0,8%
Companies - Interim	154.323	145.428	-5,8%
Investment - estimate	5,51	5,56	0,9%
Exports - 1000 million € (1)	35,2	36,5	3,7%
Imports - 1000 million € (1)	76,9	80,2	4,3%
Balance of trade 1000 million € (1)	-41,7	-43,7	4,8%
Investment / turnover - interim	2,6%	2,6	
Added value / Turnover - interim	30,2%	30,2%	

Over the last century, the European textile industry has played a leading role in the world textile market, representing the world's second largest exporter of textile products after China. In 2007 the EU exported €33.7billion worth of textiles and continued to dominate global markets for upmarket and high quality textiles and clothing.

However, over the past decades this leading role has changed rapidly in other textile segments, due to the increasing competence of Asian and North African countries, which are capable of producing textiles at lower cost.

The difficulty to compete in cost force a large number of textile companies to close (mainly SMEs). Others in order to be competitive decided to move their production facilities to low wage countries. These actions resulted on a progressive loss of jobs from the European textile industry.

To be able to compete in the global market, the European textile and clothing industry has focussed their efforts on the first steps of commercialization (e.g. design and branding) but also on the optimization of their supply chain management, aiming to provide costumers with high added value products in a very short notice.

In this case, where competitiveness depends considerably on the capability to develop innovative products and processes (incl. commercialisation processes), the textile industry is investing in research and implementation of new technologies, which previously were not considered. According to experts, the key areas for increased textile competitiveness in the future are related to Information Technology, Biotechnology and Nanotechnology.

1.2.1 Chemical industry & textile

To complete the general market overview it is necessary to briefly analyse the European chemical industry, which is closely linked with nanotechnology and with the textile industry i.e producer of coatings and fibers.

In 2006, the EU chemical sales reached, according to CEFIC, €476 billion, of which €30 billion were consumed by the textile industry. This means that 6,3% of the total chemical sales in Europe resulted in the production of man-made fibres, dyes and pigments for the textile sector.

The figure below shows a breakdown of the end user consumption of chemical products, demonstrating that the textile and clothing sector accounts for one of the most significant shares, larger than other industries such as construction, automotive, etc..

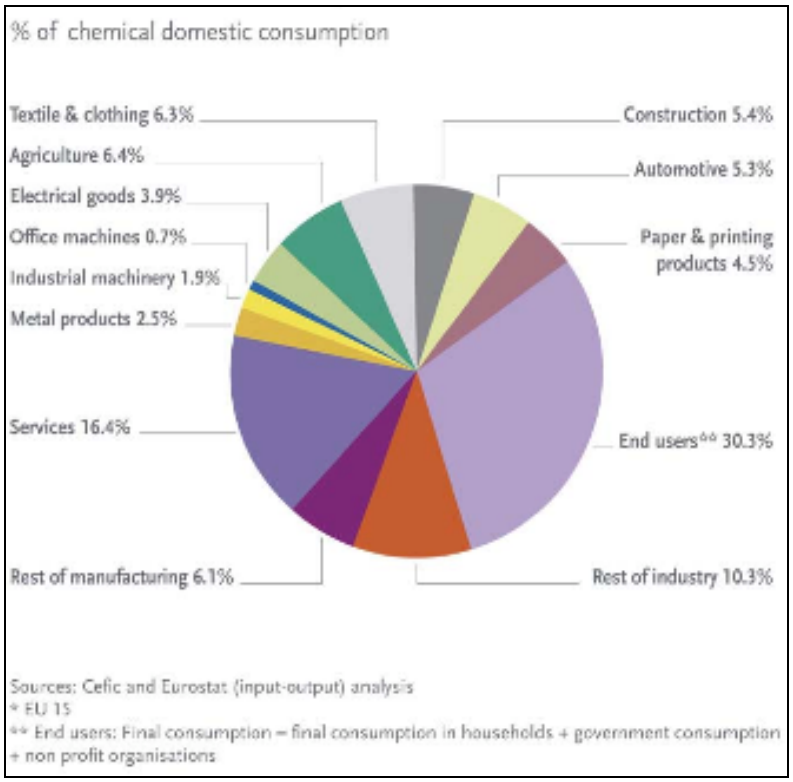

Figure 1 Chemical industry consumption structure *(source:CEFIC)*

1.2.2 Nanotechnology Impact

Once a general market overview has been presented, it is possible to move forward analysing the potential impact of nanotechnology on the textile sector.

The "European technology platform (ETP) for the future of textiles and clothing" presented in their strategic research agenda some of the most demanded functionalities of textiles and their present or future areas of application.

Table 2: Textile functionalities and areas of application, *source: European Technology Platform for the future of the textiles and clothing / EURATEX*

Functionality	*Application*
Stain or water repellence	*Table cloth, curtains, furniture, cars, bus, airplanes seats*
Flame retardant	*All possible textile interiors of buildings and transportation systems*
Abrasion resistance	*Carpets, all types of seats covers*
Anti-static behaviour	*Upholstery and seat covers*
Anti-bacterial behaviour	*Beddings, medical textiles*
UV-protection	*Roofs, tents, awnings, blinds, curtains*
Insect repellence	*Tents, nets*
Odour absorption	*Bedding, furniture, car, bus, train, airplane seats*

As an example of the relative importance of nanotechnology all functionalities previously mentioned can be obtained/improved using nanotechnology. Nanotechnology has the ability to provide textile products with new and enhanced properties. Over the past years nanotechnology has gained a significant reputation as one of the key technologies for the future of textiles.

Technical textiles, which comprise a wide variety of textiles from industrial filtration or car interiors to sport and outdoors clothing (i.e. Medtech, agrotech, builtech, protech, sporttech, etc), are characterized by the importance given to the material performance. This importance of the textile performance gives the opportunity for the use and development of nano-enhanced products, which in some cases might have a higher cost but are capable of providing unique functionalities.

Nanotechnology's potential has led chemical companies to dedicate a significant effort in the development of new treatments/products using nanotechnology. This enables the companies to provide costumers i.e. textile industries, finishers, etc, with new materials, which are capable of achieving previously unforeseen properties.

As a result some of nano-enhanced products are being successfully commercialized. However, and despite being a pioneer in the use of nanotechnology in consumer products, nanotechnology still represents a minor share of the total textile market, with less than 1% of all products incorporating nanotechnology.

Most of the commercially available nanotechnology-enhanced products belong to the sports and outdoor clothing sector as well as to the clothing and apparel sub-sector, this indicates that despite the potential of technical textiles for the use of nanotechnology, the existing current technical constrictions limit further implementation.

According to experts other causes for the low penetration of nanotechnology are the difficulty to obtain the functionalities required by consumers, high costs associated to product development/production and lack of knowledge of nanotechnology opportunities/benefits (Both consumers and textile industry).

1.2.3 Drivers and Barriers to Innovation

As previously presented, one of the main boundaries for further implementation of nanotechnology in the textile sector is related to the **technical limitation of the technology**, which is still not capable to meet some of the market requirements and standards (e.g. long lasting effects, wear resistance, washability, etc). This situation is even more critical for certain technical textiles (e.g. medical textiles), which have very strict standards regarding performance and HSE issues. Another example would be plasma-based treatments that due to **textile materials complexity** makes that developments arising from other sectors cannot be transferred one-to-one (e.g issues with cleanliness of substrate, large surface area,..).

Another limitation for a wider use of nanotechnology is related to the **cost of nanotechnology-enabled products**. Nanotechnology production costs are higher than traditional ones. These high costs are not only related to the investment on (expensive) equipment, but also to the hiring of expertise, (nanotech experienced resources, capable to operate the equipment), use of more expensive raw materials, etc. For certain sub-sectors (e.g. clothing & apparel), which are mainly cost driven, this increase in the final product cost and the required investment make the use of nanotechnology unfeasible at this moment.

The **lack of knowledge** of the potential of nanotechnology represents a key barrier for the implementation of nanotechnology. The later prevents companies and consumers to consider nanotechnology as a feasible alternative to solve existing problems. This lack of knowledge is also extensive to HSE hazards and environmental issues; this generates insecurity amongst users, which are afraid of possible future side effects.

Other concerns from the textile industry include **low compatibility of new production processes with current production processes** and the **insufficient production capacity** of the new production methods.

In addition to technical barriers there are some other **specific characteristics from the textile industry**, which condition the further penetration of nanotechnology. These barriers are:

- The textile industry is (in general) very **conservative and reluctant to change**. They are sceptic about the adoption of new technologies. In general textile companies consider that there is a large gap between R&D at Universities and industrial applicability of technologies/process under development.

- The textile industry is mainly **dominated by SMEs**. This fragmentation complicates the implementation of new developments, as most companies are not well informed about what is being done in research centres. In addition they have limited resources to invest in new developments.

In this framework, only few industrial players are willing to take the risk and invest in the manufacturing of new textile products, which making use of nanotechnology.

Actions taken by chemical companies to progressively introduce nanotechnology in market products include the production of chemicals (incorporating nanotechnology), which can be used in traditional production processes, as well as the use commercialization strategies based on higher involvement of consumers in the product definition phase to ensure existing demand of nano-enhanced products.

Benefits foreseen from the use of nanotechnology include, the capability to produce new products with unique/enhanced properties, which are not achievable with other technologies, properties that will last for the whole duration of the textile and do not change product characteristics (breath ability, softness, texture, etc).

In addition, the use of nanotechnology results in a reduction in material consumption. Less material is required to achieve desired characteristics in fibers and less coating is required to achieve the expected results. In the specific case of self-cleaning materials products also result in a decrease in the "maintenance" cost, since less washing is required.

In order to overcome the possible scepticism from companies and end users about the use of nanotechnology and also as a tool to provide consumers with more information, some international organizations (ISO TC 229) as well as research centres (e.g. Hohenstein Institute) are defining standards, which allow companies and end-users to be aware about products and their properties/specifications.

Hohenstein Quality label for Nanotechnology

The Hohenstein Institutes, in conjunction with NanoMat, a network of various research institutes and leading suppliers of nanomaterials, have found a definition for nanotechnology, which can be applied to the textile sector: Nanotechnology refers to systematically arranged functional structures, which consist of particles with size-dependent properties

In accordance, the ***Hohenstein Institute*** has implemented the Nano-Quality label for textiles, which evaluates: soil repellence due to the nano effect, skin compatibility, abrasion resistance and "washability" of the final product.

1.3 Economic assessment

In previous years several world market forecast for nanotechnology in the textile industry were released. According to publicly available information, the market for textiles using nanotechnology (world wide) was estimated in 2007 around US $13 billion and by 2012 this market is expected to reach US $115 Billion (Cientifica - Nanotechnologies in the Textiles Market 2006).

Other sources (NanoPost - Nanotechnology and Textiles: Market and Applications to 2015) quantify the global market for nanotechnology in the Textiles industry in 2007 around US $480 million and forecasts predict that nano-based products and processes will be worth US$4.9 billion by 2015. Meaning that 24.6 per cent of all textiles products would incorporate some form of nanotechnology.

In order to get a clearer overview of the situation of nanotechnology in the textile industry, it is important to consider where nanotechnology is applied along the textile value chain.

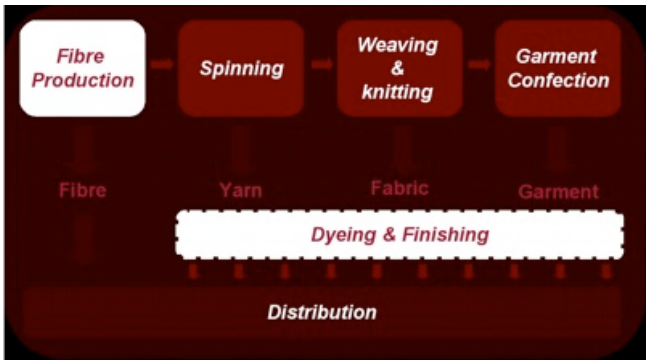

Figure 2 Simplified textile value chain

Basically, nanotechnology can be implemented during two steps within the textile value chain: either at the fibre production or at the finishing step (addition of coating or additives to the textile yarns). In both cases the chemical industry plays a key role, either producing basic compounds for extrusion of the fibres or producing/supplying the additives for the coating process.

According to *BCC Research,* world nanofibres sales in 2006 were lower than $45 million. On the other hand, and according to the survey carried during the project, the use of nanoparticles during the fiber production process is still very limited. Experts estimate that less than 0,1% of textile fibers contain nanoparticles. These figures give a clear indication of the limited market penetration of nanotechnology in the textile fiber industry.

In the case of nano-enabled coatings the market penetration of nanotechnology is larger than the one of fibers. Certain applications such as self-cleaning and antibacterial are slowly wining market share. However, according to experts these nano-enabled coatings still represent less than 1% of the total textile coating market.

These two values give a clear indication of the limited market penetration of nanotechnology in the textile chemical industry. Textile industries consider nanotechnology a technology, which is still in a development phase, not ready for implementation yet.

Chemical companies are dedicating a great effort to overcome this perception, through both the development of new nano-enabled products and the use of interactive commercialisation strategies.

Some chemical industries dedicate up to 5% of their R&D budget to the development of new nano-enhanced products (R&D budget dedicated to development of nanotechnology applications oscillates between 0,5 - 5% depending on the size of the company and degree of specialization).

In most cases, companies prioritize process optimization and search of competitive raw materials, over investments in breakthrough developments. Being a pioneer could represent a competitive advantage in the long run, but it could also result in a major failure. For this reason chemical companies are focussing their efforts in the development of chemicals, which can be used in the existing production processes, thus minimizing the required investment.

Based on experts feed back, the current impact of nanotechnology in the textile sector could be assumed to be less than 1%, which is roughly in line with some of the previous estimations.

Currently there are several products on the market, claiming to incorporate nanotechnology. Moreover, for some specific properties nanotechnology is considered to be the best alternative method currently available.

However when analysing present figures one must be aware that since the term “nano” is not a protected term, some companies may use it just as a marketing tool (e.g. Some recent studies have confirmed that in some cases self claimed “nano” textile products did not contained nanotechnology at all).

More than 90% of existing nano-enabled products are produced by coating technology, in most cases the coating process is the same, and nanotechnology is introduced in the additives.

When analysing future forecast, experts consider that it is quite unlikely that market penetration of nanotechnology (products incorporating nanotechnology) by 2015 will be higher than 10%.

On top of the previous mentioned technical limitations and market barriers, the current economic situation makes it unlikely that forecasts previously released will become true.

In the specific case of the textile industry, nanotechnology has just “reached” the market, and at this stage it seems too optimistic to assume that nanotechnology will grow exponentially in the next 5 years, so to reach the foreseen market quotas.

According to experts, it can be estimated that a moderate growth (one digit growth rates - 5-9%) of nanotechnology use in conservative sub-sectors (clothing & apparel and home interiors) will take place over the coming (five) years. This growth will be the result of both the development of functionalities enhancing products performance, as well as the use of innovative commercialization strategies, informing people about the benefits of nanotechnology.

The growth rates of technical textiles over the coming years are expected to increase between 10-15%. This assumption is based on the growing interest of textile industries in certain technical applications, which is only achievable trough the use of nanotechnology. In some cases companies prioritize the performance over cost (e.g. reinforced textiles, encapsulates for technical applications, fire retardant textiles, nanofiltration, etc).

1.4 Relevant sector segmentation and applications

Despite intensive investment in nanotechnology and the various techniques available to implement nanotechnology in textile products, there are still few products on the market incorporating nanotechnology.

Most of the nanotechnology-enabled products identified belong to the clothing and apparel sector. These results are somewhat surprising, since the largest market for nanotechnology according to experts is the technical textile sub-sector.

Experts explain this situation due to high requirements of technical textiles, which require of proven technologies with reliable performance, most nano-enabled functionalities are not yet up to these "standards", making not possible their use in technical applications.

If we consider the step within the value chain where nanotechnology is implemented, it can be seen that most of these nano-enhanced products (>95%), incorporate nanotechnology during the finishing processes/treatments (i.e. coatings containing nanoparticles, plasma treatment of finishing goods).

Experts pointed out that despite of the advantages of incorporating nanotechnology into the fibers (e.g. long lasting effects less tendency to wear-off or wash-out compared with coatings), technical issues, such as the difficulty to achieve homogeneous dispersions of nanoparticles make it unfeasible to produce fibres containing nanotechnology.

On the other hand, the use of nanofibres (produced by electrospinning) is still limited to filtration purposes. Companies are currently searching for new application methods for these nanofibres (e.g. nano-coatings).

Amongst the nano-enhanced products identified more than 80% contain either the self-cleaning or antibacterial property.

Nanotechnology is already considered as the "best" technology to achieve these two properties being the term "nano" a proof of quality. This is leading in some cases to the promotion of some "nano-enhanced" products, which in reality do not contain nanotechnology at all.

Other products claiming to contain nanotechnology provide properties such as: UV-protection, flame retardant or anti static. However these properties are still in their early stages of industrial implementation.

Below you can find the most relevant nano-enhanced textile properties (commercially available) identified during the survey:

- Self-cleaning textiles - Two types of self-cleaning surfaces involving nanotechnology are considered in this report. Following the approach from industrial companies, which group self-cleaning products into extremely water repellent surfaces (which are already available in the market) and self-cleaning materials using photo catalytic particles/layers (Still under development).

- Antibacterial/anti-odour textiles - In sport clothes, underwear or medical textiles a key issue to be solved is the presence of bacteria and the bad odour (which in most cases is associated to bacteria presence). In order to provide textiles with antibacterial properties, different metallic ions (silver) and metallic compounds (e.g.TiO_2, ZnO) are being tested. Antibacterial products include: socks, shirts, as well as sponges and bed sheets. These are some of the most common nanotechnology-enabled products currently available on the market. Possible future fields of application for this nano-enhanced property, include the medicine sector (e.g. surgery material) and transport sector(e.g. airplane/car interiors), etc.

- Moisture management - The moisture absorption property is closely related to the bacteria generation. However, the main driver of the development of such a property is the improvement of quality and comfort from sports products and work wear. This functionality is achievable without the use of nanotechnology, though the use of nanocoatings allows fabrics to improve their moisture management properties.

- UV- Protection textiles- Nowadays the UV-blocking property is one of the main concerns for textile industries producing outdoor material (from outdoor clothes to sunshades and tents). Currently there are already several products available on the market offering this property. Amongst other technologies, nanotechnology can provide UV-protection through the addition of a coating, which absorbs ultraviolet radiation and blocks its transmission to the skin.

- Nano Filtration. Nanofibers are being used in air filtration in order to improve the efficiency of filters, reducing energy consumption and increasing the air quality of the air treated.

Nanotech enabled properties/functionalities with more future potential (according to experts) are:

- Flame retardant textiles
- Reinforced textiles
- Conductive textiles
- Nano-encapsulates for medical applications
- Textiles with optical effects
- Conductive antistatic textiles

1.5 Textile nanotechnology application: Self cleaning textiles

This application together with the antibacterial property is the most widely commercialised textile application using nanotechnology.

1.5.1 Short application description

Water and soil repellence has been one of the major targets for fibre and textile scientists and manufacturers in the past few years.

The self-cleaning application results in a series of benefits, such as:

- Ease of maintenance -> environmentally friendly (Reduction costs associated to cleaning (laundry, water and energy at home)
- Increase of textiles life (Less washes are required, resulting in a longer product life)

There are basically two types of self-cleaning surfaces involving nanotechnology. The first type are extremely water repellent, microscopically rough surfaces, where dirt particles cannot get attaches to the fabric and can therefore be removed by rain or by a simple rinse of water (1.5.1.1). The second type is consists of photo catalytic degradation of organic dirt and stains (1.5.1.2).

1.5.1.1 Hydrophobic and oleophobic surfaces

Different techniques have been used to achieve the desired super hydrophobicity. One of the most common approaches used to achieve the super hydrophobicity of textile fabrics consists on the use of the Lotus effect.

This effect is based on the Lotus plant, which has super hydrophobic properties, capable of keeping the surface of the leave dry even during a heavy shower. Furthermore, the droplets pick up small particles of dirt as they roll over the leave, keeping the leaves of the lotus plant keep clean even during light rain.

Available technologies to achieve super-hydrophobic textiles include:

- Coating technology - Nanoparticles are added to the textiles during the finishing bath/process. This technology is the most widely used at the moment (E.g. Nanosphere-Schoeller, Nanotex, mincorTX - BASF)
- Plasma treatment - Water repellence is achieved through a surface treatment using plasma. Despite few products on the market making use of this technology it is still under development.

1.5.1.2 Photo catalytic self-cleaning

Another possibility to remove dirt of textiles is through the use of photo catalytic layers, where organic materials are destroyed by solar irradiation.

Catalytic self-cleaning effect can be achieved through the use of a TiO2 layer, which is able to decompose organic matter when expose to sunlight. Furthermore, in this circumstance, titanium dioxide exhibits hydrophilic properties, which facilitates washing away the decomposed dirt.

This technology is not yet available on the market (see boundary conditions section below).

1.5.2 Functional requirements

Despite products incorporating the self-cleaning effect include technical textiles, home textiles as well as clothing and apparel. They do have some common requirements, which include that the properties of the textile products remain unaffected (hand feel, softness, etc.) and that the effects are long-lasting and do not get affected by the washing of the product.

1.5.3 Boundary conditions

At present, most of the products available on the market, which are considered to be self-cleaning textiles, make use of the lotus effect technology. The technology is applied using a new chemicals/coatings, which can be applied with traditional finishing processes/machinery. The later has facilitated its adoption by industry.

Several chemical companies are already producing and commercializing coatings incorporating nanoparticles, which provide textiles with the desired self-cleaning effect (super-hydrofobicity).

The main limitations for the use of these coatings are: difficulty to achieve the desired particle dispersion (possible issues with agglomerations); degree of attachment of particles and coatings to the textile. The strength of the coating-textile bond determines the "lifetime" of the property, which is one of the most important concerns of the consumers and industry.

Another key limitation to its further implementation is the textile industry's scepticism about the added value of having a self-cleaning textile (ratio between investment vs revenues).

Plasma treatment presents some technical and economic boundaries, such as the high production costs associated to the purchase of new equipment and the scale-up of the process.

As well as for traditional coating one of the main limitations is related to the number of washing cycles the product can under go before the property disappears. Long term washing stability has been proven but the process strongly depends on the specific surface conditions of the textile being treated.

In the specific case of self-cleaning textiles making use of Photo-catalytic effect, the impossibility to achieve the desired results with low exposure times reduces the range of products in which this technology can be applied (need of exposure to UV light). Another limitation for its implementation is related to the degradation of the textile itself.

1.5.4 Product examples

Super Hydrophobicity

Nanosphere - (Clariant - Schoeller) Textiles surface treatment, which provides textiles with the self-cleaning effect (lotus effect) that repeals liquids and dirt. It has been tested for harmful effects to humans and the environment and it has been awarded with the *Hohenstein Quality label for nanotechnology*.

Schoeller Technologies AG owns the patents and is responsible for NanoSphere marketing and branding activities.

Mincor TX TT - (BASF) Chemical surface treatment based on the use of nanoparticles forming little papillae, keeping water drops and dirt at bay. The treatment reduces the contact between dirt particles and the garment surface, thus making possible to wash away with a shower or by rain. Dirt-repellent textiles incorporating Mincor coating are mainly used in the manufacture of awnings, parasols, and tents

Nanotex resist spills -(Nanotex) Textile surface treatment, which provides textiles with water-repellency and spill resistance. Each fiber is transformed through nanotechnology. The treatment consists of the creation of nanowhiskers, which are made of hydrocarbons and have about 1/1000 of the size of a typical cotton fiber. They are added to the fabric to create a peach fuzz effect without lowering the strength of the textile.

AEROXIDE® LE - (EVONIK) can generate self-cleaning nano-structured hydrophobic surfaces, with a contact angle in excess of 140°, which characterizes Lotus-Effect® surfaces.

X-clean EC 5000 are impregnation materials for synthetic fibres and leather based on transparent inorganic-organic composites with hydrophobic side chains in nano-meter dimension. A transparent film around the fibre leads to a better durability against discoloring substances.

Plasma treatment

Ion-mask - Vacuum Plasma treatment developed by P2i, which provides technical textiles (e.g. sports shoes) with extreme water repellency.

1.5.5 Profiles of selected key companies

NANO-TEX (US) - http://www.nano-tex.com/

Textile Technology Company, which provides nanotechnology-based textile enhancements to the apparel and commercial interiors markets. The company's products include resists spills, repel and releases stain, coolest comfort, and resist static. Its products are used in apparel, home furnishings, commercial interiors, and industrial fabrics items.

BASF (DE) - http://www.basf.com/

BASF is the world's largest chemical company. It is divided in six business segments: plastics, performance products, chemicals oil and gas exploration and production, functional solutions and agricultural products. The BASF Group comprises more than 160 subsidiaries and joint ventures and operates in more than 150 production locations in Europe, Asia, Australia, Americas and Africa

SCHOELLER (CH) - www.schoeller-textiles.com/

Schoeller is a company specialized in the development and production of special fabrics and textile technologies for sports, fashion, leisure, occupational safety, industrial and interior design. Their headquartersare located in in Sevelen, Switzerland.

CLARIANT (CH) - www.clariant.com

Clariant is a global leader in the field of specialty chemicals. and is represented in five continents with over 100 group companies, and employs around 20,000 people. Headquartered in Muttenz, Switzerland. Clariant's businesses are organized in four Divisions: Textile, Leather & Paper Chemicals, Pigments & Additives, Masterbatches and Functional Chemicals.

EVONIK *former DEGUSSA* (DE) - www.degussa.com

The Chemicals Business Area of Evonik Industries (Former DEGUSSA) operates in attractive areas of specialty chemicals, a field in which it ranks among the top global players. Evonik has over 100 production sites in 28 countries around the world.

NANO-X GmbH (DE) - www.nano-x.de

NANO-X develops and produces customized materials in the field of chemical nanotechnology with multi-functional properties.

The services provided by the company range from innovation consultancy to target-oriented adjustment developments to production and support in the application of the desired coating solutions.

Plasma treatments

P2I (UK) - www.p2ilabs.com

International, high technology Company established in 2004 as part of the UK Ministry of Defense programme for commercializing government technologies.

1.6 Textile nanotechnology application: Anti-bacteria /anti-odour textiles

1.6.1 Short application description

One of the areas where nanotechnology is being applied more frequently in the textile industry is the development of clothing capable of removing bacteria and odours.

The most common technology used to provide textiles with this specific anti-bacterial property is the addition of metallic ions (displaying a certain degree of sterilising effect) to the textile fibres. Silver is the most widely used material for this purpose, other compounds such as titanium dioxide and zinc oxide have also proven anti-bacterial properties, and however they are not yet used in industrial applications.

Similarly to self-cleaning, most antibacterial products are produced through the addition of a coating layer during the textile finishing process. Most of these coating contain silver in their different forms (ions, nano silver particles, matrix) - according to the survey carried out by the International Centre for Technology Assessment (ICTA), there are already more than 260 nano-silver products on the market-

1.6.2 Functional requirements

Products containing anti-bacteria/anti-odour components should be able to maintain the texture and quality properties of the presently used textile products, while at the same time provide the desired anti-bacterial / odour properties.

Most of the antibacterial products available on the market are related to the clothing and apparel sub-sector (socks, t-shirts, under-wear). Despite the potential of this application in technical textiles (e.g. Medical textiles), its application is still limited, mainly due to the high functional requirements and to the need for standards proving the effectiveness of the application as well as the lack of health or environmental hazards.

1.6.3 Boundary conditions

Most European chemicals companies are not using nanosilver for the production of their anti-bacterial products but silver ions, which are considered environmentally friendly. However, there are still a large number of products incorporating nano-sized silver, causing concerns about potential toxicity and possible effects on the environment and health.

It must be noted that **Ag is also frequently used** as salts (ions), NPs or coatings **in wound bandages**, also in high concentrations. The beneficial effects are considered to be higher than possible toxic effects, however there is still not enough data on the possible effects of increase of silver concentration on wastewater and soil. Several studies are being carried in this regard such as the ones from ETH Zurich, EMPA, or the Hohenstein Instute

1.6.4 Product examples

In this section some examples of products incorporating antibacterial /anti-odour property is presented.

Argentano (Bekaert Textiles) - Argentano is an antimicrobial finish with silver ions (*Hohenstein Quality label for nanotechnology*). It is used to protect mattresses against bacterial infestation.

Eco-fabric (Green Yarn) Contains nano-particles of bamboo-charcoal in its fibers, providing the textile with antibacterial and anti-odour properties.

SmartSilver™ (NanoHorizons) is an EPA-registered antimicrobial performance brand for a line of nanoscale silver additives. Originally developed to keep medical devices germ-free, SmartSilver is now available in many different applications for apparel and footwear, homes, offices, health care facilities, and other products and places where superior antimicrobial performance is required

PuckSkin (Macker International Apparel Inc) - The Silver Ceramic Ion embedded yarns bacteriostatic, odour-controlling properties are permanently embedded into the yarn polymer.

AgActive antibacterial (Ag Active) - Use of "nano" particles of 99.99% pure silver, which are infused into fabric and materials.

1.6.5 Profiles of selected key companies

Some of the chemical companies presented in section 1.3.5 also produce chemical coatings incorporating antibacterial properties. In order not to duplicate these profiles, they have not been included in this section.

Bekaert Textiles (BE) - www.bekaerttextiles.com

Founded in 1892 by Ivo Bekaert and since 1992 a member of Gamma Holding, one of Europe's largest textile groups, Bekaert Textiles is a multi-national company with production units in 10 countries worldwide and headquarters in Belgium.

Greenyarn (US) - www.greenyarn.com

Nanotechnology Company developing advance-materials for consumer use. Their technology is based on the use of bamboo-carchoal nano-particles from bamboo.

NanoHorizons (US) http://www.nanohorizons.com/

NanoHorizons was founded in 2002 by a team of scientists from The Pennsylvania State University for the purpose of developing and commercializing nanomaterial-enabled products based upon an extensive intellectual property portfolio.

Healthy Channels (AUS) - http://www.healthychannels.com.au/

Healthy Channels Pty Ltd is a fully Australian owned business founded in 2003. They are suppliers of nano-silver antimicrobial products.

Goodweaver Textiles Co. Ltd. (TW) http://www.goodweaver.com/

Founded in 1987 by the Chen family, in 2005 developed Nano Silver fibres for clothes with anti-bacterial and deodorant functions.

1.7 Textile nanotechnology application: Moisture management

1.7.1 Short application description

One of the main problems for clothes (mainly in sports and outdoors) is the "management" of moisture and "breathability" of clothes.

Synthetic fibres are not able to absorb water (reduced wicking properties) and are therefore not capable of removing the perspiration. Natural fibres, which absorb large amounts of liquid, cause the garment to get wet easily but are not able to remove this excess of water afterwards. Consequently, both types of fibres result in uncomfortable clothes when sweating.

Nanotechnology allows the development of synthetic fibres with wicking and drying capabilities. These are fibres that are able to absorb excess liquid and quickly release it again into the atmosphere.

Using these fibres for the production of textile, makes the clothes absorb moisture (drawing perspiration away from the skin) as a natural fibre would do. Additionally, it removes the residual moisture rapidly like synthetic fibres, maintaining the comfort of the cloth.

1.7.2 Functional requirements

Products containing this property must maintain the feeling and properties from non-treated garments, similarly to other nanotechnology treatments, the property must remain unaffected when washing the product.

1.7.3 Boundary conditions

Main limitation to this kind of products is the increase of cost associated to their production. Their application is currently limited to some niche markets driven by performance (E.g. sport clothes).

1.7.4 Product examples

Nano-Tex Coolest Comfort it is a treatment from NANOTEX that provides textiles with moisture wicking.

TENCEL made from wood pulp cellulose, the nanofibrils, which compose the material, are hydrophilic and optimize absorption of moisture with excellent cooling properties.

Healtha+® is a multifunctional, lightweight, quick-dry fabric developed by Ventex. Nanotechnology has been used in the development of Healtha+® which consists of 90% polyester/10% spandex yarns

Plasma Mec® allows synthetic fabrics to improve "Hydrophilic" property, by modifying the surface. Moreover, through this process the fiber improves the ability to get wet and to spread out easily the liquids on a much wider surface without absorbing them. This way, the cloth dries much easier.

1.7.5 Profiles of selected key companies

NANOTEX - www.nano-tex.com

(See section 1.5.5)

Lenzing fibers (DE) http://www.lenzing.com

The Lenzing Group is a world leader in marketing and manufacturing man-made cellulose fibers. Lenzing employs more than 6000 people and their headquarters are located in Austria.

Ventex Co. Ltd. (KR) www.ventexkorea.com

Since the establishment in 1999, Ventex Co., Ltd. has been devoting itself to making breakthroughs in the textile industry. Ventex Co., Ltd. focuses on differentiated multi-functional fabrics by the state-of-the-art technologies, which leads to the continuous growth of the general textile industry as a whole and meets customers' needs.

Mectex (Italy) http://www.mectex.com

Italian manufacturers of gripper loom woven, waterproof and breathable plasma treated fabrics for electromagnetic shielding, specialty underwear, sports wear and lining applications, from cotton, viscose, polyester, steel, copper and carbon fiber and blends.

Grabher Günter Textilveredelungs GmbH (Austria)

Austrian textile manufacturer, which currently commercializes a permanent and washable hydrophilic plasma coating based on nanostructuring, to apply the coating they use the Nano-Plasma-Coater BAG (a semicontinuous reactor treating textiles up to 1000 and 1.8 meter in length and width), which offers a wide range of surface fictionalization, nanoscaled coatings etc. *Technology developed by EMPA (CH)*

1.8 Textile nanotechnology application: Filtration

1.8.1 Short application description

One of the few textile applications where nanofibers are already being applied is filtration.

This technical textile application represents a niche market driven by the need to find new technologies capable to deal with toxic compounds in indoor spaces. Most of the times these toxic compounds are complex mixtures of particles, smaller than 1 micrometer in diameter (E.g. volatile organic compounds (VOCs), microorganisms, allergens, and other pollutants).

The filter industry is constantly looking for new effective filter media. Amongst the medias currently being used in air filtration are nanofibers filters, which are produced through electrospinning.

1.8.2 Functional requirements

Filtration has very specific requirements such as, high efficiency in order to obtain cleaner air. Filters should be capable to achieve low-pressure drops (less energy consumption) and last but not least filters must have a long life reducing the maintenance costs.

1.8.3 Boundary conditions

Main boundary conditions are related to production costs. This is related to low production rate and high cost of technology.

In addition the process requires a high investment in order to recover and treat the vapours emitting from electrospinning solution.

Finally there is also a deep concern about possible health hazards resulting of possible nanofibers inhalation.

1.8.4 Profiles of selected key companies

The Czech Company Elmarco (www.elmarco.com) is the industry's first supplier of industrial scale nanofiber production equipment. Their machinery makes use of Nanospider™ technology.

There are already some companies making use of the nanofilters, some examples are the US based companies Donaldson and Clark Filter.

1.9 Textile nanotechnology application: UV-Protection textiles

1.9.1 Short application description

It is well known that an overexposure to UV from natural sunlight can cause sunburn and some forms of skin cancer. In this respect during the past years several products have been developed in order to protect the human body from this threat.

Nanotechnology has proven an effective technology in the development of UV blockers. Nano-particles have a larger surface area per unit mass and volume than conventional materials. This property results in an increase of effectiveness to block UV. In addition, the incorporation of these nanoparticles in textiles makes it possible to maintain the effect after several launderings.

Materials used to achieve the desire UV protection factor include TiO2 and ZnO.

1.9.2 Functional requirements

As for the rest of properties provided to cloth and garments, the additives providing the UV protection should be able to maintain the texture and quality properties of the textile products being used presently.

UV protecting coating should be applicable to all kind of fibres (natural & synthetic).

1.9.3 Boundary conditions

Main boundary condition is related to the lasting of the effect as well as the production costs.

1.9.4 Product examples

iSys SUN includes titanium dioxide nano particles which absorb radiation in UVA and UVB range. A binder system which is also included in iSys SUN fixes the particles on the fibre surface and thus provides an excellent durability.

Belfasun (COGNIS) Nanotechnology-based UV protection system for cotton fabrics. Belfasun uses nanoparticles of ZnO bonded to the fabric, which are capable of absorbing 100% of UVB and 70% UVA of radiation. Fabrics treated with Belfasun have an ultraviolet protection factor (UPF) up to 40, depending on the construction and weight of the fabric.

DRY-Zone (Ventex)- Dry-Zone® R506 is a lightweight, breathable 4-way stretch performance fabric developed by Ventex which delivers quick-dry moisture movement and evaporation through a unique 3-layer capillary action, keeping the athlete dry and comfortable. Dry-Zone® R506 also features fiber nanotechnology incorporating antibacterial silver dioxide for antibacterial freshness and titanium oxide for UPF 50+ UVA/UVB sun protection.

1.9.5 Profiles of selected key companies

CHT (DE) - www.cht-group.com

CHT has been very successfully engaged in the development, production and sale of additives for the textile processing industry since 1953. CHT possesses extensive expertise along the entire textile chain and provides additives for fibre production, pre-treatment, dyeing processes and textile printing and also for finishing and coating. In addition, they

develop intelligent system solutions and products for the new business areas of garment finishing and textile care.

Cognis (DE) - www.cognis.com

Cognis is a worldwide supplier of innovative specialty chemicals and nutritional ingredients, with a particular focus on the areas of wellness and sustainability. The company employs about 5,900 people, and it operates production sites and service centers in almost 30 countries.

Cognis active textiles is the business unit from the chemical company Cognis, which focus on developing active components for functional clothes.

Ventex (KR) - www.ventexkorea.com

(see section 1.7.5)

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ANNEX – Expert Engagement

This report is partially based on the interviews done with the following experts:

Dr. Jan Behringer, Hohenstein Institute Germany

Dr. Guy Boyle, CENTEXBEL Belgium

Dr. Ralf Dümpelmann, Clariant International Ltd. Switzerland

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