ObservatoryNANO

Report on Nanotechnology & Textiles

Medical Textiles, Sport/Outdoor Textiles

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1 EXECUTIVE SUMMARY

This report covers the specific areas of outdoors / sports textiles and medical textiles enhanced by nanotechnology. In the 2009 ObservatoryNano report on nanotechnology in textiles, a general overview of the complete area was given; this 2010 report focuses on these two specific application areas.

In the textile sector three main segments are distinguished: apparel (fashion), interior textiles and technical textiles. In Europe, the value distribution for the year 2008 was the following: apparel 37%, interior 33% and technical textiles 30%.

In general, during recent decades the technical textiles segment has seen the strongest growth; for example during the period 1995-2005 the value of this market has grown from €65 to €85 billion. In terms of tonnage (not value) Europe is not the largest market for advanced technical textiles; Asia consumes 8.5 million tonnes, about half of global technical textile production, whereas US and Europe consume 5.8 million and 4.8 million tonnes respectively. In Europe four countries consume about half of the technical textiles in terms of value: Germany, France, the UK and Italy. The technical textiles industry in Germany is 45% of the textile industry, compared to 30% in France, 30% in the UK and 12% in Italy.

Non conventional advanced technical textiles, are high added value products and represent, at the moment, a limited portion of technical textiles sector. However, they are expected to grow steadily in the forthcoming future, progressively gaining a larger share in terms of both volume and value, in a large variety of sectors including medical textiles and sports/outdoors textiles..

The sports/outdoors textiles business covers a quite stretched value chain all the way from fibre production (above all cotton but increasingly advanced polymer fibres) towards spinning of yarns, weaving and knitting of fabrics, subsequent design and production of finished garments and shoes, which are then transported to retailers who sell them to consumers. A relatively limited amount of advanced technology suppliers provide treatments (mainly coatings), some of them nano-enabled, which are applied either on the fibres, on the yarn or on the finished product. The value added in each step of the value chain increases from the early steps (fibres, yarns) towards the later steps (design, marketing, retailing). Major drivers in the sports/outdoor industries are the increased need to offer recognizable functional advantages for high priced brands, in order to maintain their positioning compared to second tier brands or retailer-specific low cost/mid price garments.

In the medical textiles business, value chains are similarly long but product development cycles tend to be longer and R&D efforts are more focussed on obtaining a pre-defined set of performance requirements. Branding and marketing aspects of nanotechnology are present, but less pronounced compared to the key role they play in the outdoor / sports segment, Several fundamental evolutions feed a growing demand for advanced medical textiles: the drive to allow for less frequent changes of bandages; to allow for recovery at home combined with periodical check-ups in ambulatory care regimes; and the increased drive for advanced disposable bandaging or bed linen systems that reduce the need for cleaning or sterilization of repeated use items.

Nanotechnology R&D in relation to these two areas has three main objectives:

- *Upgrading of present functions and performance of textile materials*
- *Introduction of innovative functionalities, not present before in textiles*
- *Development of smart/intelligent textiles, that is. textiles with new functions as a result of the integration of electronics into fabrics*

Researchers seek to introduce nano-enabled functionalities into these textiles following three main approaches:

- **Introduction of functional nano-materials into raw materials for fibre production**, which can combine the original features of the fibre with nano-material functionality.
- **Coating on the surface of fibre or textile** with functional nano-materials, to produce functional textiles with greater added value.
- **Spinning of polymers (electrospinning) for the production of nanometric fibres,** which can lead to non-woven fabrics with improved or new characteristics having multiple applications

Concretely the textile industry directed at sports/outdoors markets and medical markets are currently seeking the following functionalities: *Antibacterial* (containing a biocide, or photoactive*); Self-cleaning, Water/oleo repellence* (photoactive, or super-hydrophobic, or anti-adhesive); *Moisture absorption*; UV-*blocking*; *Tear/wear resistance*; *Thermal insulation*; *Conductivity (for antistatic purposes mostly)*; and Controlled release of active chemical agents such as drugs, cosmetics, fragrances. It should be noted that for each of these functionalities non-nano alternative technologies also exist, which will compete with new nano-enabled developments

The most common applications are currently infection prevention or deodorisation of medical clothing, wound dressing, and bedding. Most other applications have still to reach mass markets; for example *nanofibre* filters. In sports and outdoors textiles, the main application presently found in the market is that of nanosilver used to reduce unpleasant smells in sport garments. Hydrophobic treatments (such as the Ion Mask Technology marketed by P2i) are also gaining increasing interest from large global companies and can be expected to grow rapidly over the next couple of years.

The application of nanotechnology enabled sensing devices in the combination of electronics and textiles enables the manufacturing of "smart" clothing with active functions, such as sensing, actuating and communicating functionalities. At prototype level, garments with integrated heating elements, devices that can stimulate muscles, or which are able to control/monitor athletes' physiological parameters and their performance, have been produced.

In general, both the outdoors/sports and the medical textiles businesses are dominated by a limited number of large multinational companies that have the capability to bring innovations to large global markets. In the sports/outdoors segment, these companies (such as Adidas, Nike or VF Corporation) rely mostly on smaller, specialized companies that develop and supply technological innovations. In the medical industry big global players like Johnson & Johnson, Baxter, Beiersdorf or 3M have their own substantial R&D efforts; however, they are used to collaborating with small high tech companies in order to obtain unique selling points that they

can leverage in their global marketplaces. Thus, both sub-segments allow for small companies to gain access to global markets as long as they are willing to partner with one or more of these global players.

However, the industry still has a long way to go before nanotechnology enabled products become commonplace. Some major limitations still need to be addressed by research, including process scalability, durability of the nano-enabled functionality under repeated wash & wear, reduction of costs, increasing awareness of end users, and concern about possible negative health effects. This last point is rather important in gaining commercial success. The European textile industry will have to strengthen its efforts to formulate European standards to define an adequate regulatory framework to assure a sustainable production that conforms to the wishes and needs of the consumers in terms of effectiveness (for example in terms antimicrobial or UV protective properties) and safety (for example with respect to cytotoxicity or allergenic potentials).

2 INTRODUCTION

2.1 Definition

The following definitions are as reported in the proposed ISO/DTS or ISO/DTR 12802, and ISO/DTS 11751, or as generally reported in the literature.

- **Nanotechnology** - The application of scientific knowledge to control and utilize matter at the nanoscale, where size related properties and phenomena can emerge.
- **Nanoscale -** Size range to approximately 1 nm to 100 nm.
- **Nano-object or Nanostructure**- Material with one, two or three external dimensions in the nanoscale
- **Nanoparticle** - Nano-object with all three external dimensions in the nanoscale.
- **Nanofibre** - Nano-object with two external dimensions in the nanoscale and the third dimension significantly larger.
- **Nanotube** - Hollow nanofibre
- **Nanoporous -** Structure with pore sizes in the nanoscale.
- **Nanoclays -** Layered silicates, as for example montmorillonite, in the nanoscale
- **Nanocomposite -** A composite of different materials or chemical substances in which at least one component includes a nanoparticle or other nanostructure
- **Nano-textiles or Nanoengineered textiles -** Textiles or textile products in which nanotechnology is used during a production or finishing step.

2.2 Keywords

Abrasion resistant textiles; Antibacterial/Antimicrobial textiles; Antistatic textiles; Antiageing textiles Breathable textiles; Communicating textiles; Conductive textiles; Controlled release textiles; Electronic textiles; Flame retardant textiles; Healthcare textiles; Hybrid textiles; High performance textiles; Hydrophylic textiles; Hydrophobic textiles; Insulating textiles; Luminescent textiles; Medical textiles; Moisture absorbing textiles; Self-cleaning textiles;

Sensing textiles; Shape memory textiles; Smart textiles; Sport/Outdoor textiles; Tear/wear resistant textiles; UV-blocking textiles; Wound care dressing textiles.

2.3 Overview

In the frame of the ObservatoryNANO project, two reports dealing with a general overview of the applications, perspectives and market of the nanotechnology-related textiles were published in 2009 [1]. This new report is devoted to the analysis of two specific segments where such innovative technologies have a wider potential, namely, the medical/healthcare and sport/outdoor sectors.

Textiles products are usually classified according to their end market. Therefore we can talk of apparel (fashion), interior textiles, and technical textiles. In Europe, each of these segments account, roughly, for 1/3 of total market share (Apparel 37%, interior 33% and technical textiles 30%) [2]

The technical textiles segment has experienced the largest increase in consumption during last years with high performances and non conventional technical textiles gaining ever growing attention. According to the European Commission (EC): ”expenditure on research and development (R&D) is higher in this field than for 'conventional' textiles reaching an investment of up to 8-10% of the total turnover¨ [3]. The technical textile sector looks set to be the ideal framework for the introduction of new functionalities resulting from the use of innovative technologies such as nanotechnology.

Nanotechnology research in textiles is rather intense and has three main objectives:

1. **Upgrading of both present functions and performance of textile materials**, characterised by, for example, enhanced strength and tear/wear resistance, hydrophilic or hydrophobic, or insulating properties, and flame resistance.
2. **Introduction of innovative functionalities**, not yet present in textiles. Among these are, features like antibacterial, self-cleaning, UV-blocking, conductivity, controlled release for active agents, etc.
3. **Development of smart/intelligent textiles**, that is textiles with new functions through the integration of electronics into fabrics, which make them responsive to inputs, to show/modify specific properties, or with sensing and actuating capabilities.

The technological approaches for the production of nano-related textiles are based on the following three processes:

- **Introduction of functional nano-materials into raw fibre materials**, which can combine the original features of the fibre with nano-material functionality.
- **Coating the surface of fibres or textiles** with functional nano-materials, to produce functional textiles with greater added value.
- **Electrospinning of polymers for the production of nanometric fibres** leading to non-woven fabrics with improved or new characteristics with multiple applications.

Although the applications of nanotechnology in the textile sector were initially introduced through conventional garment and furnishing textiles, the applications for high performance technical textiles are garnering increasing attention. Experts consider these segments as the

main area of application for nanotechnologies on the short-medium term, especially in sectors where performance outweighs costs (for example medical, sport/outdoor, military or niche high-fashion textiles) [1, 4-7].

At the cutting edge of the above nanotechnologies are the applications to obtain smart nanotextiles. The development of smart nanotextiles has the potential to revolutionise the functionality of our clothing and the fabrics in our surroundings giving them unprecedented characteristics, such as sensing, actuating, and communicating features.

The two sectors covered by this report, that is Medical and sport/outdoor textiles, represent a clear example of technical textiles where nanotechnology can play a significant role in the near future. Both segments tend to prioritize performance over cost (though a cost /benefit trade off must always be found) and dedicate a considerable part of their R&D efforts in the research of new or improved functionalities. A clear example of the importance of the implementation and commercialisation of new functionalities in these sectors is the increasing use of nanotechnology-related antibacterial products.

Due to the overlapping needs of the two sectors (similar functionalities and properties required) the report focuses on product functionalities, dealing jointly with innovative textile features for both the medical and the sport/outdoor sectors, but indicating the specificities for each segment.

2.4 Methodology

The content of this report is the result of a desk analysis of information from publicly available documents. For an analysis of the present status, future visions, and economic perspectives of nanotechnology expert interviews, either personally or via on-line questionnaires, were also carried out; these 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 final conclusions were also crosschecked with a number of well-respected experts.

A pool of experts selected by their background and experience reviewed the final version of the report.

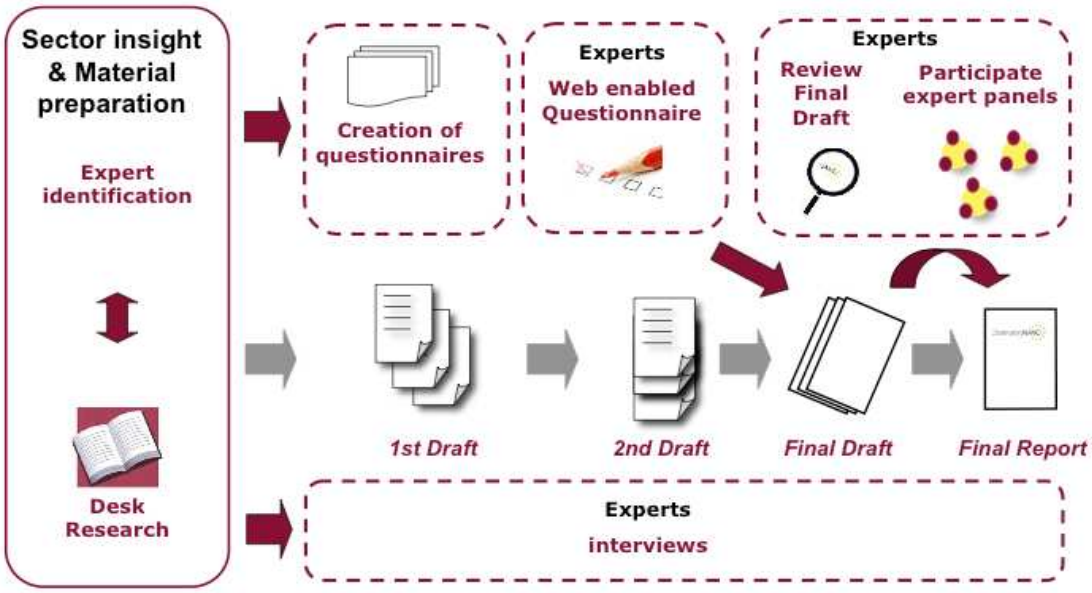

Figure 2-1 ObservatoryNANO methodology - report creation process

3 SCIENTIFIC AND TECHNOLOGICAL ASPECTS

3.1 State of R&D

3.1.1 Properties and applications of nanotechnology in the textiles sector

In last year reports [1] some of the most important functionalities required of textiles and their areas of application according to strategic research agenda of the "European technology platform (ETP) for the future of textiles and clothing" were presented, indicating how nanotechnology is helping to achieve these desired properties.
Table 1 lists some of the nanomaterials being utilised to improve the performance of textiles. These nanoparticles may be used to develop composite fibres, as nanoscale fillers, or through a foam-forming process and may also be applied as finishing to the textile, for example spray-coating TiO_2 for biological protective materials. A more detailed analysis of nanoparticles and nanotechnology applications in the textile sector can be found on [4-7].

Table 1 – List of nanomaterials used in the textile sector and resulting properties

Nanomaterials	Properties/Applications
Carbon nanofibres	Increased tensile strength High chemical resistance Electrical conductivity
Carbon black nanoparticles	Improved abrasion resistance and roughness High chemical resistance Electrical conductivity
Clay nanoparticles	Electrical heat and chemical resistance Block UV light Flame retardant, Anticorrosive
Metal nanoparticles Ag, Au, Cu)	Antimicrobial Self sterilization Antiodour
Metal oxide nanoparticles (TiO_2, Al_2O_3, ZnO, MgO	Photocatalytic ability Electrical conductivity UV absorption Photooxidizing activity against chemical and biological species Antimicrobial/self-sterilization
Carbon nanotube	100X tensile strength of steel at one sixth of the weight Electrical conductivity similar to copper Good thermal conductivity
Chitin nanofibrils	Increased tensile strength High temperature resistance Drug delivery capacity

3.1.2 Technologies available for the production of nanotextiles

Textiles' performance improvements, by means of nanotechnologies, has been obtained utilizing the following approaches:

- **Fibres containing nanomaterials -** Nanometric materials can be dispersed into the polymeric precursor matrix of the fibres or deposited on their surface to give new nanocomposites with improved performances and characteristics.

- **Finishing treatments** - Surface treatments at nanoscale, using both wet and gas phase processes, can bring about important advantages in the finishing step. The principal technologies adopted are dip coating, spray coating, sol-gel coating, low pressure and atmospheric plasma coating, and chemical vapour deposition.

- **Electrospinning** - Various polymers have been successfully electrospun into ultrafine fibres mostly in solvent solution and some in melt form. When the diametres of polymer fibre materials are shrunk from micrometers to nanometres there appear several amazing characteristics such as very large surface area to volume, flexibility in surface functionalities, and superior mechanical performance (such as stiffness and tensile strength), which can lead to non-woven fabrics with improved or new characteristics having multiple applications. A particular type of electrospinning is called Nanospider™, invented by the Czech Technical University of Liberc and developed by Elmarco. This technology allows for the production of nanofibres on an industrial scale, avoiding the use of capillaries and nozzles.

Most commercially available nano-enhanced textile products (>95%), incorporate nanotechnology through finishing treatments; for example coatings containing nanoparticles, or plasma treatment of finishing goods.

3.1.3 New nano-enabled functionalities in textiles

The introduction of nanotechnologies in the textile world has opened the path to a huge number of applications, some resulting in a significant improvement on current functionalities but also the introduction of new features. Here follows a list of the principal new nano-enabled functionalities acquired by textiles [4-6].

3.1.3.1 Antibacterial textiles

Textiles are carriers of bacteria and fungi. Bacterial or fungal growth on fabric can be controlled by (a) finishing, using resins to fix the bacterial agents to the textile surface or (b) grafting antimicrobials/antifungal agents to the fibre chain (cellulosic, viscose, etc). Antibacterial activity is closely related to soil-repellent and soil-release qualities of textiles.

Textiles containing a biocide - The antibacterial compound, generally silver nanoparticles, but also copper or triclosan, are applied on the textile surface by dip coating with a nanosol followed by heating to remove the solvent. Alternatively, Ag nanoparticles can be applied by plasma polymerisation co-sputtering on fabrics [5-9] or they can be mixed with the textile precursor followed by melt spinning.

Textiles with photoactive properties – A fully alternative approach is based on photocatalysis. The fabric is coated with a thin layer of nanocrystalline titanium dioxide (TiO_2) particles. TiO_2 is a photocatalyst that when illuminated by light of energy higher than its band-gap, electrons in TiO_2 jump from the valence band to the conduction band, forming an electron and an electric hole on the photocatalyst surface. Both these species react, respectively, with oxygen and water, with the formation of two unstable species, namely O_2 radicals and OH radicals, which are very reactive and react with dirt and microorganisms degrading them to CO_2 and water. TiO_2 is mostly applied to the textile by sol-gel processing [10-14], or alternatively by chemical vapour deposition [15].

Ag, TiO_2 and their combination are the most commonly used nanochemicals in this field [5,9,16-21], but the use of ZnO [22-24] and chitosan [25] has also been reported. In addition, the cosmetic, bacteriostatic, antifungal, and wound repair properties of chitin nanofibrils have also been studied [26-28].

3.1.3.2 Self-cleaning textiles (including water repellent)

Textiles with photoactive properties - As reported for the antibacterial textiles, the photocatalytic activity of TiO_2 has been applied to fabrics also with the purpose of stain degradation. TiO_2 nanoparticles are applied to a textile as dip coating, by sol-gel technique [11-13,16]. The high energetic species produced by the catalyst when irradiated by light react with stains oxidising them to CO_2 and H_2O.

Textiles with super-hydrophobic properties - It is known that the wettability is strongly linked to two properties, the *surface free energy* and the *surface roughness*. Surface free energy is an intrinsic property of the material that can be controlled by chemical modification, such as fluorination or other hydrophobic coating [29,30]. Fluorochemicals are chemicals capable of repelling water, oil and liquids that cause stains. Ultrahydrophobic textiles have been prepared by modifying the surfaces with various fluorinated polymers, like PFTE, fluoroalkylsilanes, and pefluorinated polymer monolayers.

A second approach, derived from nature, is the so-called lotus effect [31-33] based on the observation that lotus leaves are characterised by exceptional water repellence properties because of their rough surface; a rough surface reduces the ability of water to spread out. Tiny crevices in the leaf's surface trap air, preventing the water droplets from adhering and facilitating cleaning by the water droplets rolling off the surface picking up dirt particles.

Water repellent properties have also been obtained by means of nano-whiskers [34], by the so-called NanoSphere$^{(R)}$ technique [35], and by plasma coating [36]. Superhydrophobic properties have been realised on the surface of textiles by coating them with carbon nanotubes (CNT), or with silica, silver, and calcium carbonate nanoparticles in association with non-fluorinated hydrophobic polymers [37].

Textiles with anti-adhesive properties - A different approach to avoid the sticking of specific compounds, like proteins, to textiles, has been the one to make their surface anti-adhesive. Designed to the production of antihadesive wound dressing, good results have been obtained by sol-gel coating the textile with a SiO_2 nanoparticle derivative [10].

3.1.3.3 Moisture absorbing textiles

With the aim of obtaining textiles with moisture wicking and transpiration absorbing features, fabrics have been coated with TiO_2 nanoparticles [10]. An alternate deposition onto the textile surface of TiO_2 and poly(dimethyl diallylammonium chloride has been reported [38]. Plasma techniques are also commercially used to achieve the desired functionality.

3.1.3.4 UV-blocking textiles

For many applications, mainly in the case of sport/outdoor textiles, UV-blocking properties are highly desirable. Materials reported to obtain textiles with this feature are metal oxide nanoparticles, mostly ZnO [22, 39-41] and also TiO_2 or lutein [42-44] by coating the fabric by means of sol-gel processing [14, 41, 42].

3.1.3.5 Tear/wear resistant textiles

The mechanical properties of textiles can be improved by the help of nanotechnologies, allowing the production of fibres and fabrics with increased strength, elasticity or tear and wear resistance [45-49]. The most widely used nanomaterials for this application are carbon nanotubes (CNT). They can be mixed to many fibre precursor polymers, like polystyrene, polypropilene, polyvinyl alcohol, followed by spinning, or alternatively, applied to fabrics by spay coating or dip coating [50, 51].

In addition, the textile performance can be improved using metal oxide nanoparticles, like ZnO (increased stiffness) [52], Al_2O_3 (increased fracture toughness [48], or SiO_2 (increased abrasion resistance) [10].

3.1.3.6 Insulating textiles

With the purpose of obtaining textiles with improved insulating properties for the production of exceptional environment garments, nanoporous structures that minimise the mechanisms of thermal transport have been utilised. Particularly suitable to this purpose are aerogels, which are synthetically produced amorphous silica gels impregnated into a non-woven flexible fabric substrate, offering both the benefits of exceptional thermal performance and a flexible blanket form.

In this case, the external size of the aerogel is not necessarily at the nanoscale but the voids incorporated in the amorphous silica gel matrix are. It is the nanosized void space which gives rise to the exceptional insulation performance of these materials. The voids are filled with air, lowering the density of the material; the more air enclosed within the aerogel, the more efficient the insulation. [53, 54].

3.1.3.7 Conductive textiles

Traditional textiles, both natural and synthetic, are almost always insulators. The interest in transforming them into conductors arises from the need to obtaining antistatic [55-57] or electromagnetic shielding garments, or for the production of the revolutionary electronic “smart” textiles.

The technologies utilized to make a textile conductive are based on the introduction into the fabric of conductive agents, like metal nanoparticles, carbon nanotubes (CNT), carbon black (CB), or conductive polymers, like polypyrrole, polyaniline, and polythiophen [58-59].

These conductive agents are introduced into fibres and fabrics using processes such as physical vapor deposition (Cu [60], dispersion into polymer followed by spinning(CNT) [61, 62] or electrospinning (CB) [59], dip coating [63], vapour or solution polymerisation of conductive polymers [64-66].

The "electronic/smart textiles" are attracting increasing attention; they contain sensors, actuators and control units but still retaining the features necessary for comfortable clothing. They may be either passive, i.e. capable of sensing the surrounding conditions, and active, i.e. containing both sensors and actuators to respond/adapt to specific inputs.

Textiles involved are natural materials, like cotton, wool and flax, and synthetic fibers, like Lycra and Kevlar, with the addition of ICPs (inherently conducting polymers), like PPY (polypyrrole) or PANi (polyaniline), and CNT (carbon nanotubes). Such fabrics are able to absorb substances from the skin or can release therapeutic or cosmetic compounds to the skin [5,7].

3.1.3.8 Textiles with controlled release agents

This type of textiles find application in many fields such as drug releasing wound dressings, insect repelling outdoors clothing, fragrance emitting clothing, moisturizers or skin care cosmetics [67-69]. The nanomaterials employed in this purpose are nanoclays, like montmorillonite, which is impregnated with the active agent, or chitin nanofibrils which are complexed with active ingredient, melt compounded with a polymer followed by spinning. As an alternative, SiO_2 nanosols have been used, by addition of the active species and coating of the fabric by sol-gel-processing [10, 67].

3.1.4 Medical Textiles

Nanotechnology-related textiles can play an important role in the medical sector. Currently, woven and non-woven anti-bacterial fabrics are the most used applications of nanotechnology in the medical textiles segment, being used to prevent infection or deodorise medical clothing, wound dressing, and bedding.

The number of fields where nanotechnology-related textiles are finding applications are growing and include:

- **Surgical, with surgical drapes** for the aseptic techniques used in every day wound dressing, catheter changing and the like, to reduce the chances of contamination and cross-infection.
- **Medical, three-dimensional** textiles to prevent and reduce contact irritations and wound infections
- **Prostheses**, with fibres that are able to facilitate the bonding of the implant to the living bone, or with resorbable guidance devices for the regeneration of peripheral nerves.
- **Dental**, with textile that release medical active gases for therapeutic applications, or with multi-component nanofilament for dental care applications.
- **Garments**, with lightweight, flexible, lead-free X-ray shielding aprons, or clothing incorporating electronic functions to monitor biological parameters or improve the quality of life.
- **Drug delivery**, with drug-loaded fibres for the delivering and the controlled release of therapeutic agents.

- **Fabrics surface-functionalized** and utilised for tissue engineering.
- **Non-woven nanofibre filters** used in a variety of medical equipment, such as respiratory equipment and transfusion/dialysis machines.
- **Hygiene**, with composite non-wovens with improved liquid absorbing features for nappies, sanitary napkins, adult incontinence pads, panty liners, etc.

3.1.5 Sport/Outdoor Textiles

Sports textiles are one of the textile segments where performance is very important. These high performance characteristics are achieved making use of innovative technologies (e.g Gore-Tex nanotechnology). The use of these technologies aims to improve different product properties as well as incorporating new functionalities, some of the properties with higher importance for costumers include:

- ***Improvement in comfort*** **-** The physiological comfort of sportswear can affect not only a wearer's wellbeing but also his performance
- ***Increase of protection*** **-** Protection of the wearer is of fundamental importance, dealing with: impact protection; protection against the cold; water resistance; and water vapour transfer.
- ***Performance enhancement*** **–**Improvement of athlete's performances; for example, the hydrodynamic characteristics of swimmers.
- ***Addition of monitoring and training features in the textiles*** **-** The combination of sport textiles with sensor devices allows the monitoring of the athlete's physiological conditions leading improvement in physical abilities, training status, athletic potential, and responses to various training regimens.

Combining clothing functions with wearer comfort is a growing market trend, and for all active athletes this constitutes a vital factor for achieving a high performance level [71]. The sports industry has driven a lot of research within the textile industry towards improving athletic performance, personal comfort, and protection from the elements [72]. To reach the above goals, innovative fibres and fabrics, including high performance and high functional fibres, smart and intelligent textiles and coated and laminated textiles have been utilised. Synthetics that were once thought to be inferior to natural fabrics now boast high performance characteristics.

Additionally, the application of nanotechnology and combination of electronics and textiles make the manufacturing of clothing, with integrated heating elements or fabrics for example, which stimulate muscles.

The technical developments in the sports clothing industry have resulted in the use of engineered textiles for highly specialised performances in different sports. With highly functional and smart materials providing such a strong focus in the textile industry generally, companies are increasingly looking for 'value added' textiles and functional design in sportswear as well as intelligent textiles, which monitor performance with in-built sensors.

3.1.5.1 Nanotechnology used to improve textile performance on sport & outdoor applications

Following are some of the principal "nano-tools" applied to improve textile performance in the sport/outdoor applications.

- **Carbon nanofibres** are used to increase the tensile strength, improve the chemical resistance, and to introduce electrical conductivity.
- **Carbon black** nanoparticles are used to improve the abrasion resistance and toughness, to increase chemical resistance and to introduce electrical conductivity.
- **Carbon nanotubes** are used to impart outstanding increase of tensile strength, electric conductivity similar to copper and good thermal conductivity.
- **Clay nanoparticles** are used to increase electrical, heat and chemical resistance, as flame retardant and anticorrosive, and as blocker of UV light.
- **Metal and metal oxide nanoparticles** (Ag, Au, Cu, TiO_2, Al_2O_3, ZnO, MgO) are used to impart photocatalytic activity, electrical conductivity, UV absorption, and antimicrobial properties to textiles.

3.2 Additional Demand for Research

The application of nanotechnology to the textile sector has great potential, but the success of nano-enabled developments is linked to the relative weight of the drivers and barriers, and consequent cost/benefit ratio, that can vary according to the sector of application. The trade off between them will determine the rate of their success, but it must be also be noted that nano-enabled innovations will often compete with other, more conventional, approaches.

Therefore there is a constant demand for additional research along the nanotextiles value chain; to clarify base principle and mechanisms of action, for example the size/quantity-related properties, surface interaction or nanoparticles diffusion/distribution into a polymeric matrix; to improve effectiveness, scalability and industrialization of processes and procedures; to adapt nano–related processes and products to existing equipment and procedures, to reduce costs. Also the quest to enlarge the sectors of application of nano – related functionalities/properties ask for a continuous effort of research.

The challenges are many and require both basic and application oriented research.

Another field with a growing demand for research is related to the possible health and environmental hazards potentially associated with nanoparticles along the entire life cycle of nano-textiles. Rigorous control of the interaction of nanomaterials with the human body and the environment is mandatory. Thus, integrated research strategies bridging preclinical-clinical gaps must to be combined with physico-chemical characterization of the material, *in vitro, in vivo* and *ex-vivo* mechanistic studies, toxicogenomic analysis, biokinetics and molecular interactions investigated by biophonic methods, goal-driven risk/benefits assessment and first-in-human studies with INDs

3.3 Applications and Perspectives

3.3.1 Publicly available Nanotechnology-based Consumer Products

Amongst the huge number of scientific publications, patents, press advertisements, projects and products, all dealing with nanotechnology related products, it is useful to determine the true level of transfer to the consumer market of this worldwide nanotechnology effort.

Recent data, from the USA and EU, has provided us with information concerning the consumer availability of products containing nanotechnologies; it should be noted that the data is provisional due to the constant introduction of new items. In spite of this, the data available provides an indication of the repartition of these innovative products in the different consumer product compartments, the relevance of the different producing countries, and of the most widely used nanomaterials.

Project on Emerging Nanotechnologies

The Project on Emerging Nanotechnologies was established in April 2005 as a partnership between the Woodrow Wilson International Centre for Scholars and the Pew Charitable Trusts [73]. It has produced the *first publicly available on-line inventory of nanotechnology-based consumer products.*

As of August 25, 2009, the nanotechnology consumer products inventory contains 1015 products or product lines. The inventory has grown by nearly 379 % (from 212 to 1015 products) since it was released in March 2006.

Products have been grouped according to relevant main categories that are loosely based on publicly available consumer product classification systems.

The largest main category is Health & Fitness, with a total of 605 products, followed by Home & Garden (152), Food & Beverage (98), Automotive (68), Electronics & Computer (57), etc.

The sub-categories associated with the largest main category, Health and Fitness, include Cosmetics (137 products), Clothing (155)**,** Personal Care (193), Sporting Goods (93), Sunscreen (33), and Filtration (43). Again, products with relevance to multiple categories have been accounted for multiple times. The Cosmetics, Clothing and Personal Care sub-categories are now the largest in the inventory.

The breakdown of products by region indicates that companies based in the United States produce most of the products, with a total of 540**,** followed by companies in East Asia (including China, Taiwan, Korea, Japan) (240), Europe (UK, France, Germany, Finland, Switzerland, Italy, Sweden, Denmark, The Netherlands) (154), and elsewhere around the world (Australia, Canada, Mexico, Israel, New Zealand, Malaysia, Thailand, Singapore, The Philippines, Malaysia) (66).

The most common nanomaterial mentioned in the product descriptions is nanosilver (259 products). Carbon, which includes fullerenes, is the second most referenced (82), followed by titanium (including titanium dioxide) (50), silica (35), zinc (including zinc oxide) (30), and gold (27).

European study of products containing nanoparticles (BEUC & ANEC)

In Europe, BEUC (The European Consumers' Organisation) and ANEC (The European Consumer Voice in Standardisation) have published a non-exhaustive inventory of products claiming to contain nanoparticles that are available on the EU market. [74]. The purpose is to prepare a public debate to gather knowledge about benefits and risks for health and the environment given by such materials.

The study has identified 110 products**,** divided by sector as follows: Cosmetic products (52)**;** Food products (10); Products used by children (5); Other products (43). Belonging to the last group are some textiles of interest to our report:

- 100% cotton sheet set (AgActive, UK). Sheet able to kill over 99% of bacteria including MRSA (Methicillin Resistant Staphylococcus Aureus).
- AgActive Towel (AgActive, UK); Cotton towel treated the silver treatment "SilverSure" to become bacterial and odour free.
- Acticoat antimicrobial barrier dressing (Acticoat, UK), Antimicrobial barrier dressing for use over wounds using the patented silver technology "Sylcryst" nanocrystalline.
- Nanotech Coolest Comfort (Nano-Tex, USA); Fabric that balances body temperature, retains natural softness and breathes naturally.
- Men's no-iron comfort waist plain front chinos (Land's End, UK); Clothing made with Nano-Tex finish that resists spills and wrinkles.
- Solefresh nanosilver Socks (SoleFresh, UK); Non-toxic, non-allergic socks preventing foot odour and some foot diseases.
- Shoes Annapolis (Timberland, USA) Shoes Agion treated footbed to inhibit growth of odour causing bacteria.

From these two studies it can be concluded that textiles is one of the sectors where nanotechnology is having a larger impact. More specifically Sports and outdoors is the segment with more products. It is also clear that nanosilver is the most widely used nanoparticle, with the anti-bacterial property representing the most common functionality provided by nano-enhanced textiles.

3.3.2 Nanotechnology product applications in medical/healthcare textiles

In the medical/healthcare sector the nanomaterial principally utilised are silver nanoparticles, for their recognised antibacterial activity.

3.3.2.1 Antibacterial textiles

The applications in the medical sector cover the range of antibacterial textiles with a broad-spectrum of antimicrobial activity and the absence of drug resistance, capable to prevent mite sensitization in atopic dermatitis; antibacterial wound dressings, patient dresses, bed lines or reusable surgical gloves and masks [12, 74, 75]. But they can be extended also to protective facemasks and suits against biohazards [76] or to toothbrushes [10].

The need to sanitise clothing, and and many other everyday items, has resulted in the extension of the antibacterial war to many other objects such as sports clothing, domestic and automotive interior textiles, and toys [77, 78]. The antibacterial activity of these textiles is utilised, in particular, to produce anti-odour clothes for the sport/outdoor and furniture sectors [17]. In addition, possible uses of antibacterial textiles are considered for the household products such as kitchen clothes, sponges or towels.

3.3.2.2 Antimicrobial wound dressings

This is a very important application of nanotechnology in the medical field. Wound dressings are manufactured by means of a bi-layer of silver-coated, high-density polyethylene mesh with a rayon adsorptive polyester core. The dressing delivers nanocrystalline silver from a non-adherent, non-abrasive surface [79]. In vitro studies have shown that the sustained release of

this ionized nanocrystalline silver maintains an effective anti-bacterial and fungicidal activity [80, 81]. In addition, nanocrystalline silver dressings have been clinically tested in a variety of patients with burn wounds [82], ulcers and other nonhealing wounds [83] facilitating wound care by adequate debridement, and bacterial and moisture balance.

Wound dressings have been also developed, which combine an electrospun polyurethane nanofibrous membrane and silk fibroin nanofibres [84, 85]. These electrospun materials are characterized by a wide range of pore size distribution, high porosity, and high surface area-to-volume ratio, which are favourable parameters for cell attachment, growth and proliferation. The porous structure is particularly important for fluid exudation from the wound, avoiding wound desiccation, and impairing exogenous microorganism infection.

3.3.2.3 Anti-adhesive wound dressings

Textile wound dressings such as plasters or bandages find wide range of uses in medical applications to cover wounds until the healing process can protect the wound against external environmental attack. Traditional wound dressings, generally adhere to the healing wound, causing a new injury on removal, and thereby interrupting the healing process. The close control over fibre architecture offered by embroidery is also of potential interest for highly loaded structures, enabling fibres to be placed in the position and with orientations necessary to optimize strength and stiffness locally. The textile surface of these wound dressings is also of importance for comfort and prevention of mechanical irritation

Innovative wound dressings with anti-adhesive properties to the healing wound have been obtained by coating the common viscose bandages with silica nanosol modified with long-chained alkyltrialkoxysilanes. An additional, not secondary, feature of the above innovative wound dressings is their ability in water uptake. Good absorption properties for the wound exudates are of great help to the healing process and are of special value for bedridden patients with chronic wounds.

3.3.2.4 Product examples

- ***Acticoat™*** *(Smith & Nephew plc, UK*). Smith & Nephew has created a fast-acting, bacteria-destroying wound dressing. It contains safe bactericidal concentrations of silver with patented nano- crystalline technology.
- ***Face Masks;*** *(Nanbabies® Face Masks, USA*). It works against all types of bacteria and viruses, even killing antibiotic resistant strains as well as all fungal infections. The nano-crystalline silver particles used remains active up to 100 washes.
- ***Nano Cyclic Towel*** *(NanoCyclic Inc, USA*). Super absorbing and antibacterial cloth. It absorbs water and repels germs.
- ***NanoMask*** *(Emergency Filtration Products, USA*). It is the first protective facemask in the world to utilize nanoparticle-enhanced filters to address potentially harmful airborne contaminants.
- ***Greenyarn*** produces ***Eco-f*****abric** which is anti- microbial, anti-static and has other health benefits
- ***NanoPro Wrist Supporter****; NanoProElbow Supporter; NanoProBack Supporter (Vital Age, USA*). It helps to increase microcirculation, in the elbow and in the lower back areas to help relieve tired muscles. It utilises an exclusive ceramics compound utilised in the production of all NanoPro products.

- **NANOVER™ Wet Wipes** - Safe to use for children's toys Soft like cotton, protect babies' frail skin Low irritative natural ingredients protect and moisturize your skin, and prevent skin trouble Cleans hands and around lips (GNS Nanogist Co. Ltd)

3.3.2.5 Medical Smart Textiles

Textiles provide an excellent substrate for integration with electronic devices, including sensing, monitoring and information processing tools, able to react to the conditions and stimuli, like the mechanical, thermal, chemical, electrical, transmitted by the wearer. [86]

The healthcare field could take advantage of these smart textiles to provide for a patient's extended monitoring during a long rehabilitation perios [87, 88]. In this field a new class of electrically conductive material, called Quantum Tunnelling Composite (QTC) is being produced by the UK based Peratech [89]. QTC has the unique ability to smoothly change from an electrical insulator to a metal-like conductor when placed under a pressure; these features will find a number of medical applications including blood pressure control, respiratory monitoring, and sensing in prosthetic socket.

3.3.3 Nanotechnology product applications for the sport/outdoor sector

Apart from the application of smart textiles as futuristic aids for the improvement of the sport performance, that will be dealt with later, many are the interventions of nanotechnology in the production of sport/outdoor clothing. Here we have included some of the currently available products, grouped according to their main functionality.

3.3.3.1 Stain Resistance / Water repellence

Stain resistant and water repellence finishing is probably the largest nanotechnological application in textiles. Its market is no longer considered as niche, since its request is not limited to the sport/outdoor clothing, but extends also to work, casual, and evening wear. The desired textile performance has been obtained by different technological approaches, such as coating with perfluorochemicals, silica nanoparticles, carbon nanotubes, or with the dirt destroying photocatalyst TiO_2.

Products examples

- **Hi-tech** Ion-mask – Technology: Plasma Ion mask (P2i)
- **Nike** Lunar Wood TZ – Technology: Plasma Ion mask (P2i)
- **Ecco** Biom running shoe – Technology: Plasma Ion mask (P2i)
- **Magnum** boots **-** Technology: Plasma Ion mask (P2i)
- **Adidas** Golf shoes **-** Technology: Plasma Ion mask (P2i)
- **New Balance** Performance Outerwear vintage-inspired Circa-V outerwear line – Technology: NANOTEX outdoor (NANOTEX)
- **Odlo** Jacket – Technology: water resistance (HeiQ)
- **Cloudveil** Switchback jacket – Technology: Lotus effect - Nanosphere - (Clariant - Schoeller)

3.3.3.2 Antibacterial / Odour Control

Odour control in sport/outdoor clothing is an important topic. Such control can be achieved in different ways, such as by covering up the odour with a fragrance, by removing the odour molecules as they are formed, or applying an antimicrobial finishing.

- In the first approach, odours are covered with fragrances by means of microcapsules containing fragrances that can be applied to the fabric to provide a slow release over time.
- In the second approach are used cyclodextrines. These are compounds with a peculiar structure characterised by a hydrophilic surface and a hydrophobic cavity. The odour molecules, being hydrophobic, become trapped in the cavities of the cyclodextrine and are removed during laundering.
- In the third approach the problem is paced at its root. Being odours formed as result of bacterial growth, the application of antibacterial finishing to the fabric is able to prevent bacterial growth and consequently the odour formation. This topic has been previously treated in the Medical Textiles chapter.

Product examples:

- **Puckskin -** Bamboo Athletic Socks / Short Sleeve Top / Long Sleeve Top / Long Pants / Sleeveless Top
- **Extera** Taekwondo Uniform – Culture Maker Corp.
- **Wigwam** socks – Technology: Smart silver (NanoHorizons)
- **AgActive** Antibacterial Socks
- **Greenyarn's** socks – Eco-Fabric (Greenyarn)
- **Funtional sport wear** – Sinotextiles Co.Ltd.
- Lexon Nano-Silver Sock

3.3.3.3 Moisture management

Synthetic fabrics and resin treated (e.g. to become wrinkle free) are hydrophobic; however, by nanotechnological treatment these fabrics become able to absorb moisture, pulling away perspiration from the body and allowing the wearer dry and comfortable.

Product examples:

- **Adidas** Yocum activewear line - Technology: NANOTEX coolest comfort – (NANOTEX)
- **Plasma Mec** (MECTEX)
- **CW-X** Compression support socks - Technology: Healtha+® (Ventex)

3.3.3.4 Strength / wear resistance

Product example

Adidas *Nanotech Shoe* .The *Lone Star* is the world's first asymmetrical 400m spike, featuring the first ever **full-length carbon nanotubes reinforced plate**.

3.3.3.5 Prototypes

*Conducting textile platform based on novel e-fibres***.**

The presented prototypes are coated yarns, fabrics or simple garment containing the coated fibres to demonstrate electric conductivity whilst maintaining an original haptics. A low-pressure plasma sputtering process is used to coat a 100-200 nm thick metal coating on

common monofil- or multifil- yarns, which thereby do not change their properties, but become reliably conductive for low-current signals; this includes audio signals, computer interfaces (e.g. USB), low current supply, or, dissipative heating [90].

Smart Textiles for Sport Clothing

In addition to the above features finalised to increase the athlete's comfort, the sport garments are asked to be equipped also with sensors to provide information about the athlete's physiological conditions (physical abilities, training status, athletic potential and responses to various training regimens) [71].

Strain sensors, made from piezoelectric materials may be used to detect posture, improve movement performance and reduce injuries [91]. The stress and strain applied to the fabric by the athlete's movement will affect the conductivity, allowing the monitoring of body kinematics [92-95].

Examples of such applications are: a garment for the athlete's kinesthetic monitoring, developed at the University of Pisa, for the detection of posture, improvement of movement performance, and reduction of injuries [93]; an Intelligent Knee Sleeve, developed at the University of Wollongong and CSIRO, for the monitoring of the wearer's knee joint motion during jumping and landing to reinforce the correct landing technique [94]; a sensor applied close to the athlete's rib cage for the breathing monitoring, or in smart insoles for the monitoring of plantar pressure [96, 97]. The integration of chemical sensors into textiles for the analysis in real time of the sweat composition is also an appealing prospect [98].

Table 2 - ObservatoryNano - Technology Readiness Level (TRL)

FUNCTIONALITY	TRL*	COMMERCIAL PRODUCTS
SELF CLEANING / WATER REPELLENCE	*4*	HI-TECH ION-MASK NIKE LUNAR WOOD ECCO BIOM RUNNING MAGNUM ADIDAS GOLF NEW BALANCE PERFORMANCE OUTERWEAR ODLO JACKET CLOUDVEIL SWITCHBACK JACKET
ANTIBACTERIAL	4	PUCKSKIN - BAMBOO ATHLETIC SOCKS / SHORT SLEEVE TOP /LONG SLEEVE TOP / LONG PANTS / SLEEVELESS TOP EXTERA TAEKWONDO UNIFORM WIGWAM SOCKS AGACTIVE ANTIBACTERIAL SOCKS GREENYARN'S SOCKS FUNTIONAL SPORT WEAR – SINOTEXTILES CO.LTD.
MOISTURE MANAGEMENT	4	ADIDAS YOCUM ACTIVEWEAR PLASMA MEC (MECTEX) CW-X COMPRESSION SUPPORT SOCKS
UV PROTECTION	4	
TEAR WEAR RESISTANCE	3	ADIDAS *LONE STAR*
INSULATION/ ANTISTATIC	3	
CONDUCTIVITY	2	
AGENTS RELEASE	2	

*ObservatoryNano 1-Basic Research 2-Applied research 3-Prototype 4-Market entry 5- Mature market

3.3.4 Perspectives

With the purpose of acquiring information on the development trends in nanotechnology-related textiles in the medical/health care and sport/outdoor sectors, we have performed some interviews, and circulated a short questionnaire to academic and industrial expert of the sectors.

The questions asked and the opinions received from eight experts are summarized as follows.

1. The perspective development of nanotechnologies scored (in a range between 1 = nil, and 4= excellent), 3.5 for the medical/healthcare and 3.1 for the sport/outdoor sectors.
2. The most promising fields of applications of nanotechnologies were suggested as:
    a. for the medical/healthcare sector, antibacterial textiles; wound care dressing; drug controlled delivery; multifunctional sensors and biosensors; tissue engineering;

b. for the sport/outdoor sector, garments protecting against weather; thermoregulated, antiodour, breathable and low friction coefficient textiles, anti ageing textiles.

3. The most important advantages deriving from the application of nanotechologies were:
    a. for the medical/healthcare sector, miniaturization; reduction of raw materials and energy expenses; very high surface/volume rarios allowing increased reactivity; bacterial shielding; increase of sensor sensitivity; customized drugs;
    b. for tthe sport/outdoor sector, oleo-hydro repellency; self cleaning and antifouling activity; increase of comfort; increase of mechanical performance.

4. The most important barriers to the application of nanotechnologies both in the medical/healthcare and the sport/outdoor sectors were: fear of the impact of nanoproducts on the human health; lack of regulation; reduced tendency to innovation; difficulty in large scale production; high interdisciplinarity needs of competencies.

3.4 Current situation within EU

The development of technical textiles is very dependent on the global economic climate, and given the current crisis, they are likely to grow less in the coming months. Nevertheless, the sector remains the most dynamic in the textile sector today in Europe.

It seems crucial that European businesses specialising in technical textiles should better identify the needs of the sector to support the efforts to grow and innovate, and to allow some businesses to begin the required transfer from “classical” textile and clothing products towards more technical, and therefore higher value added products.

As the technical textile industry is mostly made up of SMEs, who do not have sufficient resources for an intense R&D activity in house, it is important for public R&D structures to promoting links of collaborative research with industry. The European Technology Platform for the Future of Textiles and Clothing by 2020 plays an important role in this direction.

According to Euratex 2008 Annual Report, the technical textile industry will also have to increase its efforts to formulate European standards in order to define an adequate regulatory framework to assure a sustainable production that conforms to the wishes and needs of the consumers.

3.4.1 Medical/healthcare textiles

Europe holds an important position in this sector with companies active in UK (JR Nanotech), Ireland (Alltracell Pharmaceuticals), and Czech Republic (Elmarco/Nanopeutics). Important competitors in the rest of the world are located in Japan (Takeda Chemical Industries, Osaka), USA (Nanotech Institute, University of Texas, Dallas), Canada (Nucryst Pharmceuticals), South Korea (Chonbang Co.), and China (Fountain Set, Hong Kong).

3.4.2 Sport/outdoor textiles

The nanotechnology applications in sports/outdoor textiles see the USA as the clear leader. Important players in this sector are: Nike, Adidas, VF, New Balance, ARC Outdoor, W.L Gore Associates, NanoHorizons, Nano-Tex, GreenYarn. Active in Europe are, among others, textiles

nanotechnology specialized companies such as Mectex (IT), P2i (UK), and Schoeller (CH). Other players in the rest of world include Thomson Research (Canada), Hyosung (South Korea), Suzutora (Japan), and NanoGroup Holdings (China).

3.4.3. EU Projects on Nanotechnology-related Textiles

In Europe, a large effort of research for the improvement of the technological content of textiles is represented by EU funded Projects. They are intended to ensure necessary financing for R&D, innovation, technology transfer, training for the textile-clothing sector, and also to promote a positive forward-looking image for this industry, which is too often wrongly viewed as a traditional declining sector.

Among others, the following projects have given a broad impulse to the textile sector modernization:

- LEAPFROG project has been finalized to modernize and ultimately transform the clothing sector into a demand-driven, knowledge-based, high-tech industry, by exploitation of recent advances in a broad area of scientific-technological fields ranging from nanotechnology and polymeric material science, robotics and innovative joining techniques, 3D computer graphics and animation, to e-business and management research. The result of such innovation is a new business potential across the entire spectrum of textile, clothing, machinery and service companies in Europe.
- The main objective of the AVALON project, concluded in 2009, has been the cross-sectoral development of novel hybrid textile structures integrating multifunctional Shape Memory Alloys (SMAs) and the related processing techniques as well as design, simulation and organisational methodologies.
- The eBIZ-TCF project, a 2-year cooperation project launched in January 2008 by the European Commission, has been finalised to boost e-business processes in the Textile/Clothing and Footwear (TCF) Industries.

With objectives more specifically focused on the medical/healthcare and sport sectors the following EU projects are aiming to realise the convergence of textiles, nanotechnology and electronics: WEALTHY project (concluded in 2005) and My Heart project (concluded in 2007) have been devoted to e realisation of smart textiles integrating sensors, electrodes and connections able to monitoring respiration, electrocardiogram, electromyogram, body posture and movement, and to tackle cardiovascular diseases [99, 100].

The opportunities for the above devices are not limited to the health sector, but also sport, leisure and fun are sectors able to take advantage of them.

Smart textiles have been also envisaged as aids to augment the sensory system of the skin, by sensing external stimuli, like proximity, touch, pressure, temperature and chemical/biological substances. That may be useful for patients affected by diabetes mellitus (reduced sensitivity of limbs) or bedridden (to reduce the occurrence of pressure ulcers) [101]. The smart textiles provided with inherently conducting polymers (ICP), used for kinesthetic as physiological monitoring discussed for the sport application, may also be used for patient rehabilitation [102]. The inherently conducting polymers, used as sensing devices, may be used also as

actuators and configured as electrodes. By applying a potential the ICP electrode changes its dimension working as a mechanical actuator, and opening the way to the artificial muscles.

Today around fifteen European projects involve activities in the area of intelligent textiles, demonstrating that Europe has taken the lead in further developments in this area. Nevertheless only very few products are actually available on the market. This failure to transfer research results to the market, despite huge European interest in the field, has led to the formation of SFIT (Smart Fabric and Interactive Textiles; 2008-2011), a cluster grouping the EU Projects Context, Proetex, Sweet, Stella, Ofseth, Biotex and Clevertex, which takes advantage from the results produced by the concluded projects Wealthy and MyHeart.

In particular, the Stella project is looking to obtain stretchable electronics for garments capable of monitoring a variety of bodily during sports or everyday life. The Ofseth project is aiming at applications in oxymetry, a clever non-invasive way to measure the oxygen content of blood.

The Biotex project aims to measure the conductivity, electrolyte level, temperature and pH of users sweat, all enormously useful indicators for sporting applications. In addition, this project also is looking at monitoring wound healing by placing biosensors in contact with exudates present in wounds.

Dealing with the development of these technologies to the level of market entry, developers are looking preferentially to sporting applications; medical applications are very difficult to bring to market and require enormous validation efforts to ensure reliability in a medical setting.

Additionally, important European institutions are active with projects in medical nanotechnology-related textiles, including the Institut für Textiltechnik of RWTH Aachen University, which is developing a partly absorbable textile-foam-composite for small intestine replacement in collaboration with the Institute of Plastics Processing and the University hospital Aachen [103] and the Denkendorf Institute of Textile Technology and Processing Engineering, which is studying capillaries and fibres for the peripheral nerve regeneration [104].

4 Economic aspects

4.1 General market description

4.1.1 European textile sector

Technical textiles have seen their share of production grow considerably in Europe over the last fifteen years, increasing constantly both in value and in volume. This market has increased from 65 to 85 billion € from 1995 to 2005. 8.5 million tonnes, about half of global technical textile production, is consumed in Asia, followed by US and Europe with 5.8 million and 4.8 million tonnes respectively. In Europe four countries consume about half of the technical textiles in terms of value: Germany, France, the UK and Italy. The technical textiles industry in Germany represents 45% of the European textile industry, followed by France (30%), UK (30%) and Italy (12%).

Europe is one of the world leading exporters of textiles; according to EURATEX, the annual turnover of the textile industry in 2008 was over €203 Billion and the sector employed 2.3 million workers in more than 145,000 companies [105] (mainly SMEs).

However, over the last couple of decades the European textile sector has dropped its production due to the globalisation of the economy and the relocation of the European companies outside Europe. These circumstances have worsened due to the world economic crisis that started in 2008 and almost 68,000 textiles jobs have been lost. During the first quarter of 2009 this negative trend has continued and production of the textile industry production dropped 23% on average.

4.1.2 Medical textiles

The global market in 2007 for medical textiles was about $8 billion [106]. Every year this niche market becomes more relevant and its importance will increase even more in the future, the forecast world consumption in volume of medical textiles for 2010 is shown in the figure 4.1.

The increase of population over 60 years in Europe and consequently the increase of doctor visits is the main problem that new technologies will have to cope in order to assure a good medical service. Currently patients are offered periodic visits to the doctor and prescription medicine. However, the incorporation of nanotechnology in textiles may boost the so-called “telemedicine” (use of sensors and telecommunications in textiles to transfer medical information with the aim of consulting and remote medical measures or examinations). Moreover, the nanocoating textiles can offer a longer textile lifetime within the body and therefore visits to health facilities to replace dressings may be less frequent [107].

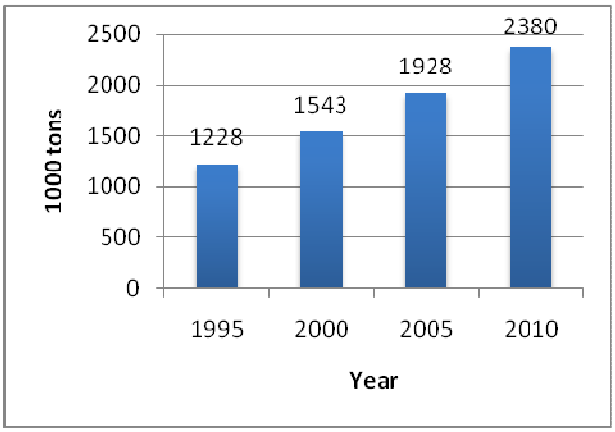

Figure 4-1 – Forecast world consumption of medical textiles 1995-2010. Volume (1000 tons) [97]

Health and hygiene textile materials have a wide variety of uses; however, nano-enabled developments remain in the early stages of development. The products range from simple gauze or bandage materials to scaffolds for tissue culturing and a large variety of prostheses for permanent body implants [108]. The huge number of categories where the medical textiles can be applied, and the additional fields of applications regarding personal wellness that will emerge in the future, will drive growth in the number of nanotechnology products in the sector. However, there remains concern about the safety of nanoparticles introduced in the human body [107].

4.1.3 Sports and outdoors

The sports and outdoor textiles market is an important and growing sector within the technical textiles subsector. In 2008 around 10 % of the Europe consumers' expenditure on clothes was on sports clothing [109] with the figure rising to 19% when considering sports footwear and clothing. These values show the importance of this segment to the overall textile sector.

The outdoor sector is one of the textile sectors where the impact of the economic crisis is lower. According to the German Sports Retailers (VDS) the market for sport outdoor products grew 11% on 2008 [110] and the values from 2009 show that the growth remains stable. Proof of the potential for the outdoor sector is that big sports companies (even accounting for the global economic crisis), who focus their activities in traditional sports goods, are starting to position themselves within the "performance-sports gear" releasing new products aimed at the outdoor market [111].

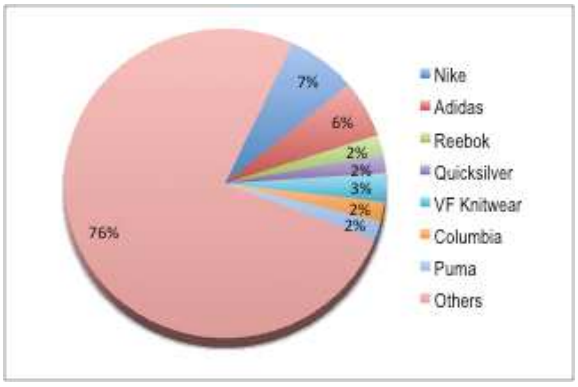

Figure 4-2 - Athletic apparel - Global Market share Commerzbank equity research 2008 [92]

Figure 4-2 reveals the market for athletic apparel in 2008; the top five firms control only the 20% of the market. According to the a market research company NPD Group, Inc., worldwide sales of sports equipment, apparel, and footwear in 2008 achieved € 219 billion (almost 75% in textiles)[91]. Nike and Adidas are the two market leaders in this sector with sales of around $18,6 billion (Nike) and $10,8 billion (Adidas) in 2008[1] [112]. VF (which owns brands like North Face) and Columbia are other key players in the outdoors segment.

Company	Turnover
Nike	$18,6 billion
Adidas	$10,8 billion
VF	$7.6 billion
Puma	$2,5 billion
Quicksilver	$2,26 billion
Pentland Group	$2,04 billion
Sketchers	$1,44 billion
Columbia	$1,32 billion
Under Armour	$0,73 billion

Figure 4-3 – Turnover from world market leaders in the sports & outdoor sector [various sources]

European and US companies have for decades been leaders in the textile sector; however, Chinese companies are gaining market share rapidly with an annual growth over the past 2 years of 40%. [113-115].

All these facts (e.g. high growth of the performance-sports goods, steadily growth in the past years, etc.) confirm that the sports and outdoor segment, due to its capability of increasing textile performance, is one of the key textile sectors where nanotechnology can play a major role in the coming years.

4.2 Drivers and barriers

Innovative medical textiles and sport/outdoors textiles will be one of the main concerns/priorities for the coming years. Nanotechnology brings to these textile products the opportunity to fulfil their performance requirements while retaining key characteristics such as aesthetic properties and comfort level.

In the case of sports and outdoor textiles the main features required by customers are related to comfort: water repellence to keep the body dry; moisture management (e.g. moisture wicking, quick drying); anti-bacterial/anti-odour; UV protection; and wind resistance [116]. Nano-enabled products can meet all these customer demands. In the past, several large sport and outdoor brands incorporated functional nano-coating technology in some products and this has result in a boost of confidence of SMEs in nanotechnology as the brands noticed that the use of nanotechnology was a good marketing tool. However, in the past few years some countries have noticed an uncertainty with respect to potential health hazards. As it has not been proven beyond doubt whether nanoparticles/nanomaterials are harmful or not, uncertainty remains.

[1] Values do not differentiate turnover based on sales from textiles or other sports goods.

Furthermore, medical textiles must fulfil specific characteristics related to non-toxicity, non-carcinogenic, non-allergic and sterilisation capability, without suffering chemical or physical damage [96]. These performance requirements represent the main driver to use nanotechnology as a promising way of obtaining the desired performance requirements while retaining the key textile features/properties.

However, there are still several barriers that must be overcome in order to make nanotechnology a common technology within the sports/outdoor and medical textiles sectors. These barriers are the environmental and health factor and legislation, which is not clear for a product incorporating nanotechnology.

The **environmental factor** is a key aspect to take into account. Nanotechnologies can have beneficial effects on the environment, but their use can also raise concerns for the potential harmful impact on it. During the last few years environmental legislation has forced the textile industry to address concerns about the possibility to change current textile processes to others with greater efficiency and a lower environmental impact. On one hand, the main issues of the textile industry are the high water and energy consumption, the generation of huge amounts of effluents with high chemical oxygen demand, and excessive colour. With wet dyeing processes like plasma treatments, the fibre surface of the material can be modified to reach the end-properties without less industrial wastes and using less water [117]. On the other hand, textiles with nanoparticles (nanometals) in the fibres or in a coating can make their disposal and the recycling process more difficult.

Another factor, mentioned above, is the **potential risk for human health** of textiles incorporating nanotechnologies. The need to assure the safety for the wearer of these types of garments is fundamental for the acceptance/success of these products on the open market.

Regarding legislation in the field, it applies in the same way conventional materials and nanomaterials; however, the laws should distinguish them because they can behave very differently. As mentioned before, there are concerns about the effects of nanomaterials and the methods currently used to assess risks are unsuitable for testing nanomaterials, that's why if the law says that companies can only place products on the market if they are safe, it will not always be easy to determine whether a particular nano-based product is danger or not. Stakeholders tend to think that **existing laws are inadequate** and are not always clear for a product incorporating nanomaterials.

4.3 Boundary conditions

The boundary conditions include:

1. Technical limitations of nanotechnology – State of the art of the technology
2. Cost - production costs increase
3. Lack of knowledge about nanotechnology opportunities and scepticism about their benefits

The **technical limitations** include: issues with scale-up of the process; reproducibility of results; availability of raw materials; and production of materials with long lasting effects. To overcome these limitations it is neccessary to invest in R&D, to create prototypes, and to develop large-

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

Another key limitation for a wider use of nanotechnology is related to the **production costs of nanotechnology-enabled products**. Nanotechnology production costs are higher than traditional production costs. 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) and use of expensive raw materials for example. Despite sports/outdoor and medical textiles being less sensitive to the increase of cost than the clothing sector, the production costs remains as one of the most important factor avoiding a wider use of nanotechnology.

Finally, the **lack of knowledge about the technology and the processes** results into a limitation of further use of nanotech processes in the textile industry. Most of the companies (end-users) are aware of the existence of nanotechnology and their potential, but they still have doubts about how this technology can be implemented in their products/processes and whether the required investment will be recouped. Some leading sources from the textile nanotech sector have stated that people tend to associate nanotechnology to nanoparticles and complex technology processes, assuming that it would be very difficult to implement this new technology into their production lines and that it would require a large investment in expertise and machinery. However, reality shows that when the results are presented and production processes are explained in detail, this initial hesitation disappears.

Amongst the measures being taken in order to overcome the insecurity in utilising nanotechnologies, due to advertising messages insinuating nanotechnology is not healthy, could be labelling. However, at the moment, there is not a generally accepted regulation for it at European level. In Germany the Hohenstein Institutes in conjunction with Nanomat have created a standard to enhance the brand value and facilitate the access of new products to the market (the so called Hohenstein Quality label for Nanotechnology). Product labels convey certain quality properties to consumers as breathability, skin compatibility, abrasion resistance and wash resistance, in addition to evaluation of the nanostructure and its function. Furthermore, the Hohenstein Quality Label provides the opportunity to stand out from all the textiles that claim to be “nano” and are not [118].

4.4 Economic information and analysis

Nanotechnology enabled products, still represent a very minor part of the total market of sports and outdoor textiles (around 1-2%). One reason that can explain the small contribution of nanotechnology in the final product, as mentioned before, is the increase of the final price. Some experts point out that the use of nanotechnology can increase the cost by 0.1 €/m^2 of textile in the textile industry or by €2-3 euros per shoe.

Nano-enabled developments in textiles include developing new (nano) fibres and yarns or in the fabric or in the finishing. However, regarding the textile value chain, the advances in fabric finishes have contributed to the implementation of nanotechnology developments in textiles because the margin in the final steps of the textile value chain is higher than in the production

of new nano-fibre where the prices are much more competitive. Some nanomanufacturers have identified the finishing and the textile product as a market opportunity and they are already selling their nanotechonology to such clients (Figure 4-4).

Figure 4-4 – **Textile value chain for a shoe in the Sport/Outdoors sector**

An example that clearly reflects the situation of nanotechnology in the sports and outdoor textile segment is the case of P2i and their Ion Mask. During 2009 the first products incorporating Ion Mask technology were released onto the market (around 0.5 million Hi-Tech shoes incorporating P2i's plasma treatment are already on the market). However, in the past months the company has reached agreements with some of the world leading sports and outdoors brands (Adidas, Nike) to commercialise new products incorporating Ion Mask. These new agreements will result in a significant growth of the number of products on the market that incorporate P2i technology.

In figure 4-5 the different functionalities (resulting from the use of nanotechnology) available in the sports and outdoor segment are presented. The figure presents, qualitatively, the relative market penetration and the potential adoption of (market interest in) nanotechnology. The size of the bubble indicates, again qualitatively, the number of products in the market incorporating a specific feature. The figure reflects that there is a major consumer interest in products incorporating moisture management and hydrophobicity; however, the largest numbers of products possess these two functionalities so this may be expected.

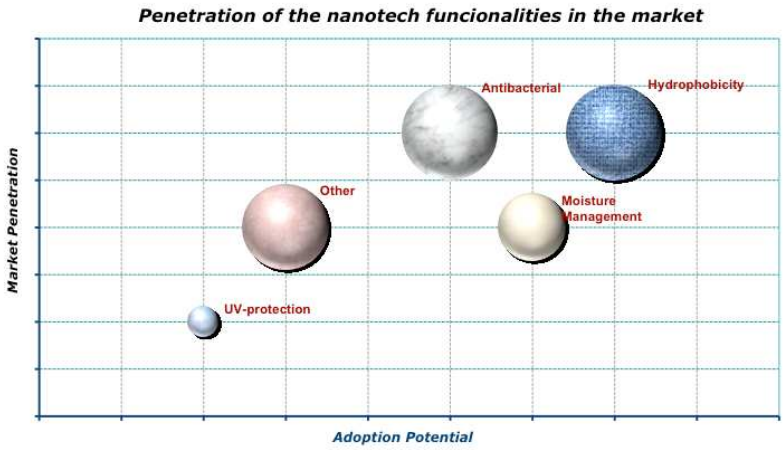

Figure 4-5 – Market relevance of the nanotech functionalities in the sports and outdoor market.

US companies were first to concentrate their efforts in the sports/outdoor sector but during the past 5 years the European sports and outdoors industry has rapidly evolved to allow it to compete with USA manufacturers. This has resulted in the creation of some new companies and the reorientation of already existing companies. In some cases these manufacturers are licensing their technologies to larger sports and outdoors companies, such as Nike, Adidas or VF.

In the case of Medical textiles the market penetration is significantly lower (less than 1% of the total market share). This market segment has a very high potential but nowadays the use of nanotechnology in this field is limited to nanosilver-enabled products (for example wound care products and other minor applications making use of antibacterial properties). The value chain for medical textiles is similar to that of sports/outdoors textiles; retailers deliver products for which the customer is willing to pay more than the sum of the cost activities in the value chain, that means that if the nanotechnology can be implemented in the later stage the cost of early stage activities will not be altered.

Figure 4-6 – **Textile value chain in the medical sector**

4.5 Selected company profiles

This section presents the profiles of the companies that provide the nanotechnology to end-users. This is a non-extensive list based on an internet survey and completed with experts' feedback.

P2i (UK) – www.p2ilabs.com - Company specialised in liquid-repellent nano-coating technology. P2i's patented technology employs a special pulsed ionised gas (plasma), which is created within a vacuum chamber, to attach a nanometre-thin polymer layer over the entire surface of a product.
P2i has two consumer brands for its technology:

- **Ion-mask™,** for footwear, outdoor clothing and accessories
- **Aridion™,** for consumer electronics. For industrial applications

Amongst P2i costumers are some of world best renowned sport material companies, such as: Hi-tech, Nike or Adidas.

Mectex (IT) - 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 fibre and blends. Their technology has been used in the fabrication of the Speedo LZR racer swimsuit.

Schoeller (CH) - www.schoeller-textiles.com - develops and produces highly-functional fabrics and innovative textile technologies for sport, work, lifestyle, fashion and office furnishings. And pay close attention to ecological safety and good design.
Key technologies incorporating Nanotechnology are:

- **NanoSphere ®** - nanotech-based finishing technology allows dirt and water to simply run off the surface of the textiles
- **3XDRY®** is an advanced Moisture Management-finish, which makes textiles water and stain repellent on the outside and water absorbent on the inside.
- **ActiveSilver™-** controls bacteria though a textile finish based on active silver salts.
- **Coldblack®** is a special finishing technology for textiles that reduces heat build-up on dark fabric
- **FluoroFree™** - is a finishing technology that makes the surface of textiles water and dirt repellent For long lasting, Unlike conventional textile impregnations, FluoroFree™ does not use any fluorides to achieve this effect

Nanotex (US) – www.nano-tex.com - Nano-Tex is a materials company developing innovative polymer and polymer-related chemistries to enhance and create superior performance in fabrics. Chemistries, developed for use at the nano-scale, have the ability to attach to fibres and permanently bond to the fabric at the molecular level. The result is a family of product offerings that enhance fabric performance and durability not previously attainable. Amongst the apparel and interior furnishings brands making use of Nanotex technology are Adidas, New Balance, Gap, Old Navy, Target, Hugo Boss, Paul Stuart, Rene Lezard, Lee, Champion, Levi and Simmons.

Wacoal Corporation (JP) – http://www.wacoal.com/Manufacturer of intimate apparel. Wacoal has set up operations in major areas of the world: Europe, America and Asia. The company first entered the performance sports apparel market in Japan in 1991 with CW-X® Performance Conditioning Wear. Recently the company launched the CW-X® brand in the US market through the newly formed Wacoal Sports Science Corp.

Wacoal Sports Science Corp (US) - www.cw-x.com - headquartered in New York City, is a wholly-owned subsidiary of Wacoal International. The company's mission is to meet the sports performance needs of the active US consumer.,
Its main brand is:

- CW-X – Walcoat claims that CW-X is the world's first truly anatomically-engineered high performance sports apparel.
  "**CW-X VersatX tights and tops** are made from Dry-Zone R506 fabric, which offers quick-dry moisture wicking and UV protection. It features fibre nanotechnology incorporating antibacterial silver dioxide for antibacterial freshness and titanium oxide for UPF 50+ protection."

Sinotextiles Corporation LTD (STG) (CN) – www.sinotextiles.texindex.com - is a manufacturer of textiles and garment headquartered in China, The STG member factories are located in more than ten of the Chinese provinces. One of their key brands is:

- **CLEANCOOL** is titled as the first brand in the anti-bacterial (Anti-bacterial function is achieved by fibers containg NANO silver inside), quick wicking and quick drying aspects, which is registered by STC.

MAVI Sud (I) www.mavicosmetics.it Italian manufacturer of cosmetics. Mavi develops Chtin Nanofibrils (CN**),** a natural crystallites resistant up to 240° C. capable to give particular performance in fibre and fabrics.

- **CN** has a high capacity to bind and absorb many active ingredients to be slowly released to the skin. This technology may be used to produce anti-ageing and UVA protective textiles.

GreenYarn (US) - http://sinotextiles.texindex.com/ - is a nanotechnology company that develops advanced materials for consumers seeking eco-friendly alternatives to conventional fabrics. Greenyarn's global HQ is in Boston, Massachusetts.

- **Eco-fabric**, Greenyarn's trademark yarn and fiber is used in many Greenyarn products, and the benefits such as antibacterial, deodorizing and wicking, comes from the way this sustainable fiber is processed. Amongst their products are: different kind of socks, elbow guards, knee guards, wristbands, etc.

HeiQ Materials (CH) - www.heiq.com & www.heiqmaterials.com - HeiQ Materials is a Swiss producer of high-performance textile effects, antimicrobial additives and customised masterbatches.
Two main product lines are:

- **Pure** - is a set of products offered by HeiQ aimed at making textiles antimicrobial for odour prevention in sports ware or use in hygiene demanding applications such as hospitals.
- **Barrier** - is system of water and oil repellent textile products.

Yamamoto Corporation (JP) – www.yamamoto-bio.com - Functional rubber material manufacturer
Products lines include:

- **Super composite Skin (S.C.S) -** material which is applied as a coating / layer over the surface of independent closed cell neoprene – Product examples include swimsuit **Orca Alpha** or Xterra **VertorProX2.**
- **Super composite Skin Metal** – S.C.S Metal is a neoprene material with a special coating of Titanium Alloy applied over the surface of the closed cell neoprene rubber with a further special low friction surface processing applied it.

Nanogist (KR) - www.nanogist.co.kr -Manufacturer of materials in the application of antimicrobial properties of Nano Silver as well as TiO2, TiO2 coated nano silver, and alumina nanotubes.
Nanogist is owner of two commercial brands:

- Nanover
- TiOCAT

Principal Sports Apparel Manufacturers

Some of the most important sports apparel manufacturers using technology from the companies listed above are:

Nike (US) – http://www.nike.com- Leading Company in the design and manufacture of sportswear and sports equipment headquartered in Washington County, Oregon, with annual revenue of US$ 18627 billion (2008). Nike markets its products under its own brand as well as Nike Golf, Nike pro, Nike+, Air Jordan, Nike skateboarding and subsidiaries including Cole Haan, Hurley International, Umbro and Converse.

Adidas group - www.adidas-group.com Global leader in the sporting goods industry. Adidas AG, Reebok and TaylorMade-adidas Golf are the brands of the Adidas group. The company has its headquarters in Herzogenaurach, Germany and had a revenue of €10,38 bilion in 2009.

VF Corporation (US) – www.vfc.com- American Apparel Corporation with annual revenue of $7642,6 million USD (2008). Some brands that form this group are: Eastpak, Jansport, Kipling, Napapijiri, The north face, Reef, Vans and Eagle Creek.

PUMA AG (GR)– www.puma.com- Multinational Company specialized in high-end athletic shoes, lifestyle footwear and other sportswear. The headquarters are situated in Herzogenaurach and in 2007 had a revenue of €2373,5 milion.

AMER SPORTS OYJ (FIN) – www.amersports.com **-** Manufacturer of sporting equipment. The company owns a portofolio of sports brands including Wilson, Atomic, Suunto, Precor USA and USA. The headquarters are situated in Helsinky and had a revenue of €1.577 billion (2008).

NEW BALANCE ATHLETHIC SHOE, INC. (US) –www.newbalance.com - Footwear manufacturer based in Boston. Its total revenue in 2006 was $1,55 billion USD.

JACK WOLFSKIN(D) – www.jack-wolfskin.com -Producer of mountain and leisure clothing, footwear, rucksacks, sleeping bags and tents. The brand is popular among the hikers and mountaineers as well as among urban Germans for the fashionable accessories. The revenue in 2009 was the 251 million €.

HELLY HANSEN (N) – www.helly-hansen.com **-**Producer of textiles and special gear for sports and work on the ocean and in the mountains. The headquarters are situated in Moss and in 2005 the revenue was $228 million.

SPYDER (US) – www.spyder.com -Manufacturer of high-end skiing apparel. Spyder manufactures apparel for the outdoor, snowsports, fly finishing and casual apparel markets. The headquarters are situated in Boulder, Colorado.

Medical Industry Key Players

In the medical industry the key players in the textile sector are:

Johnson & Johnson (US): - www.JNJ.com - Global pharmaceutical and medical devices and consumer packaged manufacturer. Among its consumer products are bandages, Johnson's baby products, Neutrogena skin and beauty products, clean & clear facial wash and Acuvue contact lenses. The corporation's headquarters is located in New Brunswick, New Jersey. The total revenue in 2009 was $61,9 billion.

Baxter Healthcare Corporation(US) – www.baxter.com - Health care company with headquarters in Derfield, Illinois. The company is a subsidiary of Baxter International Inc. Baxter develops, manufactures and markets products to treat haemophilia, kidney disease, immune disorders and other chronic and acute medical conditions. The total sales are estimated in $12,3 billion.

Beiersdorf AG (GE) – www.beiersdorf.com -Manufacturer of personal care products. The total revenue in 2009 was €5,748 billion and amongst its different brands are Elastoplast, Eucerin, Labello, Liposan, Nivea and Marlies Möller. Beiersdorf already sells products that include nanotechnology, including sunscreen and deodorants, and is looking to prove an effective technology for both sunscreen and anti-aging products to use with textiles.

3M Company (US) – www.3M.com - Minnesota Mining and Manufacturing Company. Among the products they manufacture include adhesives, abrasives, laminates, passive fire protection, dental products, electronic materials, electronic circuits and optical films. The company sells an Aldara skin cancer cream that is improved by nanotechnology and is improving using nanotechnology the ScotchGard protectant for use in textiles and clothes. The headquarters are in Mapplewood and the total revenue in 2008 was $25.26 billion.

Smith & Nephew (UK) – www.global.smith-nephew.com - Smith & Nephew is a medical company specializing in Orthopaedic Reconstruction, Orthopaedic Trauma and clinical Therapies; Endoscopy and Advanced Trauma Management. They are involved in business like orthopaedic reconstruction, trauma endoscopy and wound management. Smith & Nephew's has developed the brand Acticoat, a wound management that contains nanocrystalline silver. The Company operates in 32 countries and annual sales in 2007 were nearly $3.4 billion.

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6 ANNEX: EXPERT ENGAGEMENT

This report has been partially based on interviews with the following experts:

Dr Jan Behringer, Hohenstein Institute Germany
Dr. Guy Buyle, CENTEXBEL Belgium
Dr. Dirk Hegemann, EMPA Advanced Fibres Switzerland
Javier Pascual, AITEX Spain
Roshan Paul, LEITAT Spain
Prof. Maria Letizia Terranova - Univ. Roma Tor Vergata - Italy
Prof. Pierfrancesco Morganti - MaviSud - Italy
Prof. Cosimo Carfagna - Univ. Napoli - Italy
Prof. Danilo De Rossi - Univ. Pisa - Italy
Prof. Giorgio Mazzuchetti - CNR-ISMAC - Biella - Italy