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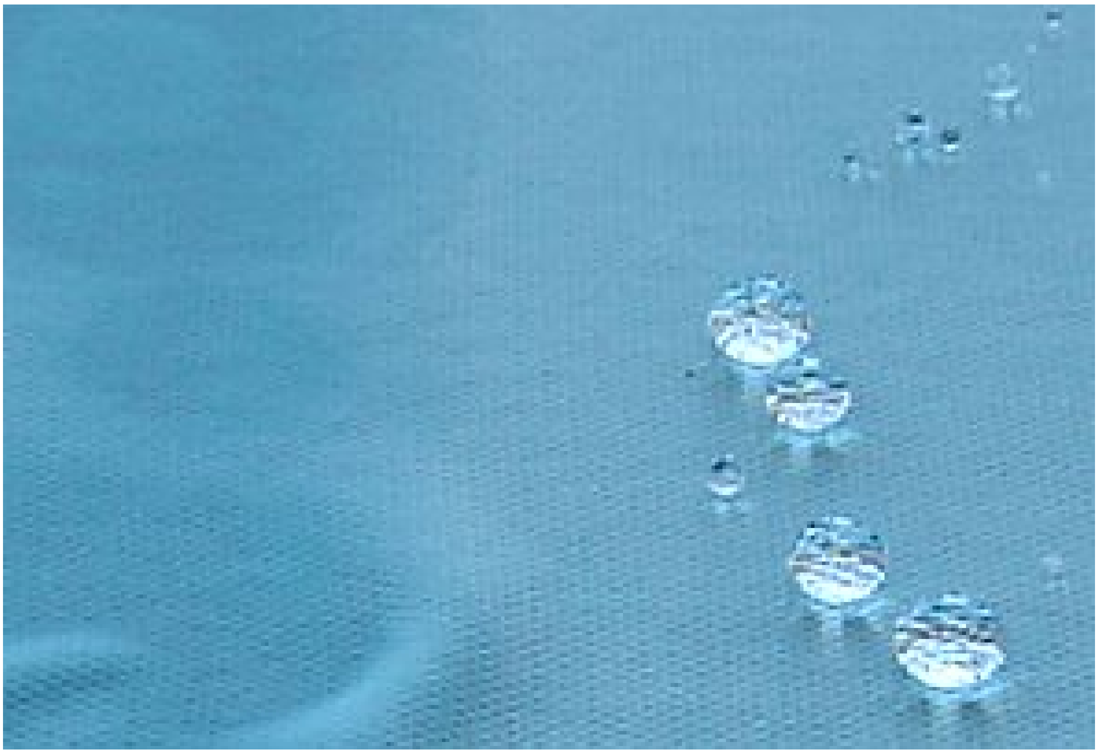
NanoTextiles:

Functions, nanoparticles and commercial applications



Semester Thesis in the frame of the "Nanosafe-Textiles" project
TVS Textilverband Schweiz and Empa

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Abstract

The semester thesis here present was written in the frame of the “Nanosafe Textiles” project of the TVS Textilverband Schweiz and the Empa St. Gallen. In a first part, it gives an overview over nanotechnology related research activities in order to point out textile functions which can be achieved by nanoengineering. For each textile function, the used nanoparticles are listed together with the applied production methods to give references about how the respective nanoparticle (NP) could be bound in the textile matrix and thereby provide a basis for later exposure risk assessments. In a second part, an Internet research for nanoengineered textile products was run to draw a spectrum of possible commercial applications. The found consumer goods were then sorted according to their function and scanned for available information about the used nanoparticles and production methods.

1 Introduction

Over the last few years, the development of nanotechnology has attracted increasing investments from both industries and governmental institutions in many parts of the world. The global annual sum invested in the development of nanotechnology has been estimated to about 5 billion Euro while the number of published patents has risen from 531 in 1995 to 1976 in the year 2001 [1]. Possible applications of nanotechnology can be found in a very wide range of industries and products, as for example medical appliances, communication technologies or biotechnology. Also in the textile sector, nanotechnology is expected to hold considerable potential for the development of new materials. Apart from improving their functionality, the use of nanoengineering could lead to the production of textiles with completely novel properties or the combination of various functions in one fabric. These “multifunctional” textiles could open the way for the use of textile products in applications fields outside of the traditional industries as for example in the construction or medical sector. From an environmental point of view, nanotechnology probably includes both chances and risks. On one hand, Nanotechnology could provide an alternative to the integration of potentially hazardous chemical additives (e.g. flame retardant substances) or lead to more environmental friendly production methods. On the other, various NGOs have expressed their concern about possible effects on human health trough the exposure to nanoengineered materials, potential environmental impacts and the lack of regulatory measures [1]. The semester thesis here present was written in the frame of the “Nanosafe-Textile“ project of the TVS Textilverband Schweiz and the Empa St. Gallen. Its goal is to examine the nanotex related research activities to assess which textile-properties can be achieved trough nanoengineering and which are the nanoparticles (NP) and nanostructures used to obtain the desired functions. Furthermore, some of the most common production procedures for nanoengineered textiles which are currently under investigation are pointed out in order to give indications about the form in which the NP could be present in the textile matrix of the finished fabric. The information gained thereby should provide a basis for later exposure risk assessments. In a second part, the semester thesis draws a spectrum of possible commercial applications of nanoengineered textiles. To assess for which applications products are already on the market, an Internet research for available consumer goods was conducted. The found products where then sorted according to their function and listed together with the available information about the incorporated nanostructures and the used production methods.

2 Definitions

The following paragraph defines the nanotechnology related expressions used in this study. For many nanotechnology related terms, there are no internationally valid definitions yet. With regard to expressions like “nanoparticle” and “nanoscale” various diverging definitions can be found in literature. The definition and classification of these terms are under discussion by the ISO working group TC 229 which is currently working on a universally valid terminology in the field of nanotechnology [2].

Textile products: Textile products are considered to be all consumer gods which are entirely or partly made of a textile fabric. Also included are products which are used during the industrial production process of such goods and remain in the material of the end product, as for example industrial coating agents or textile additives. Furthermore listed as textile products are licenses for textile-production or -finishing methods. Not included are coating agents which are directly sold to and applied by the end consumer, as for example impregnation agents for shoes or jackets.

Nanotechnology: The term is used as defined by [3]: Nanotechnology is understood as **“**research and technology development at the atomic, molecular, or macromolecular levels using a length scale of approximately 1-100nm in any dimension” including the ability to “control or manipulate matter on an atomic scale”. The created structures, devices or system must moreover “ show novel properties and functions because of their small size” [3].

Nanoengineering: Use of nanotechnology during a production- or finishing-step of a product.

Nanoengineered textiles: Textiles or textile products in which nanotechnology is used during a production- or finishing-step.

Nano-textiles: Same as nanoengineered textiles

Nanoscale: Approximately 1-100nm

Nanoparticle: Structures with three dimensions in the nano-scale.

Nanoporous: Structures with pore sizes in the nano-scale.

Nanofibre: Fibers which have a diameter in the nano scale. Nanofibres can be produced trough electrospinning of a textile polymer, as for example polyethylene (PE).

Nanostructure: Collective term for structures in which one (e.g. layer with less than 100 nm thickness), two (nanorods or nanotubes e.g. CNT or nanowires) or three dimensions (e.g. nanoparticles) are in the nano scale.

Nanocomposites: Composites of different materials or chemical substances in which at least one component includes a NP or other nanostructure.

Nanoclays: Nanoclays are common layered silicates, as for example montmorillonite, which are often organically modified to render them organophilic and to enable their dispersion into a polymer [4]. The result of such a dispersion is a Nanokomposite comprised of nanoscale clay particles and a surrounding polymer.

3 Methods

3.1 NanoTextile related research

Information about textile-functions that can be achieved trough nanoengineering and the used NP and production methods was gained trough the examination of nano-textile related research activities. A search for published scientific papers was run on the 23.05.2007 in the Thomson Scientific Web of Science database [5] by using the search string "nano* and textil*". The result yielded more than 250 papers of which many were related to treating textile waste water trough nanofiltration. To exclude these, for this study not relevant publications, a second search was run with a more selective search string ("nano* AND textil* AND (nanoparticle* or nanotube* or nanocrystal* or particle* or nanosize* or nanoclay* or nanocoating or nanofib* or nanolayer* or nanostruct* or nanospher*)) which yielded a total of 137 papers. Of these 137 papers, 53 were related to the development or production of nanoengineered functional textiles while the remaining papers concerned topics without relevance for the goal of this study (e.g. degradation of textile dyes trough nano-scaled catalysts, description of analytical methods for the characterization of NP in textiles, etc.). The found 53 papers were sorted according to the possible textile-functions which the research group tried to achieve. For each function, the papers were then reviewed with regard to used NP, applied production methods and the integration into the textile matrix in the finished fabric.
In some of the studied papers, the incorporated structure or particles which were called "nano" by the authors were far bigger than 100nm and therefore actually out of the scale which is defined in chapter 2. Papers for which this was the case are still mentioned in the research review in chapter 4, designated with a footnote about the dimensions of the used structure. Not included in chapter 4 are papers in which the used nanostructures are nanofibres produced by electrospinning. The resulting fibers are integrated into a fibrous web, comprised of bigger, interrelated structures. We assumed that in these cases, the potential risks of an exposure to NP or nanostructures would not be bigger than in conventional textiles.

3.2 Application fields and commercial products

The possible commercial applications described in chapter 5 are based on propositions made in the examined research papers and on an Internet research for manufactures who claim to use nanoengineering in their products. The Internet research was conducted by reviewing different existing online consumer inventories and nanotechnology related news pages. A list of the screened inventories and pages is added in the Appendix. Information about the used NP or the nanostructure in the commercially available products is based on statements of the manufacturer. Commercial products for industrial clients as for example nanoengineered coating agents or textile additives are included into the listed applications, not included are textile coating or impregnation agents for the end consumer, as their not considered being “textile products” (see paragraph 2).

4 Nanoengineered textiles: Possible functions, used NP and production methods

The following chapter describes the nanotechnology related research on the Web of Science with the aim to draw a spectrum of the textile functions which might be achieved trough nanoengineering. It points out the different NP and production methods that are currently under investigation. The mechanism that leads to the desired effect is shortly described for each textile function together with the incorporated NP/nanostructure, the textile matrix, the applied production method and the form in which the NP occurs in the finished fabric. An overview on which NP can be used to achieve a certain textile function is given in paragraph 4.10.

4.1 Conductive / Antistatic textiles

Antistatic or electromagnetic shielding functions in textiles can be achieved by increasing the conductivity of the fibers. Synthetic textile polymers, as for example polypropylene (PP) or polyethylene (PE), generally have a rather low electric conductivity and therefore act as isolators. To be able to create a conductive material which still shows the in terms of manufacturing favorable mechanical properties of the polymers, small metal particles, conductive polymers (e.g. polypyrrole, polyanilline, polythiophen) or also carbon nanoparticles (Carbon Nanotubes (CNT), Carbon Black (CB)) can be included into the polymer matrix [6, 7].
One example for the possibility to increase the conductivity of textiles by using metal NP is the work of [8] where the production of a nanostructured copper-coating on the surface of polypropylene (PP) and polyamide (PA) fibers led to better surface conductivity. As reported by [7], the same effect can be achieved by the dispersion of CB particles into a polymer solution and subsequent electrospinning. For the integration of CNT into textile relevant polymers, efforts have been made by research groups around the world [9]. Most

of the examined research papers focused on the effect on the mechanical properties([9-12] see paragraph 4.2), as for example increased tensile strength or higher elasticity, but it is also possible to produce fibers with increased electrical conductivity trough the integration of CNT. [13] reports that such fibers were produced in different research projects by using polyaniline composites with incorporated CNT: [14] and [15] obtained fibers with increased conductivity trough the production of a CNT containing polyaniline dispersion and subsequent wet spinning. [16] achieved the same effect by dip-coating hollow PP fibers with CNT containing polyaniline dispersion. [17] obtained textiles with increased conductivity trough dip and spray coating the finished fabric with a dispersive CNT solution. Another possibility is the coating of finished textiles with nano-thin layers of conductive polymers, as for example polypyrrole or polyaniline. Polypyrrole was either applied by hand brushing , by dip- or spray- coating the finished textile with a nanoparticulate emulsion [18] or by solution- or vapor polymerization of the polypyrrole on the textile surface [18-20]. Polyaniline was applied by solution polymerization [20].

Table 1: *NP, textile matrices and production methods reported in the examined research papers for conductive textiles. The last column shows the form in which the NP occur in the finished fabric.*

NP / Nano-structure	Textile material	Production method	Integration into the textile matrix
Cu	PP/ PA	physical vapor deposition: sputter coating [8]	Homogeneous Cu-layer, some nm thick
CB[1)]	polyurethane (PU)	electrospinning of PU dispersion with CB [7]	CB-nanoparticles in nm thin PU fibre
CNT	not specified	dip or spray coating of finished textile [17]	Some SWCNT cluster on the fibre surface
	PP	dip-coating with polyaniline / CNT dispersion [16]	CNT in polyaniline matrix and as composite layer on and in PP hollow fibre
	-	wet spinning of dispersive CNT / polyaniline solution [14, 15]	Polyaniline CNT composite fibre
polypyrrole	viscose, wool	vapor or solution polymerization of polypyrrole on the textile [18, 19]	Homogenous layer of polypyrrole on the fabric, partial penetration of polypyrrole into fibre interior, Aggregates of polypyrrole on the fibre surface, complete

1) CB in dispersion: 400-1700nm

			penetration of polypyrrole into interior of fibre.
	wool	hand brushing , dip or spray coating of finished textile with a polypyrrole emulsion [18, 19]	Non homogeneous, nanoporous polypyrrole layer
polyaniline	polyester	solution polymerization [20]	Polyaniline layer on PET fibre

4.2 Reinforced textiles / Tear and wear resistant textiles

Nanotechnology can be used to change and improve the mechanical properties of textile fibers according to the corresponding application. Such properties include increased tensile strength, elasticity or fiber stiffness [11, 21-23]. These properties can lead to the production of stronger or more elastic textiles or increase the tear and wear resistance of a fabric.

The probably most investigated way of improving the mechanical properties of textiles trough nanoengineering is the integration of CNT which was found to increase tensile strength or elasticity significantly [10-12, 21, 24]. CNT reinforced fibers were produced by melt compounding CNT with polystyrene (PS) and polypropylene (PP) [11] or the production of a CNT-PP Masterbatch [10], both followed by melt spinning. [24] uses the co-flowing of a CNT dispersion during solution spinning to produce reinforced polyvinyl-alcohol (PVA) fibers. [12] reports the production of PVA-CNT-composite fibers with increased strength by a modified solution spinning process. CNT can also be applied to the fabric by spray-coating or simply dipping the textile into a CNT solution [17] . Apart from CNT, also other NP were reported to alter or improve the mechanical properties of the textile fibers. The appliance of a ZnO nanoparticle based coating was observed to increase the stiffness of a fabric. The coating was thereby applied by dipping the fabric into a nanodispersive ZnO solution and a subsequent dry-pad-cure process [25]. [26] used a similar process to provide different textile materials with a nanoparticulate Al_2O_3 coating which led to an increase in fracture toughness. To optimize the mechanical properties of carpet backings, [27] used a PS – composite containing polybutylacrylate (PBA)-NP as coating. [28] furthermore reports the possibility to increase the abrasion stability of polyester by treating the finished fabric with a SiO_2 coating. The coating is produced trough a sol-gel process which involves the production of a nanoparticulate SiO_2 dispersion.

Table 2: *NP, textile matrices and production methods reported in the examined research papers for textiles with altered mechanical properties. The last column shows the form in which the NP occur in the finished fabric.*

NP / Nanostructure	Textile material	Production method	Integration into the textile matrix
CNT	PVA	Co-flowing stream of CNT-dispersion during solution spinning [24]	No information
	PVA	modified solution spinning process of CNT dispersion [12]	PVA coated CNT
	PS, PP	melt compounding and subsequent melt spinning [10, 11]	PS CNT composite
	not specified	dip or spray coating of finished textile [17]	Network of CNT clusters on fibre surface
ZnO	cotton	coating of finished fabric by dip pad dry cure method [29]	ZnO NP coating
Al_2O_3	not specified	dip coating of finished fabric [26]	Single Al_2O_3 particles on the surface
SiO_2	polyester	coating of finished fabric by sol-gel process [28]	Nanoporous SiO_2 coating as a crosslinked network
Polybutylacrylate (PBA)- NP[1)]	not specified	production of PBA/PS nanocomposite by two stage solution polymerization; dip coating of the finished fabric with aqueous dispersion of the obtained composite [27]	PBA/PS nanocomposite coating

[1)] PBT-particles in the produced nanocomposite: 170-212nm

4.3 Antibacterial textiles / „Anti-odour“ textiles

According to [28], biocidal textiles can basically be divided into three groups:

1. Textiles with photoactive properties
2. Textiles with non diffusible biocides
3. Textiles with controlled release of the embedded biocide

One example for the first group would be the coating of a fabric with TiO_2 [30]. Trough the absorption of light, the valence electrons of TiO_2 can be lifted into a higher energetic state, which produces excited charge carriers, an electron and a positively charged electron-hole. The positively charged holes can cause the oxidation of organic molecules while the electrons can react with oxygen and lead to the formation of hyperoxid radicals which also attack and oxidize the cell membranes of microorganisms [31]. The described photocatalytic process can lead to the degradation of stains, so that TiO_2 can also be used for the production of self cleaning textiles (see paragraph 0).
In the textiles of the second group, the biocide is immobilized in the textile-matrix itself or in the matrix of a coating. The antibacterial effect is then caused by the interaction between the positively charged biocide and the negatively charged cell membranes which damages the microorganism and inhibits their growth and reproduction [28].
The third group is comprised of coatings where the biocides (e.g. triclosan, Ag^+, Cu^{2+}) diffuse out of the matrix. In the case of metallic antibacterial agents, the nanoparticles in the matrix are oxidized by air. The formed cations then diffuse out of the matrix and lead to the inhibition of bacterial growth [28].
In the majority of the examined research papers, Ag, TiO_2 or a combination of both NP were used to achieve a biocidal effect [30, 32-40] . In a research paper by [41], the desired effect in the textile is reached trough the integration of ZnO nanoparticles while [42] uses Chitosan Core-Shell-NP to obtain an antibacterial coating for cotton fabrics. [28] furthermore mentions the possibility of including different organic (e.g. Triclosan, chitosan) or inorganic biocides (Ag, Cu), into the matrix of a silica coating.
In most of the examined research papers, TiO_2 is applied to the textile by sol-gel processes [33, 34, 39, 43]: In a first step, a TiO_2 dispersion with a particle size of about 50 nm, a so called nanosol, is prepared [28]. The fiber, yarn or finished fabric is then dipped into the nanosol which leads to the aggregation of the particles on the textile surface and the formation of a solvent-containing lyogel layer. The lyogel is then heated to remove the solvent and a solid, porous xerogel layer is obtained [28]. The antibacterial coatings mentioned by [28], where the biocides are embedded into a Si-matrix are also the result of sol-gel processes. [35], [41] and [36] use different dip-pad-dry-cure methods to provide the textile with an antibacterial Ag, Ag/TiO_2 or ZnO coatings. The textile is dipped into a nanosol and afterwards dried and heated to remove the solvent. [37] obtains an antibacterial coating using a layer by layer deposition method where the finished fabric is dipped sequentially into an Ag-nanosol and a polyelectrolyte solution. Other possible methods to produce an antibacterial coating include the co-sputtering of Ag-NP during plasma polymerization [38] or the deposition of TiO_2 NP by chemical vapor deposition [44].
In contrast to procedures in which NP are applied as a coating, it is also possible to incorporate them at an earlier stage of the manufacturing process, for example trough direct

melt compounding of Ag and the textile polymer [40] or the production of Ag /PP Masterbatches and subsequent melt spinning [32].

Table 3: *NP, textile matrices and production methods reported in the examined research papers for biocidal textile properties. The last column shows the form in which the NP occur in the finished fabric.*

NP / Nanostructure	**Textile matrix**	**Production method**	**Integration into the textile matrix**
Ag	polyester, cotton, spandex	coating of finished textile by dip-pad-dry-cure method [35, 36]	some Ag NP on textile surface, partial diffusion into the textile
	PA , silk	production of Ag/PP Masterbatch, melt spinning [32]	PA/Ag nanocomposite in PP matrix
	PP	melt compounding of Ag/PP [40]	PP/Ag nanocomposite in PP matrix
	PP	production of Ag/PP Masterbatch, melt spinning [32]	PP/Ag nanocomposite in PP matrix
	not specified	acetylene/Ag coating of finished fabric: Plasma polymerization of acetylene with co-sputtering of Ag-NP[38]	some Ag NP on nanoporous acetylene coating
TiO_2	cotton, cellulose fibers	coating of finished fabric by sol gel process [33, 34, 39, 43]	TiO_2 NP on textile surface Some TiO_2 NP on cotton
	cotton	coating of finished fabric by plasma enhanced chemical vapor deposition [44]	1 µm TiO_2 coating on fiber
Ag + TiO_2	cotton	coating of finished textile by dip-pad-dry-cure method [35]	Some Ag NP on textile surface
ZnO	cotton	coating of finished textile by dip-pad-dry-cure method [41]	Starch matrix coating with ZnO NP

Chitosan-polybutylacrylate (PBA)-NP[1)]	cotton	Production of NP with a PBA core and a chitosan shell, coating of finished textile with these NP by dip-pad-dry cure method [42]	PBA chitosan NP coating
SiO_2 matrix with embedded biocides	not specified	addition of biocides to Si nanosol, coating of finished textile by sol-gel process [28]	Nanoporous SiO_2 coating as a crosslinked network

4.4 "Self cleaning" textiles / textiles with antiadhesive properties

"Self cleaning" properties in textiles can basically be achieved by three different processes. One is the integration of NP that act as photocatalyst and are able to degrade organic dirt and stains [30, 31] (Section A). The second method is the production of superhydrophobic surfaces which provide stain and grime repellency and are "self-cleaned" by the rolling water drops that collect dust and other debris [31, 45] (Section B). Furthermore, antiadhesive surfaces with repellent properties towards specific compounds or substances, as for example proteins, can be designed trough nanoengineering [28] (Section C).

A) Photocatalytic coatings

In the examined research papers, stain degrading properties in textiles were achieved by coating the fabric with nanoparticulate TiO_2. A TiO_2 nanosol was produced and applied to the fabric by the dip-pad-dry-cure technique. The textile fabrics were comprised of cotton, wool-polyamide and polyester fibers [30, 33, 34, 39]. When exposed to light, the electrons of TiO_2 are lifted into an excited state and electron/hole pairs in the valence band region are formed which leads to the formation of superoxid and hydroxyl radicals [30]. These radicals are then able to oxidize organic material adsorbed at the surface and lead to the degradation of stains. As the formed radicals also attack the membranes of microorganisms, textiles which are coated with TiO_2 also show antibacterial effects (see paragraph 4.3).

***Table 4:** NP, textile matrices and production methods reported in the examined research papers for stain degrading textiles**.** The last column shows the form in which the NP occur in the finished fabric.*

NP / Nanostructure	Textile matrix	Production method	Integration into the textile matrix
TiO_2	cotton, wool/PA,	coating of finished fabric by sol gel process [30, 33,	TiO_2 NP on textile surface

1) Chitosan-PBA NP: 300nm

	polyester	34, 43]	some TiO_2 NP on cotton

B) Hydrophobic surfaces

Attempts to produce super hydrophobic textile surfaces have been made by research groups trough the integration of CNT, silica-NP (Si-NP) and fluoro containing polymer-NP [46-48]. In all three cases, the NP were applied to the textile fabric in form of a coating: [48] produced an emulsion containing fluoroacrylate copolymer NP which was then applied as a coating to nylon and polyester fabrics. Si-NP were applied to cotton fabrics by the production of a nanosol and a subsequent dip-pad-dry-cure-process [49]. In the third case, hydrophobic properties could be achieved by producing artificial lotus leaf structures on cotton fiber-surfaces trough the application of modified CNT using a common dip-dry-cure method [46].

***Table 5:** NP, textile matrices and production methods reported in the examined research papers for hydrophobic textiles. The last column shows the form in which the NP occur in the finished fabric.*

NP / Nanostructure	Textile matrix	Production method	Integration into the textile matrix
CNT	cotton	coating of finished textile by dip-dry-cure method [46]	absorbed CNT on cotton Network of CNT cluster around every fibre
CNT grafted with Polybutylacrylate (PBA)	cotton	grafting of CNT with PBA, coating of finished textile by dip-dry-cure method [46]	absorbed CNT on cotton PBA shells penetrate in cotton and forming a durable linkage
SiO_2 1)	cotton	production of SiO_2 nanodispersion, coating of finished textile by dip-pad-dry-cure method [49]	some SiO_2 aggregates on cotton
fluoroacrylate-NP	polyester, PA	coating of finished textile with nanodispersive fluoroacrylate-polymer emulsion [48]	fluoroacrylate coating

C) Surfaces with antiadhesive properties

[28] reports the production of antiadhesive wound dressings by coating viscose fabrics with a modified SiO_2 coating.

***Table 6:** NP, textile matrices and production methods reported in the examined research papers for antiadhesive textiles. The last column shows the form in which the NP occur in the finished fabric.*

NP / Nanostructure	Textile matrix	Production method	Integration into the textile matrix
SiO_2 matrix with embedded hexadecyl-triethoxysilane	viscose	addition of hexadecyl-triethoxysilane to Si-nanosol, coating of finished textile by sol-gel process [28]	SiO_2 network matrix

1) SiO_2 particles after the coating: 60-200nm

4.5 Moisture absorbing textiles

As described in paragraph 4.4, nanoengineering can lead to the production of hydrophobic surface, but also the opposite, the development of hydrophilic surfaces is possible. Apart from the attempts to obtain moisture absorbing functions in a textile which are described in this paragraph, hydrophilic surface modifications can also improve the dyeing properties of a fabric. The research papers related to this topic are described in paragraph 4.6. One possibility to obtain a textile with moisture absorbing functions might be the integration of TiO_2 which increases the water absorbance at the surface through a photocatalytic process. The “electron holes” that emerge when TiO_2 valence electrons are lifted into an excited state oxidize lattice oxygen, leaving vacancies that can be filled by absorbing water [28]. [50] obtains hydrophilic properties by the deposition of thin films of TiO_2 alternating with poly(dimethyldiallylammonium chloride) (PDAC) on polyethylene fibers by a layer by layer deposition method.

Table 7: *NP, textile matrices and production methods reported in the examined research papers for hydrophilic textiles. The last column shows the form in which the NP occur in the finished fabric.*

NP / Nano-structure	Textile matrix	Production method	Integration into the textile matrix
TiO_2	PE	layer by layer deposition [50]	coating with negative loaded TiO_2-NP layer and positive loaded poly(dimethyldiallyl-ammonium chloride) (PDAC)

4.6 Improved colourability / Enhanced bleaching resistance

In connection with the dyeing of textiles, nanoengineering can fulfill the following functions:

1. Nanoparticulate pigments can directly be used as dyes [51].
2. Textile surfaces can be treated with nanostructured coatings to render them hydrophilic and improve their colourability [38].
3. Dyes can be included into nano-thin coatings to improve bleaching resistance and leaching stability [28].

The use of nanoparticles as dyes is reported in [51] where cotton-, acrylic-, and nylon fibers are dyed with surface modified CB. The hydrophobic CB particles were thereby modified to obtain carboxylic surface structures which made the absorption of the CB to the textile fibers possible. To improve the colourability of textiles surfaces, [38] produces a hydrophilic nano-thin coating trough plasma polymerization of C_2H_2 mixed with ammonia. The resulting

hydrophilic coating and the included functional groups can enable substrate independent dyeing. After coating the surface of polyester fabrics, the textile was dyed with acid dyestuffs. Without surface modification, this would be impossible due to the lack of amino groups on the polyester surface which are needed for the dye-fiber reaction mechanism of this group of dyestuffs [38].
As mentioned above, nanoengineering can also be used to improve the bleaching resistance and leaching stability of textiles dyes [28]. These properties can be achieved trough the integration of dyes into an inorganic nanosol (silica or metal-oxid nanosols) which is then applied to the textile as a coating. The immobilization of the dye in the nanosol matrix significantly reduces the leaching fastness [28]. Particularly good results can be achieved by using mixed metal oxide nanosols (e.g. aluminium or titanium oxides in a silica oxide sol) which are able to form complexes with anionic dyes. In terms of bleaching resistance, the nanosol-dye-coatings can be optimized by the addition of an organic UV-absorber to the nanosol [28].

Table 8: *NP, textile matrices and production methods reported in the examined research papers for improved colourability and enhanced bleaching resistance. The last column shows the form in which the NP occur in the finished fabric.*

NP / Nanostructure	**Textile matrix**	**Production method**	**Integration into the textile matrix**
SiO_2 matrix with embedded dyes or UV absorbers	not specified	addition of UV-absorbers to Si nanosol, coating of finished textile by sol-gel process [28]	nanoporous SiO_2 matrix with dye and UV absorber
CB	polyamid, cotton, acrylic fibers	dying of finished textiles with CB by exhaustion process [51]	CB with COOH for hydrogen bonding to cellulose
nanoporous hydrocarbon coating	polyester	coating of finished textile by plasma polymerization [38]	nanoporous, crosslinked hydrocarbon network with nitrogen functional groups (a-C:H:N)

4.7 UV-blocking textiles

The UV blocking properties of textiles can be improved by the integration of metal particles, dyes, pigments or the application of a UV-absorbing finish to the fabric [52]. The examined research paper all focus on the application of such finishes to achieve the desired effect. [25] reports the application of a nanoparticulate ZnO- finish to cotton fabrics by means of a dip-pad-dry-cure-method. A similar coating, where soluble starch was added during the synthesis of ZnO-NP to inhibit their agglomeration also led to enhanced UV-blocking [41]. Another possibility to produce cotton fabrics with UV-blocking properties is their coating with a nanoparticulate TiO_2 film by sol-gel-process using the dip-pad-dry-cure method [43].

Apart from the options described above, [28] furthermore mentions the possibility of including organic UV absorbers (e.g. benzotrialzoles) into a Si-nanosol which can then be applied to the fabric using sol-gel techniques.

Table 9: *NP, textile matrices and production methods reported in the examined research papers for UV-blocking textiles. The last column shows the form in which the NP occur in the finished fabric.*

NP / Nano-structure	**Textile matrix**	**Production method**	**Integration into the textile matrix**
ZnO	cotton	coating of finished fabric by dip-pad-dry-cure method [25, 41]	no information
TiO_2	cotton	coating of finished fabric by sol gel process [43]	Some TiO_2-NP on the fibers
SiO_2 matrix with embedded UV-absorbers	not specified	addition of UV-absorber to Si- nanosol, coating of finished textile by sol-gel process [28]	nanoporous SiO_2 coating as a crosslinked network with UV absorbers

4.8 Flame retardant textiles

The integration of several kinds of nanocomposites have been found to cause flame retarding effects [53]. Due to its low price, many research projects focused on the production of montmorillonite-nanoclay containing composites to achieve these properties [54-58], but also boroxosiloxanes or Sb_2O_3 containing nanocomposites were reported to inhibit the combustion process [53]. A further possible method seems to be the use of CNT which led to enhanced flame retardance when incorporated into a ethylene-vinyl acetate (EVA) polymer-matrix [59]. The exact mechanism of the combustion inhibition caused by the nanoclays is not yet known, but it is presumed that while the polymer matrix is burned and gasified during combustion, the incorporated nanoclays accumulate at the surface and form a barrier to oxygen diffusion, thereby slowing down the burning process [53]. According to [53], the integration of nanoclay-composites alone is not sufficient to provide a fabric with reliable combustion protection: The nanoclays do slow down the burning process and enhance the char formation, but they have no effect on the ignition tendency and after flaming properties. Recent research indicates, that optimized properties can be achieved by combining the nanocomposites with low concentrations of conventional flame retardants [55, 58].

For the integration of the described nanocomposites into textile fabrics, mainly two process pathways are possible [56]. For both application pathways, the nanoclay or nanoparticle is melt blended with the polymer material [54-58] Before this process, the nanoclays have to be modified by replacing the (sodium-) cations found between the clay layers with other, sufficiently organophilic ions to make the integration and dispersion of the nanoclays in the polymer matrix possible [53]. One possibility to incorporate these nanocomposites into textiles is by melt spinning them into yarns which can subsequently be knitted or woven to textile fabrics [57] .The second possibility is to apply the produced polymer-nanoclay composite as a coating to finished textiles [56, 57], as for example cotton or polyester fabrics.

Table 10: *NP, textile matrices and production methods reported in the examined research papers for flame retardant textiles. The last column shows the form in which the NP occur in the finished fabric.*

NP / Nano-structure	Textile matrix	Production method	Integration into the textile matrix
montmorillonite	PA	melt blending and melt spinning [57]	exfoliated nanoclay
	PU, cotton	melt blending of PU and nanoclay, application of resulting nanocomposite as coating to cotton fabric [56]	PU nanoclay matrix as cotton coating
	styrene acrylonitrile	melt blending and screw extrusion [54]	intercalated and exfoliated nanoclays in styrene acrylonotrile matrix
	PP	melt compounding [58]	no information
	PP	melt blending and compression molding [55]	no information
Sb_3O_2	not specified	not specified [53]	no information
boroxosiloxane	PP	melt blending and compression molding [60]	no information
CNT	ethylene-vinyl acetate (EVA)	melt blending of CNT and EVA [59]	CNT in EVA matrix

4.9 Controlled release of active agents, drugs or fragrances

Nanoengineering can be used to produce fibers that act as carriers for drugs, fragrances or other active agents and enable the controlled release of the incorporated species. Research projects with the aim to produce antibacterial fabrics trough the controlled release of a biocidal agent are described in paragraph 4.3, projects where the active species are not a biocide are described in this section. [61] used a montmorillonite-nanoclay as carrier for cosmetic jojoba oil substances to produce nylon fibers which could find applications in skin care products. The jojoba oil and nanoclays were incorporated into the polyamid-matrix by direct melt compounding. [28] reports the possibility of producing fibers with controlled release of different agents (e.g. drugs, ethereal oils, or insect repelling fragrances) by including them into a SiO_2-Nanosol coating.

Table 11: *NP, textile matrices and production methods reported in the examined research papers for textiles with controlled release of active agents. The last column shows the form in which the NP occur in the finished fabric.*

NP / Nano-structure	Textile matrix	Production method	Integration into the textile matrix
SiO_2 matrix with embedded active agents	not specified	addition of active agents to Si nanosol, coating of finished textile by sol-gel process [28]	nanoporous SiO_2 coating as a crosslinked network
montmorillonite	PA	melt compounding [61]	exfoliated nanoclay in PA matrix

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4.10 Overview over used NP and resulting properties

The following table gives an overview over the nanoparticles or nanostructures that were used in the examined research papers to produce the described functional textiles. As further functions that might be achieved trough nanoengineering of textiles but which were not explicitly mentioned in the examined research papers, luminescent textiles [62] and textiles with increased or decreased thermal conductivity [63] are added to the table below.

Table 12: Overview over functional textiles and the NP or nanostructures used in the examined research papers.

Functional textile	**NP / nanostructure**
conductive / antistatic textiles	- CB - CNT - Cu - Polypyrrole - Polyaniline
reinforced textiles / tear and wear resistant textiles	- Al_2O_3 - CNT - polybutylacrylate - SiO_2 - ZnO
antibacterial	- Ag - chitosan - SiO_2 1) - TiO_2 - ZnO
"self-cleaning" textiles / textiles with antiadhesive properties	- CNT - fluoroacrylate - SiO_2 1) - TiO_2
moisture absorbing textiles	- TiO_2
improved colourability / enhanced bleaching resistance	- CB - nanoporous hydrocarbon-nitrogen coating - SiO_2 1)
UV-blocking textiles	- TiO_2 - ZnO
flame retardant textiles	- CNT - boroxosiloxane - montmorillonite - Sb_3O_2
controlled release of active agents, drugs or fragrances	- montmorillonite - SiO_2 1)
luminescent textiles	no information
thermal conductive / insulating textiles	no information

1) SiO_2- nanosol-coating as matrix for embedded active species (biocides, dyes, fragrances)

5 Application fields and commercial products

The following chapter describes commercial applications of the different functional textiles listed in chapter 4 and shows the results of an Internet research for available nanoengineered consumer goods. The commercial applications described in the first paragraph of each section are based on the propositions in the examined research papers. The proposed products are assigned to the following product groups: Apparel, protective clothing, interior trim and upholstery, sports and leisure, household, cosmetics, medical appliances, construction materials, industrial uses and auxiliary/intermediate products for industrial processes. The last product group includes all products which are not sold directly to the end consumer but which are purchased by industrial clients and used during the production process of a nanoengineered end product. Examples for such auxiliary or intermediate products would be textile additives, fabrics that are processed on into apparel or furniture, or also licenses for the use of a certain production procedure or technology. For each functional textile, the second paragraph shows the results of the conducted Internet research for products whose provider claims to use nanoengineered textiles. The found consumer goods are shortly described together with the information about the used NP or nanostructure provided by the supplier.

5.1 Conductive / Antistatic textiles

<u>Product groups and possible consumer goods</u>

Conductive textiles could find applications in the following product groups: Apparel, interior trim and upholstery, protective clothing and products for industrial uses. In the apparel sector, conductive textiles can be used to produce antistatic clothing [6, 64]. Furthermore, they might be used to develop “smart-clothes” with integrated sensors which could for example measure heart rate or body movements. The conductive textiles might thereby take the role of the sensor (textiles that increase or decrease their conductivity, e.g. when stress is applied) or be used to transmit electronic signals form other sensors to integrated electronic devices [65]. In the product group related to interior trim and upholstery, conductive fabrics could be used to produce antistatic furniture textiles [66]. Another possible application would consist in the production of carpets or floor coverings with electromagnetic shielding functions which could protect underlying electronic devices [67]. In industrial processes, conductive textiles could find applications in antistatic dust filters and bulk containers which would prevent explosions caused by spark discharges [67]. Possible applications in the production of protective clothing include suits for the protection of static discharges or clothing with electromagnetic shielding functions [28].

<u>Commercially available products</u>

Related to the above described product groups, the following commercially available goods could be found on the Internet: Auxiliary products include production methods that yield antistatic and conductive textile properties or additives that promise the same effect [66, 68, 69]. [68] declares to use polypyrrole and polyaniline. Consumer end products could be found in the apparel sector where nanoengineered clothing is available in form of antistatic jackets, pants, caps and gloves [70]. [71] furthermore offers “SmartShirts” made of conductive fabric with included sensors to measure heart rate, body temperature or respiration.

Table 13: *Possible commercial applications for conductive / antistatic textiles. Examples for consumer products which could be found on the Internet are listed together with the available information about the incorporated NP or nanostructure.*

Product group	Product description	Examples of available products	NP
apparel	antistatic clothing	[70]	
	“smart clothes” with sensing functions	[71]	
interior trim and upholstery	antistatic furniture	-	
	isolating carpets or floor coverings	-	
protective clothing	suits with electromagnetic shielding functions	-	
industrial uses	spark preventing dust filters or bulk containers	-	
auxiliary/intermediate products for industrial processes	additives for the production of conductive textiles	[68]	polyaniline polypyrrole
	coating methods for conductive fabrics	[69]	
	production methods for antistatic fabrics	[66]	

5.2 Reinforced textiles / Tear and wear resistant textiles

<u>Product groups and possible consumer goods</u>

Reinforced fibers could find applications in the apparel industry, the fabrication of upholstery, in geotextiles [6], industrial textiles or the production of protective clothing [28]. In the apparel industry and upholstery sector, such fibers might be used to produce tear- and wear-resistant clothes or furniture textiles. Their application in the production of protective clothing could furthermore lead to the development of stronger and more lightweight safety harnesses and bullet proof vests [62]. In a lightweight military battle suit which is able to withstand blasts and which is currently under development, reinforced fibers would fulfill a similar function [72]. Nano-reinforced fibers could also be used to produce stronger and more durable Geotextiles which are used in the construction sector for sealing, isolation or erosion control [6]. In industrial textiles, the nano-reinforced fibers could find applications in filters or sieves with improved abrasion stability, as they are used in paper production [28].

Commercially available products

In the conducted Internet research, the following two commercially available products could be found: CNT-reinforced fibers for antiballistic purposes (e.g. bullet proof vests or doors) [73] and CNT containing polymer additives for the production of reinforced textiles [74].

Table 14: *Possible commercial applications for reinforced textiles. Examples for consumer products which could be found on the Internet are listed together with the available information about the incorporated NP or nanostructure.*

Product group	Product description	Examples of available products	NP
apparel	tear and wear resistant clothes	-	
interior trim and upholstery	tear and abrasion resistant furniture textiles	-	
protective clothing	bullet proof vests	[73]	CNT
	explosion-proof battle suits	-	
construction materials	reinforced, durable geotextiles	-	
industrial uses	reinforced technical textiles for industrial filters or sieves	-	
auxiliary / intermediate products for industrial processes	polymer additives for the production of reinforced textiles	[74]	CNT

5.3 Antibacterial textiles

Product groups and possible consumer goods

The product groups with possible applications for antibacterial textiles include apparel, interior trim and upholstery, sports and leisure, automotive interiors, protective clothing, medical textiles and cosmetics. In apparel-, interior trim- and automotive applications, these functional textiles could be used to produce “self-cleaning” or “anti-odour” clothes, furniture textiles or automotive interiors [32]. In household products, antibacterial textiles could possibly be incorporated into kitchen clothes, sponges or towels. In the medical sector, possible products include antibacterial wound dressings, patient dresses, bed lines or reusable surgical gloves and masks [32, 75]. Further thinkable applications are protective face masks and suits against biohazards [75] or cosmetic products as antibacterial face masks or toothbrushes [28] .

Commercially available products

With exception of the products related to the automotive sector, commercially available goods could be found for all of the above mentioned applications. In the apparel sector, antibacterial or self-cleaning shoe insoles, socks, underwear an Poloshirts can be purchased by various manufacturers [76-81]. As examples for products related to interior trim and upholstery, antibacterial bed sheets and baby blankets were found [82, 83]. In the product group related to the medical sector, biocidal wound dressings are available [84] while cosmetic appliances include toothbrushes and face masks [79, 80, 85]. Also available are protective face masks against bacterial and viral infections [86]. Various companies furthermore offer their industrial clients textile treatment technologies, additives or fabrics with antibacterial properties. [87] offers an antibacterial textile treatment which is used on a wide range of products including antibacterial underwear, kitchen sponges or clothes, bed sheets, towels, carpets or sport helmet paddings. [88] and [89] both offer antibacterial coating technologies, while antibacterial polymer masterbatches are available from [90]. Antibacterial fabrics which can be processed into outdoor clothing or household products were developed by [91] and [92].

Table 15: *Possible commercial applications for antibacterial textiles. Examples for consumer products which could be found on the Internet are listed together with the available information about the incorporated NP or nanostructure.*

Product group	**Product description**	**Examples of available products**	**NP**
apparel	anti-odour / “self-cleaning” socks/insoles	[76, 78, 80, 81, 83, 93]	Ag, ZnO
	antibacterial underwear	[76, 79]	Ag
	anti-odour T-Shirts	[76, 77, 83]	“carbon-nanoparticles”, Ag
sports and leisure	anti-odour / “self-cleaning” linings for helmets or other sports gear	[87-89]	Ag
interior trim and upholstery	anti-odour, “self-cleaning” furniture textiles and bed sheets	[82, 83, 87]	“carbon-nanoparticles” Ag
	antibacterial carpets	[87]	Ag
household	antibacterial kitchen sponges, clothes or towels	[87]	Ag
automotive interiors	anti-odour /self cleaning seat cushion or liners	-	
protective clothing	biocidal facial masks or suits	[86]	Ag
medical sector	antibacterial blankets, patient dresses, surgical gloves and masks	[84]	Ag
cosmetics	antibacterial face masks, toothbrushes	[79, 80, 85]	Ag
auxiliary / intermediate products for industrial processes	antibacterial textile treatment technology	[87-89]	Ag
	antibacterial polymer masterbatches	[90]	Ag
	antibacterial fabric	[91, 92]	Ag

5.4 “Self cleaning” textiles / textiles with antiadhesive properties

Product groups and possible consumer goods

Textiles with anitadhesive properties could find applications in dirt repellent or self cleaning apparel and furniture [45]. Also part of this group of functional textiles are hydrophobic materials [49] which could be used in waterproof sports or outdoor clothing. [94] proposes the production of vascular grafts or arterial prostheses with blood platelet adhesion resistant properties as application for the developed protein coated cotton. Consumer goods could therefore possibly be found in the following products groups: Apparel, sports and leisure, interior trim and upholstery and medical appliances.

Commercially available products

For the products proposed by the research papers, providers of the following consumer goods were found: Stain repellent, quick drying apparel [95-99] or furniture [100] and waterproof, grime repellent outdoor clothing [101-103]. Apart from these applications, the following commercial end products were found: Easy to clean luggage [104], water repellent umbrellas [105] and cleaning clothes with dirt repellent properties [106]. Furthermore, various auxiliary products for industrial production processes are commercially available. [66], [107] and [88] offer coating technologies for easy to clean, stain repellent textile surfaces while industrial coating agents which promise the same effect can be purchased from [108] and [109].

Table 16: *Possible commercial applications for "self cleaning" textiles or textiles with antiadhesive properties. Examples for consumer products which could be found on the Internet are listed together with the available information about the incorporated NP or nanostructure.*

Product group	**Product description**	**Examples of available products**	**NP**
apparel	stain repellent / self cleaning pants, ties, coats	[95-99]	
	water proof, grime repellent outdoor jackets, pants, gloves, caps	[101-103]	
interior trim and upholstery	stain repellent furniture textiles	[100]	
sports and leisure	stain repellent umbrellas	[105]	
	stain repellent, easy to clean luggage	[104]	
medical appliances	vascular grafts and arterial prostheses with blood platelet resistant properties	-	
household products	cleaning clothes with dirt repellent properties [106]	[106]	
auxiliary / intermediate products for industrial processes	coating agents for the production of water and stain repellent textiles	[108, 109]	
	coating- or production methods for hydrophobic, stain repellent textiles	[66, 88, 107]	SiO_2 [88]

5.5 Moisture absorbing textiles

<u>Product groups and possible consumer goods</u>

In the examined research papers no propositions for commercial applications of nanoengineered textiles with moisture absorbing properties were made. Thinkable commercial products could be found in the apparel and sports industry where these textiles might be used to produce quick drying, transpiration wicking sports- or outdoor clothing.

Commercially available products

For the above described applications, various commercial products could be found on the Internet. They include various moisture wicking outdoor jackets, caps and trousers [110] as well as sport pants, moisture absorbing underwear or water shorts [99, 111, 112]. [113] furthermore offers the technology for the production of fabrics which can be incorporated into all kinds of outdoor or sport clothing and promises to show moisture wicking properties.

Table 17: *Possible commercial applications for moisture absorbing textiles. Examples for consumer products which could be found on the Internet are listed together with the available information about the incorporated NP or nanostructure.*

Product group	Product description	Examples of available products	NP
apparel	moisture wicking sports- and outdoor clothing	[99, 110-112]	
auxiliary / intermediate products for industrial processes	production method for moisture wicking, transpiration absorbing fabric	[113]	

5.6 Improved colourability / Enhanced bleaching resistance

Product groups and possible consumer goods

The examined research papers do not make any propositions for commercial applications of textiles with improved colourability. Such fabrics could theoretically be incorporated into all kinds of clothing or furniture textiles as well as into textile outdoor products, e.g. tent- or parasol-fabrics. The corresponding product groups would therefore include apparel, interior trim and upholstery as well as the sports and leisure.

Commercially available products

For these applications, no commercially available products could be found in the conducted Internet research.

Table 18: *Possible commercial applications for textiles with improved colourability or enhanced bleaching resistance. Examples for consumer products which could be found on the Internet are listed together with the available information about the incorporated NP or nanostructure.*

Product group	**Product description**	**Examples of available products**	**NP**
apparel	bleach resistant clothing	-	
interior trim and upholstery	bleach resistant furniture textiles	-	
sports and leisure	bleach resistant tent or parasol fabrics	-	

5.7 UV-blocking textiles

Product groups and possible consumer goods

In the examined research papers, no propositions for commercial applications of UV-blocking textiles are made. Possible commercial applications could probably be found in apparel and sports wear with integrated sun protection or in the production of sun shields or parasols.

Commercially available products

The following commercial applications could be found in the examined consumer inventories: In the sports and apparel sector, [112] offers UV-blocking bathing shorts [112]. Further commercial applications were found in the product group related to auxiliary products for industrial processes: [88], [114] and [115] offer coating systems for the production of UV-blocking textiles while [116] directly sells a fabric with the same properties that can be processed into Shirts or Sweaters. [114] reports the launch of an industrial coating agent which leads to UV-blocking properties when applied to textile fabrics.

Table 19*: Possible commercial applications for textiles with improved UV-blocking properties. Examples for consumer products which could be found on the Internet are listed together with the available information about the incorporated NP or nanostructure.*

Product group	**Product description**	**Examples of available products**	**NP**
apparel	apparel and sports clothing with integrated sun protection	[112]	
interior trim and upholstery	UV blocking parasols or sun shields	-	
auxiliary / intermediate products for industrial processes	UV-blocking Shirt fabric	[116]	
	UV blocking coating agents	[114]	ZnO
	coating technology for UV-blocking textiles	[88, 115, 117]	SiO_2

5.8 Flame retardant textiles

<u>Product groups and possible consumer goods</u>

In the examined research papers, no propositions for commercial applications of nanoengineered flame retardant textiles are made. Conventional flame retardant textiles already find application in a wide range of industrial branches as in the automotive or apparel industry, the manufacturing of interior trim and upholstery or the production of protective clothing. Examples for possible products would therefore include apparel made of synthetic textiles, protective clothing, carpets and other interior trim fabrics, seat cushions or linings for automotive interiors.

<u>Commercially available products</u>

For the above mentioned applications, no consumer end products containing nano-engineered textiles were found in the Internet research. Concerning the offer of auxiliary products for industrial processes, nanoengineered, flame retardant textile additives for synthetic polymers are available from [118] while a industrial coating agent for the production of flame retardant fabrics is sold by [117].

Table 20: *Possible commercial applications for flame retardant textiles. Examples for consumer products which could be found on the Internet are listed together with the available information about the incorporated NP or nanostructure.*

Product group	Product description	Examples of available products	NP
apparel	clothing made of synthetic textiles	-	
protective clothing	flame resistant suits, gloves, etc.	-	
interior trim and upholstery	flame retardant furniture textiles, carpets, curtains.	-	
automotive interiors	flame retardant seat cushions, linings	-	
auxiliary / intermediate products for industrial processes	flame retardant textile additive for synthetic polymers	[118]	nanoclay
	industrial coating agent	[117]	

5.9 Controlled release of active agents, drugs or fragrances

<u>Product groups and possible consumer goods</u>

Fibers with controlled release of fragrances or oils could find applications in apparel, cosmetics, home textiles, outdoor fabrics or medical appliances. Possible products would include cosmetic pads with integrated skin care products, insect repellent textiles for clothing or outdoor fabrics, medical textiles with therapeutical properties (e.g. drug releasing wound dressings) or so called fragrance emitting clothing or home-textiles [28].

Commercially available products

Commercially available products were found only in the cosmetic sector where [119] and [120] offer facial masks with integrated cosmetics substances.

Table 21: *Possible commercial applications for textiles with controlled release of active agents. Examples for consumer products which could be found on the Internet are listed together with the available information about the incorporated NP or nanostructure.*

Product group	**Product description**	**Examples of available products**	**NP**
apparel	fragrance emitting clothing	-	
	insect repelling jackets or outdoor clothing	-	
interior trim and upholstery	fragrance emitting furniture textiles, carpets, curtains	-	
Sports and leisure	insect repelling tent fabric	-	
cosmetics	pads or facial masks with integrated skin care products	[119, 120]	
medical appliances	drug releasing wound dressings	-	

5.10 Insulating textiles

Product groups and possible consumer goods

In the examined research papers, no propositions for commercial applications of nanoengineered insulating textiles are made. In the industrial sector, conventional textiles with insulating properties are used for the isolation of various technical appliances as for example steam vessels, pipelines or boilers. Furthermore, they can be used as construction material to reduce heat losses in houses and buildings. Thinkable applications of textiles with enhanced insulating properties might also be found in the apparel industry were these textiles could be used to produce jackets, pants, shoes or insoles for outdoor uses at low temperatures.

Commercially available products

[121] offers different thermal insulating textiles for all of the above mentioned applications. Available consumer end products containing these fabrics include insulating blankets for

exhausting channels, industrial vessels or boilers as well as mountain jackets and thermal shoe insoles.

Table 22: *Possible commercial applications for thermal insulating textiles. Manufacturers who offer one of the described consumer goods and claim to use nanoengineering during the production process are listed together with the available information about the incorporated NP or nanostructure.*

Product group	**Product description**	**Examples of available products**	**NP**
apparel	thermally insulating mountain jackets for low temperatures	[121]	nanoporous Si structure
	thermal shoe insoles	[121]	nanoporous Si structure
industrial uses	insulating blankets for steam vessels, boilers, exhaust duct channels	[121]	nanoporous Si structure

5.11 Luminescent textiles

<u>Product groups and possible consumer goods</u>

In the examined research papers, no propositions for commercial applications of insulating textiles are made. Luminescent textiles could possibly find application in apparel or interior trim and upholstery for the production of clothing or home textiles with special optical properties as for example fluorescence or color-changing effects.

<u>Commercially available products</u>

In the researched consumer inventories, one example for an available commercial product was found at [122] who offers textiles with color changing effects.

Table 23: *Possible commercial applications for luminescent textiles. Examples for consumer products which could be found on the Internet are listed together with the available information about the incorporated NP or nanostructure.*

Product group	**Product description**	**Examples of available products**	**NP**
auxiliary / intermediate products for industrial processes	textile with color-changing effects	[122]	

6 Discussion

6.1 NanoTextile related research

None of the textile functions listed in chapter 4 are actual novel textile properties. All of the properties which were achieved through nanoengineering could also be obtained by using other production methods or conventional additives. Often, nanotechnology is used to optimize the obtained functional textiles with regard to a second property as for example rendering conductive textiles lighter or more flexible, or produce stain repellent textiles which still have the look and feel of natural fabrics. Furthermore, it seems that nanotechnology could have the potential to replace environmentally hazardous additives, as this might be the case for flame retardant substances.
Based on the use of nano-related terms in the examined research papers, it seems that the definition of “nano” (and the magnitude scale which is meant by it) diverge significantly. In some publications, structures and particles with dimensions up to 1700nm are still called “nanoparticles” which stands in contrast with most definitions found in literature where only particles with a diameter up to 100nm are called same wise. Very little information is available about the form in which the nanostructures are embedded into the textile matrix after the production process. Apart from some observations about the degree of aggregation of the NP no information about the integration or the chemical bonding between the matrix and the NP is given by the authors.
The functional textiles and nanoparticles related to which most publications could be found are antibacterial textiles and nanosilver (nAg). On one hand, the development of antibacterial textiles by using nAg may be a promising application which good results can already be achieved with. On the other hand, it is also possible that the production methods for these textiles, which are relatively simple and economic, contribute to the high number of publications for this application. In the examined research papers, NP or nanostructures were incorporated both into natural and synthetic textiles. Common methods for natural fibres (e.g. cotton) include coating of the finished fabric by sol-gel processes, chemical or physical vapor deposition, or simply dipping the textile into a nanoparticulate dispersion and subsequent padding and drying. For synthetic textiles, the nanostructures were often integrated at an earlier stage in the production process by melt compounding them with a synthetic polymer. The resulting composite is then used as masterbatch or directly spun into textile fabrics. No classification was made in terms of “success” of the described production method. To which degree the reported methods really led to the desired textile property is difficult to judge. The improvement was sometimes coupled with a negative influence on another textile characteristic (as for example decreased tensile strength), or the research group only developed a nanocomposite that could possibly be processed into a functional textile, but didn’t actually achieve to produce such fabric. The ability to produce functional textiles with the desired properties by means of the described production methods is rather insecure and the listed procedures should therefore not be seen as established production methods for the manufacturing of functional textiles. It is very well possible that for some of the functions listed it chapter 4, nanotechnology will never represent a serious alternative for the existing manufacturing methods.

6.2 Commercial products

With exception of textile products with improved coulourability or bleaching resistance, examples of commercially available consumer goods could be found for all of the functions. Most commercial applications were found for textile products with antibacterial or anti-adhesive properties. It seems that for antibacterial textiles, apparel and home textiles represent important sectors as many of the found products appertain to one of these product groups. With regard to textiles with antiadhesive properties, the most common products are probably stain repellent apparel or waterproof, self-cleaning outdoor clothing. How far these results are representative for the overall use of nanotechnology in textiles is disputable as the conducted research only includes products which are advertised over the Internet and for which the use of nanotechnology is expected to be a positive marketing argument. For some functions, as this would be the case for antibacterial textiles, the use of nanotechnology (e.g. the integration of nanosilver) has already achieved a certain recognition or image so that its declaration might be of advantage for the marketing of the respective consumer good. In other fabrics, as this might be the case for many technical textiles, nanotechnology is applied only in one step of a complex production process and its use forms part of the company secret. Advertisement will therefore probably mainly be based on the functional properties of the product and not on the underlying technology. Furthermore, the examined consumer inventories are targeted rather at private than at industrial clients which could also be a reason for the smaller share of technical textiles on the commercial products listed in chapter 5.

In general, very little information about the used NP and applied production methods is available from the manufacturers. In some cases, only the use of “nano” in the production name gives a hint about the possible use of nanotechnology in the production process. If and in which form nanotechnology is involved in the manufacturing of a product is nearly impossible to assess. As there is no duty of declaration and “nano” isn’t a protected notion, it can be assumed that the advertisement of a product under the name of nano is often more strongly based on marketing related considerations than on the underlying technology.

7 Conclusions

From antibacterial textiles to flame retardant fabrics, nanotechnology could cover a wide range of textile functions. In the examined papers, a certain textile function could be achieved by the integration of different NP. Vice versa, the use of a specific NP led to different textile properties, depending on the applied production method. The nanostructures were mainly included into fabrics by using textile coating techniques as sol-gel processes, chemical- / physical-vapor deposition or simple dip-pad-dry cure methods. For the integration into synthetic textiles, mostly melt compounding or the production of NP containing master-batches were used. About the form in which the NP are present in the finished fabric and the bonding of the particles to the textile matrix, very little information was found in the examined research papers. It seems that in many cases, the mechanism which leads to the altering of the textile properties is not completely known. It can be assumed that for the majority of the described production methods, the industrial up-scaling would still pose a mayor challenge for both economical and technical reasons. Some of the described methods are rather costly and the integration of the NP was often accompanied by negative effects on other textile properties. This stands somewhat in contrast with the results of the Internet research where commercial products (whose manufacturers claim to use nanotechnology) were found for nearly all of the mentioned textile functions. This can be explained by the fact that nanotechnology is not a protected notion, so that its mention might often simply be a positive marketing argument and not be related to the used production process. This is supported by the overall impression of the reviewed consumer inventories and product related Newspages. Informations about the used NP or production methods were seldom available and therefore, only few products could be found for which the use of nanotechnology seemed to be certain.

References

1. The Royal Academy of Science & The Royal Academy of Engineering, Nanoscience and nanotechnologies: Opportunities and uncertainties. 2004, The Royal Society, London.
2. ISO. TCC 229 2007 [cited 2007 20.11.2007]; Available from: http://www.iso.org/iso/iso_technical_committee.html?commid=381983.
3. EPA. Nanotechnology: Basic Information. 19.10.2007 [cited 2007 20.11.]; Available from: http://es.epa.gov/ncer/nano/questions/index.html.
4. Hay N.J., S., S.J., A review of nanocomposites. Journal of Material research, 2000. 7: p. 962-988.
5. Thomson Scientific. Welcome to ISI Web of Knowledge. [cited 8.10.2007]; Available from: http://isiwebofknowledge.com/.
6. Lübben, J., Funktionale Fasern und Textilien. tec21: Fachzeitschrift für Architektur, Ingenieurwesen und Umwelt, 2005. 41: p. 10-13.
7. Hwang, J., J. Muth, and T. Ghosh, Electrical and mechanical properties of carbon-black-filled, electrospun nanocomposite fiber webs. Journal of Applied Polymer Science, 2007. 104(4): p. 2410-2417.
8. Wei, Q.F., et al., Surface characterization of functional nanostructures sputtered on fiber substrates. Surface & Coatings Technology, 2006. 201(3-4): p. 1821-1826.
9. Gottschalk, F., Umwelt- und Gesundheitseinwirkungen von Kohlenstoff-Nanoröhren: Entwurf einer Risikobewertung mit besonderer Betrachtung potenzieller Applikationen in textilen Fasern. Master-Thesis on the Institute for Human-Environment Systems, ETH Zürich, 2006.
10. Chang, T.E., et al., Microscopic mechanism of reinforcement in single wall carbon nanotube/polypropylene nanocomposites. Polymer, 2005. 46(2): p. 439-444.
11. Hagenmueller, R., et al., Production and characterization of Polymer Nanocomposites with Highly Aligned Single Walled Carbon Nanotubes. Journal of nanoscience and nanotechnology, 2003. 3(1-2): p. 105-110.
12. Dalton, A.B., et al., Continuous carbon nanotube composite fibers: properties, potential applications, and problems. Journal of Materials Chemistry, 2004. 14(1): p. 1-3.
13. Panhuis, M.I.H., Carbon nanotubes: enhancing the polymer building blocks for intelligent materials. Journal of Materials Chemistry, 2006. 16(36): p. 3598-3605.
14. Spinks, G.M., et al., Carbon-nanotube-reinforced polyaniline fibers for high-strength artificial muscles. Advanced Materials, 2006. 18(5): p. 637-+.
15. Mottaghitalab, V., G.M. Spinks, and G.G. Wallace, The influence of carbon nanotubes on mechanical and electrical properties of polyaniline fibers. Synthetic Metals, 2005. 152(1-3): p. 77-80.
16. Spinks, G.M., et al., Actuation behaviour of layered composites of polyaniline, carbon nanotubes and polypyrrole. Synthetic Metals, 2005. 151(1): p. 85-91.
17. Hecht, D.S., L. Hu, and G. Gruner, Electronic properties of carbon nanotube/fabric composites. Current Applied Physics, 2007. 7(1): p. 60-63.
18. Foitzik, R.C., A. Kaynak, and F.M. Pfeffer, Application of soluble poly (3-alkylpyrrole) polymers on textiles. Synthetic Metals, 2006. 156(7-8): p. 637-642.
19. Dall'Acqua, L., et al., Vapor phase polymerisation of pyrrole on cellulose-based textile substrates. Synthetic Metals, 2006. 156(5-6): p. 379-386.
20. Armes, S.P., et al., MORPHOLOGY AND STRUCTURE OF CONDUCTING POLYMERS. Langmuir, 1991. 7(7): p. 1447-1452.
21. Poncharal, P., et al., Electromechanical Resonances of Carbon Nanotubes. Science, 1999. 283(5407): p. 1513-1516.
22. Stegmaier, T., Nanopartikel - Anwendungen und mögliche Risiken. 2006, Institut für Textil und Verfahrenstechnik Denkendorf: Stuttgart.

23. Kalarikkal, S.G., B.V. Sankar, and P.G. Ifju, Effect of Cryogenic Temperature on the Fracture Toughness of Graphite/Epoxy Composites. Journal of engineering materials and technology, 2006. 128(2): p. 151-157.
24. Miaudet, P., et al., Hot-drawing of single and multiwall carbon nanotube fibers for high toughness and alignment. Nano Letters, 2005. 5(11): p. 2212-2215.
25. Yadav, A., et al., Functional finishing in cotton fabrics using zinc oxid nanoparticles. Bulletin of Material Sciences, 2006. 29(6): p. 641-645.
26. Kalarikkal, S.G., B.V. Sankar, and P.G. Lfju, Effect of cryogenic temperature on the fracture toughness of graphite/epoxy composites. Journal of Engineering Materials and Technology-Transactions of the Asme, 2006. 128(2): p. 151-157.
27. Campos, G., et al., Development of new carpet backings based on composite polymer particles. Journal of Reinforced Plastics and Composites, 2006. 25(18): p. 1897-1901.
28. Mahltig, B., H. Haufe, and H. Bottcher, Functionalisation of textiles by inorganic sol-gel coatings. Journal of Materials Chemistry, 2005. 15(41): p. 4385-4398.
29. Yadav, A., et al., Functional finishing in cotton fabrics using zinc oxide nanoparticles. Bulletin of Materials Science, 2006. 29(6): p. 641-645.
30. Daoud, W.A., J.H. Xin, and Y.H. Zhang, Surface functionalization of cellulose fibers with titanium dioxide nanoparticles and their combined bactericidal activities. Surface Science, 2005. 599(1-3): p. 69-75.
31. Parkin, I. and R. Palgrave, Self-cleaning clothes. Journal of Materials chemistry, 2004. 15: p. 1689-1695.
32. Yeo, S.Y., H.J. Lee, and S.H. Jeong, Preparation of nanocomposite fibers for permanent antibacterial effect. Journal of Materials Science, 2003. 38(10): p. 2143-2147.
33. Daoud, W.A. and J.H. Xin, Nucleation and growth of anatase crystallites on cotton fabrics at low temperatures. Journal of the American Ceramic Society, 2004. 87(5): p. 953-955.
34. Qi, K.H., et al., Self-cleaning cotton. Journal of Materials Chemistry, 2006. 16(47): p. 4567-4574.
35. Yuranova, T., et al., Performance and characterization of Ag-cotton and Ag/TiO2 loaded textiles during the abatement of E-coli. Journal of Photochemistry and Photobiology a-Chemistry, 2006. 181(2-3): p. 363-369.
36. Lee, H.J., S.Y. Yeo, and S.H. Jeong, Antibacterial effect of nanosized silver colloidal solution on textile fabrics. Journal of Materials Science, 2003. 38(10): p. 2199-2204.
37. Dubas, S.T., P. Kumlangdudsana, and P. Potiyaraj, Layer-by-layer deposition of antimicrobial silver nanoparticles on textile fibers. Colloids and Surfaces a-Physicochemical and Engineering Aspects, 2006. 289(1-3): p. 105-109.
38. Hegemann, D., M.M. Hossain, and D.J. Balazs, Nanostructured plasma coatings to obtain multifunctional textile surfaces. Progress in Organic Coatings, 2007. 58(2-3): p. 237-240.
39. Bozzi, A., T. Yuranova, and J. Kiwi, Self-cleaning of wool-polyamide and polyester textiles by TiO2-rutile modification under daylight irradiation at ambient temperature. Journal of Photochemistry and Photobiology a-Chemistry, 2005. 172(1): p. 27-34.
40. Jeong, S.H., S.Y. Yeo, and S.C. Yi, The effect of filler particle size on the antibacterial properties of compounded polymer/silver fibers. Journal of Materials Science, 2005. 40(20): p. 5407-5411.
41. Vigneshwaran, N., et al., Functional finishing of cotton fabrics using zinc oxide-soluble starch nanocomposites. Nanotechnology, 2006. 17(20): p. 5087-5095.
42. Ye, W.J., et al., Novel core-shell particles with poly(n-butyl acrylate) cores and chitosan shells as an antibacterial coating for textiles. Polymer, 2005. 46(23): p. 10538-10543.
43. Daoud, W.A. and J.H. Xin, Low temperature sol-gel processed photocatalytic titania coating. Journal of Sol-Gel Science and Technology, 2004. 29(1): p. 25-29.

44. Szymanowski, H., et al., Plasma enhanced CVD deposition of titanium oxide for biomedical applications. Surface & Coatings Technology, 2005. 200(1-4): p. 1036-1040.
45. Liu, Y., et al., Artificial lotus leaf structure from assembling carbon nanotubes and their application in hydrophobic textiles. Journal of Materials chemistry, 2006. 17: p. 1071-1078.
46. Liu, Y.Y., et al., Artificial lotus leaf structures from assembling carbon nanotubes and their applications in hydrophobic textiles. Journal of Materials Chemistry, 2007. 17(11): p. 1071-1078.
47. Yu, M., et al., Superhydrophobic cotton fabric coating based on a complex layer of silica nanoparticles and perfluorooctylated quaterny ammonium silane coupling agent. Applied surface science, 2007. 253: p. 3669-3673.
48. Huang, P.Y., Y.C. Chao, and Y.T. Liao, Preparation of fluoroacrylate nanocopolymer by miniemulsion polymerization used in textile finishing. Journal of Applied Polymer Science, 2004. 94(4): p. 1466-1472.
49. Yu, M., et al., Superhydrophobic cotton fabric coating based on a complex layer of silica nanoparticles and perfluorooctylated quaternary ammonium silane coupling agent. Applied Surface Science, 2007. 253(7): p. 3669-3673.
50. Krogman, K.C., et al., Automated process for improved uniformity and versatility of layer-by-layer deposition. Langmuir, 2007. 23(6): p. 3137-3141.
51. Li, D. and G. Sun, Coloration of textiles with self-dispersible carbon black nanoparticles. Dyes and Pigments, 2007. 72(2): p. 144-149.
52. Vigneshwaran, N. Nanotechnology finishing in textiles 2007 26.10.2006 [cited 26.07.2007].
53. Zhang, S. and A.R. Horrocks, A review of flame retardant polypropylene fibres. Progress in Polymer Science, 2003. 28(11): p. 1517-1538.
54. Bourbigot, S., et al., Solid state NMR characterization and flammability of styrene-acrylonitrile copolymer montmorillonite nanocomposite. Polymer, 2004. 45(22): p. 7627-7638.
55. Zhang, S., et al., Flammability, degradation and structural characterization of fibre-forming polypropylene containing nanoclay-flame retardant combinations. Polymer Degradation and Stability, 2006. 91(4): p. 719-725.
56. Devaux, E., M. Rochery, and S. Bourbigot, Polyurethane/clay and polyurethane/POSS nanocomposites as flame retarded coating for polyester and cotton fabrics. Fire and Materials, 2002. 26(4-5): p. 149-154.
57. Bourbigot, S., E. Devaux, and X. Flambard, Flammability of polyamide-6 /clay hybrid nanocomposite textiles. Polymer Degradation and Stability, 2002. 75(2): p. 397-402.
58. Marosi, G., et al., Fire retardancy effect of migration in polypropylene nanocomposites induced by modified interlayer. Polymer Degradation and Stability, 2003. 82(2): p. 379-385.
59. Beyer, G., Short communication: Carbon nanotubes as flame retardants for polymers. Fire and Materials, 2002. 26(6): p. 291-293.
60. Anna, P., et al., Intumescent flame retardant systems of modified rheology. Polymer Degradation and Stability, 2002. 77(2): p. 243-247.
61. Persico, P., C. Carfagna, and P. Musto, Nanocomposite fibers for cosmetotextile applications. Macromolecular Symposia, 2006. 234: p. 147-155.
62. McNally, T., Nanotechnology in textiles, in Presentation on Breakfast Seminar. 2004, School of Mechanical engineering, Queens University Belfast: Belfast.
63. AspenAerogels. Exhaust Duct Heat Loss Reduced by 50 Percent. 2006 2006 [cited 1.08.2007]; Available from: http://www.aerogel.com/markets/c_exhaust.html.
64. Köhler, A., et al., Studying the potential release of carbon nanotubes throughout the application life cycle. Unpublished, draft from July 2007. Technology and Society, Empa St. Gallen.
65. Kim, Y.K. and A.F. Lewis, Concepts for energy-interactive textiles. Mrs Bulletin, 2003. 28(8): p. 592-596.

66. Nanotex. Fabric to the Next. 2007 [cited 2007 23.08.2007]; Available from: http://www.nano-tex.com/index_noflash.html.
67. Bekaert. Innovative textiles by Bekaert. 17.03.2004 [cited 9.05.2007]; Available from: http://www.bekaert.com/bft/Products/Innovative%20Textiles.htm.
68. Eeon technology. EeonTexTM Conductive Textiles. [cited 23.08.2007]; Available from: http://www.eeonyx.com/prodsp.html.
69. nanogate. Dielektrika unter Strom. [cited 23.08.2007]; Available from: http://www.nanogate.de/de/produktveredelung/funktionen/nanoadd/elektrisch-leitfaehig.php?PHPSESSID=aae7c8415e14e06254ff250691318264.
70. Lands End. ThermaCheck® Scarf [cited 23.08.2007]; Available from: http://www.landsend.com/cd/fp/prod/0,,1_2_1931_51997_151350_128897_5:view=-1,00.html?sid=0622107012275149920&CM_MERCH=SRCH.
71. Sensatex. Sensatex, Inc. Seamless technology. [cited 23.08.2007]; Available from: http://www.sensatex.com/.
72. MIT Institute for soldier nanotechnologies. Research on energy absorbing materials. [cited 9.05.2007]; Available from: http://web.mit.edu/isn/research/team01/index.html.
73. US global Nanospace. About US Global Nanospace. [cited 8.10.2007]; Available from: http://www.usgn.com/.
74. Zyvexpro Materials. Additives and Concentrates. [cited 8.10.2007]; Available from: http://www.zyvexpro.com/products/applications.htm.
75. Sun, G., Halamine Chemistry and it s applications in biological and chemical protective textiles, in Presentation on the NanoEurope conference, St.Gallen. 2006, Division of Textiles and Clothing, University of California, USA.
76. Goodweaver Textile co.LTD. Goodweaver textile. [cited 8.10.2007]; Available from: http://www.goodweaver.com/.
77. United Textile Mills Co.LTD. I-Tex “Silver Nano” – Anti Bacterial Polo-Shirt [cited 8.10.2007]; Available from: http://www.unitedtextilemills.com/index.asp#.
78. AgActive. Sports Anklet Sock. [cited 8.10.2007]; Available from: http://www.agactive.co.uk/index.cfm/fuseaction/produ.
79. Nanobabies. Nanobabies. [cited 8.10.2007]; Available from: http://nanbabies.com/SupportProductsStore.htm.
80. Song Sing Nanotechnology Co.LTD. Nano Silver Products. [cited 8.10.2007]; Available from: http://www.ssnano.net/ehtml/0418b.php.
81. Nanoinfinity Nanotech Co. LTD. Healthy deodorant series products. [cited 8.10.2007]; Available from: http://www.nano-infinity.com.tw/product01.htm.
82. AgActive. 100% cotton sheet sets. [cited 8.10.2007]; Available from: http://www.agactive.co.uk/index.cfm/fuseaction/product.display/Product_ID/8/.htm.
83. Greenyarn technology LTD. Greenyarn technology: Weaving togheter a healthy tomorrow. [cited 8.10.2007]; Available from: http://www.greenyarn.com/technology.htm.
84. Smith and Nephew. Acticoat Product Line. [cited 8.10.2007]; Available from: http://wound.smith-nephew.com/us/node.asp?NodeId=2867.
85. Nanover. Nanover WetWipes. [cited 8.10.2007]; Available from: http://www.nanogist.com/English/products/tissue.htm.
86. Emergency filtration products inc. Emergency filtration products. [cited 8.10. 2007]; Available from: http://www.emergencyfiltration.com/Products/NanoMask.htm.
87. Thomson Research Associates. Using Ultra fresh. [cited 8.10.2007]; Available from: http://www.ultra-fresh.com/tra/Content/Using_Specific/using_apparel1.cfm.
88. Nanopool. Nanopool. [cited 8.10.2007]; Available from: http://www.nanoingermany.com/smr/content/company/company_id/88/exhibition_id/16/subexhibition/0/.
89. Nanogate. Ist keimfrei, bleibt keimfrei. [cited 8.10.2007); Available from: http://www.nanogate.de/de/produktveredelung/funktionen/nanoadd/antimikrobiell.php.

90. Murray, J., Introducing a Novel Nanosilver Additive for Antimicrobial Textile Functionality, in Presentation at the NanoEurope conference. 2006, HeiQ Materials Ltd: St.Gallen.
91. Microban. Home Products.[cited 8.10.]2007; Available from: http://www.microban.com/americas/products/category.html?lang=en&CategoryID=1&SubcategoryID=200.
92. Polartec. Forward Fabric. [cited 8.10.2007]; Available from: http://www.polartec.com/.
93. Woodrow Wilson International Center for Scholars Scholars. Antibacterial Silver Athletic and Lounging Socks. [cited 8.10.2007]; Available from: http://www.nanotechproject.org/index.php?id=44&action=view&product_id=1198.
94. Coombes, A.G.A., et al., Lactic acid-stabilised albumin for microsphere formulation and biomedical coatings. Biomaterials, 2001. 22(1): p. 1-8.
95. Schoeller Textile AG. schoeller®-dynamic: The comfortable one. [cited 8.10.2007; Available from: http://www.schoeller-textiles.com/default.asp?cat1ID=128&cat2ID=126&pageID=69&emotionstate=0&emotionID=8&langID=2.
96. Shenzhen Kangnami clothing wholesale center center. Water-supply magic oil neckties [cited 8.10.2007]; Available from: http://translate.google.com/translate?u=http%3A%2F%2Fdetail.china.alibaba.com%2Fbuyer%2Fofferdetail%2F41040846.html&langpair=zh%7Cen&hl=en&ie=UTF8.
97. Woodrow Wilson International Center for Scholars. NanoTousers by Pro-Idee GmbH&co. KG. [cited 8.10.2007]; Available from: http://www.nanotechproject.org/index.php?id=44&action=view&product_id=1287.
98. Woodrow Wilson International Center for Scholars. Stain resistant tie by Brooks Brothers. [cited 8.10.2007].
99. NanoTsunami. Nano-Tex Adds Knits, Outerwear to Its Performance Apparel Roster [cited 8.10.2007]; Available from: http://www.voyle.net/Nano%20Textiles/2005%20Textiles/Textiles-2005-0009.htm.
100. Woodrow Wilson Internatonal Center for Scholars.Super stain resistant Gripper Cushions by Improvements. [cited 8.10.2007]; Available from: http://www.nanotechproject.org/index.php?id=44&action=view&product_id=1058.
101. Franz Ziener GMBH. Ziener Technik: Nano Tex. [cited 8.10]-2007; Available from: http://www.ziener.de/Technik/technik_aqua.php.
102. Beyond clothing. Featured new products. [cited 8.10.2007]; Available from: http://beyondclothing.com/; http://www.schoeller-textiles.com/default.asp?cat1ID=128&cat2ID=126&pageID=69&emotionstate=0&emotionID=8&langID=2.
103. Woodrow Wilson International Center for Scholars. Bike and Hike Pants by Jack Wolfskin. [cited 8.10.2007]; Available from: http://www.nanotechproject.org/index.php?id=44&action=view&product_id=1404.
104. Schoeller Textile AG. nanosphere. [cited 8.10.2007; Available from: http://www.schoeller-textiles.com/nanosphere/main.asp?site=nanosphere&language=english&webpageID=255.
105. Pro Idee. Give it a shake and it s dry. [cited 8.10.2007]; Available from: http://www.proidee.co.uk/shop/SID_vgThzuGoexUuvTmwJhzj7adSkBB2/F=produkt_formular/P=02_GB_HPN570366/K=02_GB_120057.
106. Percent AG. Nanotechnology solutions. [cited 9.10.2007]; Available from: http://ch.percenta.com/special-celo-reinigungstuch.php.
107. nanoproofed. nanoproofed® protection Leder und Textil Versiegelung. [cited 8.10.2007]; Available from: http://www.nanoproofed.de/reload.html?home.htm.
108. Nanotec. Nanoprotex. [cited 8.10.2007]; Available from: http://www.nanotec.com.au/nanoprotex.htm.
109. Nano-X. Markenportfolio. [cited 8.10.2007]; Available from: http://www.nano-x.de/deutsch/portfolio.htm.

110. Globetrotter Ausrüstung. Nanodry. [cited 8.10.2007]; Available from: http://www.globetrotter.de/de/shop/search.php?suchfeld=Nanodry&GTID=bb468a2220f61b968bf13541024b8e68a34.
111. Woodrow Wilson International Center for Scholars. New Balance Womans Sky Crop by New Balance. [cited 8.10.2007]; Available from: http://www.nanotechproject.org/index.php?id=44&action=view&product_id=1120.
112. Edi Bauer. 8” Water Short. [cited 8.10.2007]; Available from: http://www.eddiebauer.com/eb/product.asp?cm_cg=T319&product_id=29068&.rand=disabled.
113. Nanotex. Coolest comfort. [cited 8.10.2007]; Available from: http://www.nano-tex.com/applications/apparel_P3.html.
114. NanoTsunami. Nanophase launches textil and non-woven nanoengineered products. [cited 8.10.2007]; Available from: http://www.voyle.net/Nano%20Textiles/2005%20Textiles/Textiles-2005-0004.htm.
115. nanogate. Licht und Schatten. [cited 8.10.2007]; Available from: http://www.nanogate.de/de/produktveredelung/funktionen/nanobarrier/uv-schutz.php.
116. Tianjin Tianfang Investment Holding CO. Sell Nano Antibiotic and Deodorizing Shirting Fabric. [cited 8.10.2007]; Available from: http://rongze.en.alibaba.com/offerdetail/52555693/Sell_Nano_Antibiotic_and_Deodorizing_Shirting_Fabric.html.
117. Luko International Technology. Produktserie Nanofin. [cited 8.10.2007]; Available from: http://www.luko-international.de/index.php?id=72.
118. Nanocor. Nanomer® Nanoclays [cited 8.10.2007]; Available from: http://www.nanocor.com/products.asp.
119. Woodrow Wilson Internatonal Center for Scholars. Nanorama - Nano Gold Mask Pack by Lexon Nanotech, Inc. [cited 8.10.2007]; Available from: http://www.nanotechproject.org/index.php?id=44&action=view&product_id=1407.
120. Woodrow Wilson Internatonal Center for Scholars. Nano Gold Mask by Quan Zhou Hu Zheng Nano Technology Co., Ltd.®. [cited 8.10.2007]; Available from: http://www.nanotechproject.org/index.php?id=44&action=view&product_id=1386.
121. Aspen Aerogels. Aspen Aerogels: Products. [cited 9.10.2007]; Available from: http://www.aerogel.com/products/overview.html.
122. DAIICHI ORIMONO CO.LTE. Morphotex. [cited 8.10.2007]; Available from: http://www.dicros.co.jp/e/textile03.html.

Appendix

<u>Reviewed consumer inventories and nanotechnology related news-pages</u>

Database/Newsgroup:	Project on emerging nanotechonologies
Author:	Woodrow Wilson Institute for scholars
Date of Access:	9.07.2007
Country:	USA
URL:	http://www.nanotechproject.org/index.php?id=44&action=view
Database/Newsgroup:	The A to Z of Nanotechnology
Author:	AZoNano: AZo Journal of Nanotechnology Online
Date of Access:	9.07.2007
Country:	-
URL:	http://www.azonano.com/
Database/Newsgroup:	Nano Tsunami: Europe’s largest independent nanotech news site
Author:	Nano Tsunami
Date of Access:	9.07.2007
Country:	Netherlands
URL:	http://www.voyle.net/
Database/Newsgroup:	Nanotechnik Schweiz
Author:	Wild, M.
Date of Access:	9.07.2007
Country:	Switzerland
URL:	http://www.nanotechnik-schweiz.ch/?gclid=CN3KtrKV6osCFQbnlAodsT9fQQ
Database/Newsgroup:	Nano in Germany
Author:	VDI-TZ Internetagentur Düsseldorf
Date of Access:	9.07.2007
Country:	Germany
URL:	http://www.nanoingermany.com/smr/
Database/Newsgroup:	Nanotechnology Portal
Author:	Nanowerk LLC.
Date of Access:	9.07.2007
Country:	USA
URL:	http://www.nanowerk.com/n_contact_us.html