Introduction

The past twenty years has seen the rapid introduction of nanomaterials into a wide variety of textile processes, from anti stain and wrinkle finishings to nanofiber wound care. This has opened up new markets for nanomaterials suppliers and textile producers alike. While some of these products have been on the market since the early 2000's, for example Nano-Tex coatings, others such as conducting coatings for fibers or graphene coatings for non-wovens are only just emerging.

The past 30 years has also seen a rapid decrease in the size of computers, from large mainframes through laptops to smartphones and smart watches. As a result, devices have increased in both computing power and ubiquity. But rather than just being ever smaller versions off the same device a range of new technologies are blurring the lines between traditional industries such as textiles and apparel and information technology. This is creating what we believe to be a 4th Industrial Revolution for the textiles and fashion industry.

However, this revolution it is not being driven solely by increases in computing power. Advances in fields such as nanotechnology, organic electronics (also known as plastic electronics) and conducting polymers are cruising range of textile–based technologies with the ability to sense and react to the world around them. This includes monitoring biometric data such as heart rate, the environmental factors such as temperature and The presence of toxic gases producing real time feedback in the form of electrical stimuli, haptic feedback or changes in color.

Fitness trackers and smart watches are just the beginning. Already there are a growing number of products on the market which integrate textiles with sensors to create new forms of wearable technologies. These range from first generation technologies where sensor is attached to apparel, second-generation ones were centers are embedded in clothing and growing a lot of third generation technologies very active element is the fiber itself.

How to Use This Report

Smart Textiles, Wearable Technologies and the 4th Industrial Revolution looks at how textiles and computing are converging and the factors driving this.

Markets examines the global market for nanotechnology and smart textiles by application area, looking at apparel, home textiles, medical textiles, military textiles, technical textiles and textile based wearables. It also provides figures for the nanomaterials inputs (materials, coatings, inks, masterbatches etc.) required for each application.

Nanotechnology and Graphene In Textiles examines why these materials are being used in textiles and what advantages they confer.

Applications gives detailed description of current and proposed applications of nanotechnology by sector and covers Clothing and Apparel, Sports and Wellbeing , Energy

Storage and Generation , Energy Harvesting , Fashion, Entertainment, Personal Protection, Military Textiles., Home Textiles, Medical Textile and Technical textiles.

Key Technologies such as strain sensors, conductive fibers and photochromic textiles are explained, along with examples of the types and application of each technology.

The textile industry will experience a growing demand for high-tech materials driven largely by technical textiles and the increasing integration of smart textiles to create wearable devices. This will enable the transition of the wearable market away from one dominated by smartphone based hardware. Unlike today's 'wearables' tomorrow's devices will be fully integrated into the garment through the use of conductive fibers, multilayer 3D printed structures and two dimensional materials such as graphene.

Table 4 illustrates the nanotechnology-enabled market growth in textile by sector. The most value will be added by textile applications in wearable devices, with traditional sectors such as apparel and home textiles showing the lowest growth.

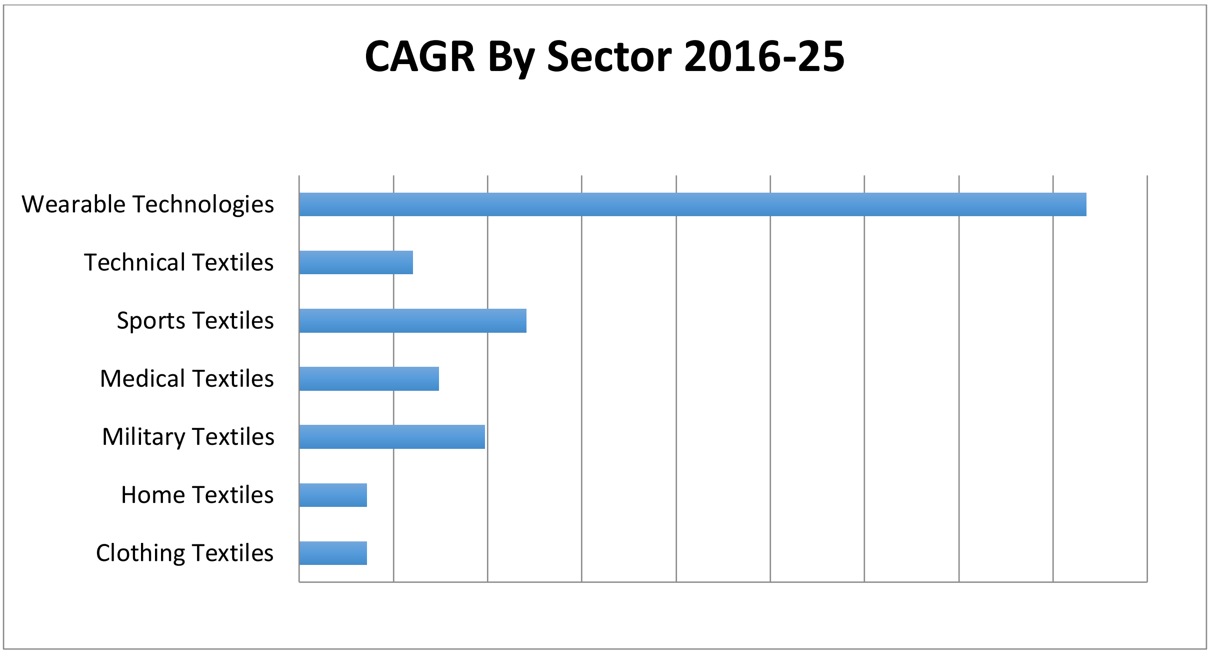

Figure 13 Compound Annual Growth Rates (CAGR) by Sector (2016-25)

This represents significant opportunities for existing smart textiles companies and new entrants to create and grow niche markets in sectors currently dominated by hardware manufacturers such Apple and Samsung.

By 2022 wearable technologies will account for of the global textiles market rising to by 2025. Combined with increased use of technical textiles, clothing and apparel will decline to below of the total market. Although this still represents a billion opportunity, margins and competition will be increasingly fierce while more technology focussed companies will generate higher revenues from wearables.

of the textile Industry this will be a demand for intermediate materials such inks, pastes and master batches rather than raw or untreated materials.

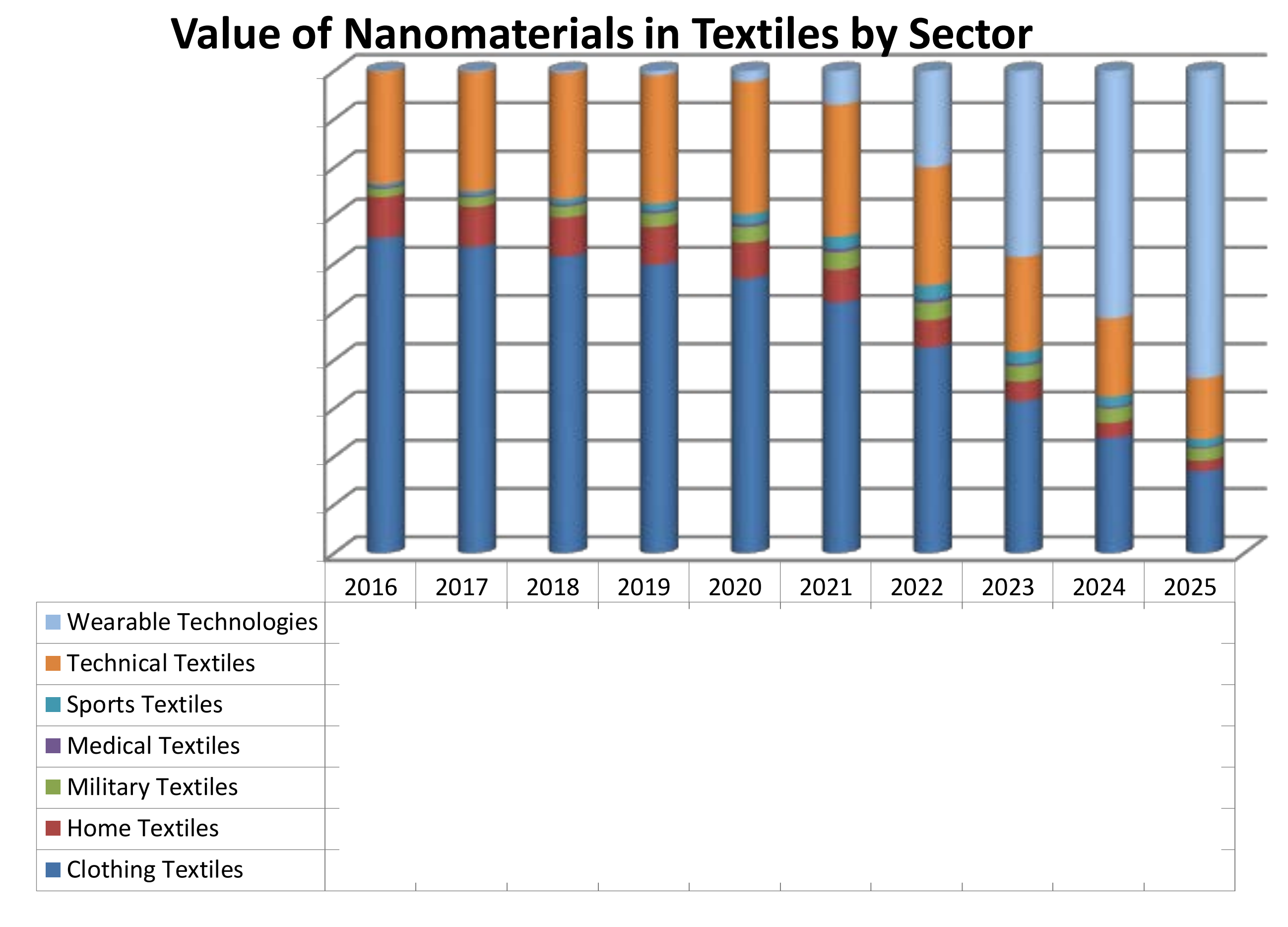

Figure 18 Value of Nanomaterials in Textiles by Sector 2016-2025 (US$ Millions)

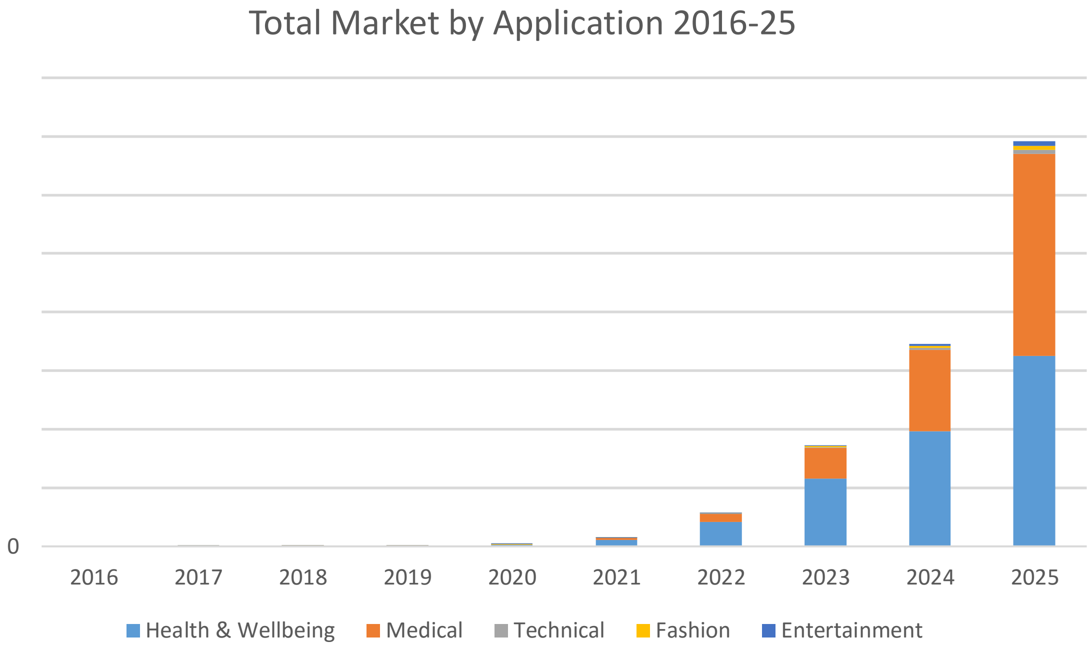

Figure 31 Total market for textile based wearables 2016-25 (US$ Millions)

The major markets for textile based wearables will be initially sports, health and wellbeing, as it is for current silicon based wearable technologies. While this is a significant market totaling by 2020 and by 2015, we expect that as these technologies mature many of them will begin to be repurposed for medical monitoring by 2020. As a result, within ten years the medical market will represent the biggest opportunity for wearables. However, opportunities will be scarce before

Current Applications of Nanotechnology in Textile Production

Nanotechnology in Fibers and Yarns

Currently, there are two common ways of manufacturing nanofibers. One is to use electrospinning where the polymer stream (solution or melt) is "extruded and drawn" by producing a 20KV voltage differential among the polymer solution and the collector. This method has been used effectively to produce research quantities of nanofibers and discover applications for polymers that are not melt-spinnable or solution-spinnable. Recent research has verified that nanofibers can be created using melt-spinnable polymers by means of conjugate spinning methods and designing special spinpacs. The results have formed nanofibers in the range of 100 nm to 400nm. The benefit of melt-spinning methods for nanofibers is that the productivity is comparable to the productivity for other melt-spun fibers.

It can be readily observed that the progress of a new range of fibers with cross-sections ranging from circular, segment pied, ribbon as well as other cross-sections authorize the incorporation of bonus functionality. Furthermore, nanofibers have considerable surface areas that can be used to react with the environment. Unique monomolecular layers and decreased pore size in the resultant fabrics lead to decontamination and entrapment potential. Ribbon fibers, for example, provide low abrasion and low air and water permeability. Hollow segment pie and islands in the sea structures offer micro and nanofibers as fiber blends where functionality of the polymer mechanism can be combined to functional advantage. The promising world of nanofibers gives the textile materials technologist an exclusively new world of materials and functions to create the next generation of textile materials.

Nano-Structured Composite Fibers

Nano-structured composite fibers employ nanosize fillers such as nanoparticles (clay, metal oxides, and carbon black), graphite nanofibers (GNF) and carbon nanotubes (CNT). Moreover, nano-structured merged fibers can be generated through foam-forming process, other than using nanosize fillers. The main utility of nanosize fillers is to increase the mechanical strength and improve the physical properties such as conductivity and antistatic behaviours. Due to their huge surface area, these nanofillers have a healthier interaction with polymer matrices. Being in the nanometer range, the fillers might interfere with polymer chain movement and thus condense the chain mobility. Being uniformly distributed in polymer matrices, nanoparticles can carry load and increase the toughness and abrasion resistance; nanofibers can relocate stress away from polymer matrices and enhance tensile strength of composite fibers. Distribution of nanofillers in polymer matrices through mechanical and chemical approaches is one of the important phases leading to high quality of nanostructured composite fibers. Further physical and chemical performances attribute to composite fibers vary with specific properties of the nanofillers used.

Medical Textiles

Most of the applications of nanotechnology in medical textiles have been covered in the "Sports and Wellbeing section. One area that deserves special mention is wound care.

Nanosilver Wound Dressings

Nucryst Pharmaceuticals, a division of Westaim Corporation originally developed nanosized silver particles which increase the surface area to convalesce its antibacterial efficiency against 150 types of microbes, including drug-resistant bacteria. Nucryst reported that its nanosilver product Acticoat kills bacteria in as little as 30 minutes, and works continuously over several days. While the product has been on the market since 1999, Nucryst's partner Smith & Nephew paid a US $5 million fee to Nucryst for attaining one of its sales and regulatory milestones in the first quarter of 2004 and acquired the assets of Nucryst in 2009.

Covatec, who sell similar products under the Aquacell and Hydrofiber brand names are involved with in a long running patent dispute with Smith and Nephew over the "silverization of fibers.

- Barrier material (for infection control)
- Bandaging & pressure garment
- Wound care material
- Hygiene material
- Implantable material (sutures, artificial joints)
- Extra Corporal devices (e.g. artificial kidney)

Electrospun Nanofibers to Stop Bleeding

One of the recent breakthroughs in medical textile is "nano bleed-stop technology." Textile applications of nanotechnology are already growing and the recent addition of nano bleed-stop technology will strengthen nanotech medical textile made from electrospun nanofibre technology.

Electrospun nanofiber technology has revolutionized the medical industry. However, nanofiber net is delicate and cannot be used on its own, so conventional dressings are coated with electrospun nanofiber to harvest their full potential. Electrospun nanofiber dressing enhances moisture management and offers unmatchable barrier properties, besides assisting control of fluid drainage.

A polymer solution is electrospun into very fine fibers, which are then collected on a grounded electrode. The basic electrospinning unit contains a needle nozzle, a high voltage power supply, a container for spinning fluid and an electrode collector. Electrospun nanofiber technology is also widely used in tissue engineering to repair, maintain, replace or enhance function of a

Another large potential application is in the coating of non woven with thin layers of graphene to alter their hydrophilicity and enable their use in the filtration of liquids.

G2O Water Technologies

UK based G2O Water Technologies s offering a graphene-based water membrane technology that can be applied to any filter medium used today and reduce their energy costs of those filters by 80-90%, which translates to saving $30 million per year for a water desalination plant that produces 50 million gallons a day, and thereby reducing water costs by 40%.

H&V Nanowave Filtration Media

For years, the filtration industry has been looking for a synthetic alternative to glass mat media that offers better filter performance with lower energy costs. To meet this challenge, Hollingsworth & Vose Company has developed a unique, environmentally friendly choice for air filtration that meets the standards for HVAC bag applications.

H& V's proprietary extended surface synthetic media, offers the same efficiency and resistance in an uncharged state as glass mat media. However, NanoWave synthetic media eliminates the occurrence of fiber shedding that is associated with glass media during filter processing, installation, and use.

Designed specifically to meet ASHRAE 52.2 and new EN779 standards, NanoWave can be converted into a filter using conventional bag manufacturing equipment, eliminating capital expenses for plant equipment switching costs.

NanoWave is currently being used in applications that include Commercial HVAC systems and Aircraft paint spray facilities

Donaldson Torit Nanofiber Dust Filters

Donaldson use nanofibers to create a performance layer for industrial air filtration applications. To produce a nanofiber layer, an electro-spinning process creates a very fine, continuous, resilient fiber of 0.2 – 0.3 micron in diameter that is then applied to a filtration media substrate material. The nanofibers form a permanent web with very fine interstitial spaces on the surface of the substrate. The web collects dust, dirt and contaminants on the surface of the filter; this offers many benefits over conventional filters built with cellulose, cellulose/synthetic, spunbond, or meltblown commodity filtration media.

Companies Mentioned

Adidas
Advanced Nano Products, Inc.
AdvanPro Limited
AiQ Smart Clothing Inc.
ALATEX
Alexium
Algebra
Alink Co., Ltd
Alltracel Pharmaceuticals
Alphabet
Analog Devices
Andeson Bio-tech Co
Applied DNA Sciences
Applied EM
ARC Outdoors
ARC Technologies
Arc'teryx,
Asahi Kasei
Athos
Avelana
Baar
BAE Systems
Balton Sp. Z.o.o
Barclays
BASF
BeBop Sensors
Beijing ChamGo Nano-Tech Co
Belt Tech
BigSky Technologies LLC
Bischoff Textil AG,
Bluestar
Bonar Technical Fabrics NV,
Borgstena Group
Brooks Bros., USA
Bruck Textiles
Burlington Industries, Inc., USA
Canada Goose,
Cardinal Health
CC-NanoChem, Germany
Chamchuree
Chonbang, Co. Ltd.
Chromat
Ciba Specialty Chemicals
Cintas
Clariant
Clothing+
Cocona Fabric
Cook Medical
Cool Sensations
Covestra
Creative Materials
CTT Group
Cute Circuit
Cyanine Technologies srl,
Daniel Hechter,
Degussa
Delta Galil Industries Ltd
Denizli Basma ve Boya Sanayii a.s. (DEBA),
Donaldson
Dow Corning
Duke University, USA
DuPont
DuPont Speciality Chemicals
Durex
Duro Textiles
Easyjet
Eddie Bauer
EHO Textiles
Eleksen
Element 47
ELMARCO s.r.o.
EMPA
Endomondo,
Energenics
ETH Zurich, Wearable Computing Lab;
Evonik