Graduation Project

‘Nanotechnology in the textile industry’

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What are the issues in the adoption process and (how) can they be solved?

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Amsterdam, January 2009

Coach: Marco Mossinkoff
Preface

This report is written by order of the Amsterdam Fashion Institute, part of the Hogeschool van Amsterdam. It is part of my graduation project from the International Fashion and Management degree programme.

Working on this report has been a good experience for me to construct a research of this size individually, I learned a lot from it. It gave me the opportunity to enhance my knowledge in one of the area’s I enjoyed the most during my education: technical textiles. Next to this, it is a good way to show what I have learned from my education at AMFI in the past years.

My project was coached by Marco Mossinkoff, who I would like to thank for his advise and support of the various proceedings that have led to the completion of this report. I would also like to thank the other teachers at the Amsterdam Fashion Institute who have helped me the past months. Finally, I want to thank all the specialists from the industry that I have interviewed, and everyone else that supported me during this research.

Amsterdam, January 2009

Tessa Rijnbeek
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Summary

This report provides an answer to the question: What are the issues in the adoption process of nanotechnology and (how) can they be solved?

Nanotechnology is often referred to as the most important and revolutionary technology for the 21st century. It focuses on new material behaviours and properties that occur when reaching the nano-scale: the level between atoms and the micro (µ) level. Nanotechnology creates promising possibilities in many realms of society: health care, electronics, environment, textiles, and many more.

There are many opportunities for nanotechnology in the textile industry, especially in the field of technical textiles, an area which has grown fast in the past decade. There are numerous examples of nanotechnology applications in coatings, fibres and electronic textiles.

On the short term, success is expected in the non-cost-sensitive areas like professional sports, defence, protective workwear and health care. In these fields the extra functions nanotechnology brings are more important than price. Mass markets like clothing and home textiles will not be reached in the coming five years.

Through nanotechnology, the textile industry can better anticipate to the changing consumer needs: a demand for higher quality and new functions in clothing that enhance comfort. It also forms an important asset for the industry (mainly in Europe and the US) to improve their competitive position by offering high quality products that cheaper countries in Asia can't offer.

But, as often the case with new technologies, there are a number of crucial issues in the development process of nanotechnology, both in general and in textiles. I used the innovation theories of Dany Jacobs to clarify and further explain these issues.

The first and main issue is the lack of information and knowledge, mainly on the effects nanoparts may have on the environment and public health. Nanoparts could be dangerous, and are often compared to asbestos which behaves in the same way inside the body. Much research is being performed, but the effects are not yet monitored, which causes concern amongst both companies and end-users. When this monitoring is not happening soon, this might enlarge the gap between the technology and society, hindering public acceptance. This stagnates the adoption: the added value of nanotechnology does not add up to its problems.

Next to this there are four smaller problems. Because the effects of nanotechnology are not clearly monitored, there are hardly laws or regulations regarding the handling of nanoparts in products. This again forms a risk for public health, and raises concern in society. There are also problems in the commercialisation of products, caused by the high prices of the technology. Another problem is formed by the low level of investments and the large gap between public funding and the commercial market, which stagnates growth. The final problem is the fear of a nano-divide between developing countries and the western world, because the technology is too expensive for them to adopt.

Analysing these issues made clear that they are quite common in adoption processes of new technologies, and showed similarities to the adoption processes of other technologies. Of course this does not mean that nothing should be done.

Governments and EU should invest more in research into the effects of nanoparts on public health and stimulate the investment of companies. When effects are monitored, they should develop laws and regulations regarding the handling of nanoparts in order to protect consumers and companies and stimulate public acceptance.

So the keyword in stimulating further development of nanotechnology in the textile industry is investment, by both governments and EU and companies.
1. Introduction

1.1 Occasion for the subject and problem definition

‘Nanotechnology is thought to be the key technology for the 21st century. Nanoscience is expected to open up whole new fields of knowledge and engender a host of new products with enormous economic potential. It will change our everyday lives and impact the environment as well. In addition, work at the nanoscale will bring together many of the research and technological disciplines we currently think of as being separate: physics, chemistry, medicine, biotechnology, computer science, electronics and materials science. Despite all this, the broader public shows little appreciation of nanotechnology’s momentous significance.’

(Part of an editorial letter from Michael Emmenegger, taken from the Information Brochure ‘Know Your Nano!’ by TA-SWISS, Centre for Technology Assessment, August 2006)

When I started thinking about the subject for my final thesis, I soon found that I wanted to do something with new developments in textiles. Ever since mister Jordaan gave a lecture about this in the Private Label block, the subject had my interest. The enormous amount of developments and the possibilities this creates fascinates me.

While doing research on the subject I found many amazing developments in textiles. In a number of books and articles about smart fibres, I came across the word nanofibres and nanotechnology. I started researching the subject a bit more and found that nanotechnology is a promising technology for the future, not only in textiles. The complexity of the subject and promising future prospects made me very curious.

I read in several reports by Cientifica (a nanotechnology information company) that even though early observers predicted major breakthroughs in medicines and electronics, it appeared that the textile industry has been one of the first adopters of nanotechnology.

This made me wonder what the future possibilities of nanofibres will be for the textile industry. What possibilities does it create in textiles? In which areas will nanofibres break through? And what are the issues nanotechnology has to deal with?

I soon found that there are many issues in the adoption process of nanotechnology.

It appeared that working at this new found level entails many uncertainties and risks, and that there are hurdles in investment and commercialisation. This made me wonder what the origin of these issues is, if and how they can be solved, and how the industry deals with these problems.

Nanotechnology will play a very important role in the near future in many fields of society, including the textile industry. My goal is to monitor this role, and analyse the issues in the adoption process in order to create a clear view on the true prospect for nanotechnology in the textile industry.

I came to the following research question:

What are the issues in the adoption process of nanotechnology in the textile industry and (how) can they be solved?
My coach Marco Mossinkoff came to the idea of combining the subject with the innovation theories of Dany Jacobs. He wrote a book called ‘Adding Values: the cultural side of innovation’ (2007), in which he describes the importance of the cultural side of innovations in adoption processes. This could help me in understanding and explaining the adoption issues of nanotechnology, and so it did.

1.2 Subsidiary questions, research methods and chapter division

In order to structure my research I came to a number of subsidiary questions:

1. What is nanotechnology exactly and in which areas can it be used?
2. How does nanotechnology work in textiles and what are the main fields of application?
3. What are the opportunities for nanotechnology in textile industry?
4. What are the issues in the development process of nanotechnology and where do they come from?
5. How does technology adoption work and how can this explain issues in nanotechnology?
6. How does the industry cope with the issues?
7. What can be done to solve the issues in the adoption process?

In order to answer these questions I made use of both desk and field research. A lot of information on the basic elements of nanotechnology and its applications (questions 1, 2, 3) I found on the internet and in specialised reports. The problem in this is that there is too much information, and sometimes reports contradict, so I spoke with nanotechnology (textile) specialists to verify parts of my information. In order to answer the question about the issues, I again used specialised reports by for example the EU, NanoNed, etc. I also spoke about the issues with specialists from the industry and universities. They also helped me in finding the answers to questions 6 and 7.

The above mentioned questions will be answered in the next five chapters of this report. The chapter division is as follows:

• Chapter two will explain the basic elements of nanotechnology. It describes how the technology developed and what the main fields of application are.
• The third chapter will go deeper into nanotechnology in the textile industry. It describes the nano-textile industry, how nanotechnology works in textiles and what nanotechnology can add to the textile industry. It also provides an overview of the main (future) applications of nanotechnology in textiles.
• Chapter four will describe the issues in the development process of nanotechnology, and, if applicable, link them to issues in the adoption of other technologies.
• Chapter five describes the background of the issues in the adoption of nanotechnology, linked to the innovation theories of Dany Jacobs.
• The sixth chapter provides an insight in how the textile industry deals with the issues of nanotechnology.
• Chapter seven forms the conclusion of the report.
2. The world of nanotechnology

Though the idea of nanotechnology sounds very promising, there appears to be a lot of confusion about its exact definition and the possibilities it entails. When searching the internet numerous definitions, applications and links occur. This makes it quite difficult to determine what nanotechnology really is about. After speaking with some nanotechnology experts I believe I have found the right definitions and features. In this chapter I will explain the basic elements of nanotechnology, how the technology developed and what its main fields of application are.

2.1 Nanotechnology defined

Nanotechnology is a relatively new technology that focuses on the new behaviours and properties of materials at the nanoscale.

2.1.1 The nanoscale
The nanoscale ranges from 1 to about 100 nanometres, which is a little above the level of atoms and molecules. One nanometre (nm) is one billionth of a metre.
To put this into perspective, a sugar molecule, which measures about one nanometre, is as big in relation to an apple as the apple is in relation to the earth. The smallest thing visible to the (unaided) human eye is about 10,000 nm across.
The image below visualises the nanoscale in relation to the micro and macro world.

Nanoproducts, such as nanofibers, are built up of nanoparticles.
A nanoparticle is an atomic structure of a size between that of a molecule and a microscopic object (μm scale), and is the smallest solid thing possible to make.
As image 2.1 shows, nanoscale materials and effects are present in nature all around us, but the term nanotechnology only refers to artificially produced nanostructures.
2.1.2 Material properties at the nanoscale
What makes the nanoscale so special is the fact that materials can have different, often amazing properties when they reach this scale.

Every chemical element has characteristic, recognisable properties: colour, hardness, elasticity, conductivity, melting temperature, etc. But if an object is divided over and over again until it falls out of the macro and micro world and into the nanoworld, these properties can become totally different.

Gold at the bulk scale, for instance, is yellow in colour, but gold nanoparticles can be red, purple, orange or greenish, depending on their size. Gold at the bulk scale is an excellent conductor of heat and electricity, but not of light. Gold nanoparticles on the other hand can absorb light and turn it into heat. Through this they can even produce enough heat to act like miniature thermal scalpels that can kill unwanted cells in the body, such as cancer cells.

Another example is titanium powder. This white powder is often used in paint as a pigment. But in the form of nanoparticles it is colourless and transparent, and is used in sunscreen for its UV-blocking properties.

Unfortunately, the new properties that occur in the nanoscale cannot simply remain when going up to the macro scale. When the nanoparticles are pushed back together and joined into larger structures, they will rapidly adopt their ‘bulk properties’ again.

The trick is to arrange the particles in such a way that they are close to each other but not close enough to combine.

That is also the key of nanotechnology: putting together and combining atomic structures into new (nano) structures in such a way that the new properties can be sustained.

But that is only the start of it: to be able to produce actual products fabrication processes need to be developed for reproducing the nanostructures and fitting them into larger structures.

2.1.3 Surface areas
One of the reasons why materials at the nanoscale have different properties from the bulk scale is their relatively large surface area. When a particle is divided down to the nanoscale, the total surface area will increase. This is visualised in image 2.2 and 2.3.

![Image 2.2: The total surface area increases when particles are divided: the red part has become a surface area.](source: www.unitex.be)

<table>
<thead>
<tr>
<th>Particle size</th>
<th>10 cm</th>
<th>1 mm</th>
<th>1 μm</th>
<th>1 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>1</td>
<td>100</td>
<td>100,000</td>
<td>100,000,000</td>
</tr>
</tbody>
</table>

![Image 2.3: The particle of 10 cm is divided into 100 particles of 1 mm, which means there are now 100 relatively larger surfaces, so the total surface area has increased, etc, etc.](source: www.unitex.be)
As the particle size decreases, the number of molecules at the surface relative to the bulk increases, giving new and unexpected properties. The larger the surface area, the more surface there is available for interactions with other materials.

An example to clarify this is a piece of gum. Compare a piece of gum chewed into a wad with stretching that gum into a sheet as thin as possible. The surface area is much larger for the stretched out gum than for the wad of gum. The stretched out gum will dry out and break faster, since the sheet has more contact at the surface with the air moving around it. This shows the difference in properties between two different forms of one material.

2.2 How nanotechnology developed

The development of nanotechnology flows from the ongoing research into atoms and molecules of the past century. The downsizing of products in the past decades, especially in electronics, has also stimulated the development of nanotechnology.

Physicist Richard P. Feynmann is an important person in the discovery of nanotechnology. In his famous lecture 'There's plenty of room at the bottom' at the California Institute of Technology in 1959, he addressed the concept of what we know today as nanotechnology. Feynmann stated: 'Many of the (biological) cells are very tiny, but they are active; they manufacture substances; they walk around; they wiggle; and they do all kind of marvellous things – all on a very small scale. Also, they store information. Consider the possibility that we too can make things very small, which does what we want – and that we can manufacture an object that manoeuvres at that level.' With these famous sentences Feynmann was the first to explore the idea of what was later called nanotechnology.

The word 'nanotechnology' was invented in 1974 by Norio Taniguchi, a professor of Tokyo Science University, to describe working with measurements smaller than a micrometer.

A part of Feynmann's dream was realised with the invention of the Scanning Tunnelling Microscope (STM) in 1981. This microscope made it possible to visualise and manipulate materials at the atomic level.

The next breakthrough in the development of nanotechnology was the invention of new carbon shapes. In 1985, researchers discovered so-called 'buckyballs', which are perfect spheres consisting of sixty carbon atoms. This again led to the discovery of a cylinder molecular shape in 1991, called the carbon nanotube.

![Image 2.4: In the left corner a visualisation of the buckyball, at the right two views of the nanotube. Source: www.jeteye.com](image-url)
Nanotubes are about 100 times stronger than steel, but just a sixth of its weight. They also have unusual conductivity and heat characteristics. Many of the tools and approaches later used in nanotechnology are based on buckyballs and nanotubes.

2.3 Fields of application of nanotechnology

As mentioned, nanotechnology brings together many fields of (technological) research. It can be used to improve materials or substances in almost every realm of our society and environment. Richard P. Feynmann imagined the creation of molecular machines that are able to move and perform given tasks, often described as nanorobots. This is still much too complex, and far beyond current capabilities. In the past five years nanoproducts slowly started coming on the market, and the number of products is growing quite fast now. But what qualifies as nanotechnology today is more the research and development in laboratories and research centres.

The main fields in which nanotechnology is currently present are:

- health
- environment
- electronics
- materials

First I will briefly describe health and environment. In the next subparagraphs I will go more into electronics and materials, since they are more relevant in the area of textiles.

2.3.1 Nanotechnology in health and environment

Nanotechnology creates promising possibilities in the field of health, especially in medicine. Nanomedicines can be engineered in such a way that the particles deliver drugs, heat or other substances only to specific cells in the body. Because nanostructures can be made of the same size as biomolecules, they can interact with each other inside these targeted cells. This means that diseases or viruses will be detected and treated in the targeted cells only, so the damage to healthy cells can be minimised. Several nanomedicines are already used in healthcare at the moment.

Nanotechnology can also be used for disease prevention - by improving food safety for instance - and in cosmetics. It is already used in many sunscreens.

The application of nanotechnology in the environment is expected to provide solutions and new alternatives in energy conservation and pollution prevention and recovering. Certain nanoparticles can be added to water or other fluids to make them highly efficient energy suppliers for instance. A new type of ultra-thin silicon solar cells is expected to become a cheap and very efficient alternative for energy supply.

2.3.2 Nanotechnology in electronics

In the past decade, the electronics industry has grown quite fast. As written in a report by the European Commission (EC) called ‘Vision 2020 – Nanoelectronics at the centre of change’ (2004), investment in electronics currently accounts for about 30% of overall industrial investment in the developed world. The worldwide annual market for electronics is about €800 billion, and when the many other industries that depend on electronics (telecommunications, internet services, aerospace, defence, etc.) are included, the global value lies around €5000 billion.
Nanotechnology is expected to make a large difference in electronics by creating new opportunities and making equipment smaller, cheaper, easier to operate and at the same time much more powerful.

Due to nanotechnology, chips can be made so small and cheap that they can be integrated almost anywhere and interact with each other. Products like computers, multimedia equipment and communication devices can then be integrated into their environment (clothing, cars, homes or offices), in this way easing the interaction of information and improve working conditions, productivity and even life.

With this, sophisticated home entertainment and mobile communication systems can be created, as well as faster and more complete medical diagnostic and treatment systems.

An example in mobile devices is the Nokia Morph phone, launched in February 2008. The device is developed for the “Design and Elastic Mind” exhibition in the Museum of Modern Art in New York, through a collaboration between Nokia Research Centre and Cambridge Nanoscience Centre (UK). It is a concept that shows how nanotechnology might enable future mobile devices to be stretchable and flexible, allowing the user to transform their mobile device into radically different shapes. The device is also completely transparent, self-cleaning and charges on solar absorption – all possible because of nanotechnology. According to Technical Textiles International (May 2008), elements of Morph might be available in mobile devices within seven years, though initially only at the high-end market.

The most relevant application in the field of electronics in this case is of course the integration of electronics and textiles.

The most known application in this field is wearable electronics, in which keypads, joysticks, lighting systems and solar systems are integrated into clothing items – to name a few.

The UK company Fibretronic produces a variety of wearable electronics. Their products are used in O’Neill Europe’s latest wearable electronic snowboard garments. The H4 Ent jacket for example incorporates Fibretronic’s Fiddler joystick iPod control system on its sleeve.
The integration of sensors for body monitoring is a growing field in both the performance sports and healthcare sector (Technical Textiles International, 2008). In the healthcare sector, sensors can be incorporated into clothing, bandages, bedding or seating for patient monitoring. In the sports market, sensors in footwear, garments and other soft accessory products can monitor the wearer’s activity and performance levels.

US company Textronics has created a textile-based electrode system, which covers stretchable textile electrodes that can be incorporated into wearable garments to comfortably monitor the wearer’s heart rate, electrocardiogram (ECG) and other activity of the body. As Textronics CEO Stacey Burr states in Technical Textiles International Magazine (May 2008), their products have been worn by marathon runners, Olympic athletes and college basketball players. The US Food and Drug Administration (FDA) also uses Textronics’ ECG electrode system for general monitoring and recording procedures.

Other possibilities in textiles are the integration of switches and sensors into furniture, carpets or automotive seating, for environmental sensing or controlling interior electronics. Chapter 2 will go more into nanotechnology in textiles.

2.3.3 Nanotechnology in materials

Next to textiles, there are many other materials in which nanotechnology is expected to create improvements and new possibilities, like metals and plastics. There are many possibilities, below are some examples.

In many cases, scientists use nanotechnology to try to imitate the way nature builds materials from the nanoscale to improve the properties of existing materials. A well-known phenomenon is the nanoscale texture on the surface of the lotus leaf. When water drops on the leaf, it beads up and rolls of the surface, carrying dirt particles of the surface as well. This makes it an ideal material surface: it doesn’t get wet or dirty. In 1997 the phenomenon was first explained by a botanist from the University of Bonn in Germany. The effect arises because lotus leaves have a very fine surface structure with water repellent wax crystals of around 1 nm in diameter. The image below shows the effect: when water droplets fall on the lotus leaf they touch the surface only at a few points, resting on these microscopic ‘bumps’. When the leaf moves a little the water droplets will roll off under their own weight.

The ‘lotus effect’ can be used in metals, plastics and textiles. Examples of applications are windscreens, radio car antennas, airplane wings, hulls of ships and clothing. Unlike existing water-repellent coatings, the nano coating can be permanently bonded onto the material and is no longer visible or perceptible.
Another example is the use of nanotubes in metals and plastics. This will enable a large reduction of the material weight. The transport industry is expected to benefit from this in many ways. Vehicles can become much lighter in weight, and safety in transport will be improved through the use of nanoparticles in rubber tyres. Nano-coatings can also be used to make materials scratchproof, or inside bottles and cans to prevent carbon dioxide loss and improve beer freshness.

2.4 Conclusion

Nanotechnology takes place at the nanoscale, which is in between the level of atoms and molecules, and the micro (µm) scale. Through combining nanoscale structures in the right way, the new properties that occur at this nanolevel can be sustained and can be used in actual products or substances. This provides numerous opportunities in improving materials, healthcare, electronics, environment and many other disciplines in our world. Today, nanotechnology is still more about research, though more and more products are coming on the market. It is clear that in the coming decades, nanotechnology will play a very important role in almost every realm of society.
3. Nanotechnology in the textile industry

As written in the report ‘Nanotechnology Market Forecast to 2011’ by RCNOS Industry Research Solutions (April 2008) the main sectors in which nanotechnology is rapidly growing are energy and textiles. The market for nanotechnology in textiles is expected to grow at a CAGR (Compound Annual Growth Rate) of over 53% by 2012, for nanotechnology in energy sector applications this is expected to be even more: about 59%.

Clearly, nanotechnology is expected to play an important role in the textile industry. The question that is what this role will be exactly. What will nanotechnology add to the textile industry, and in which parts of the market will it be present?

This chapter will provide an answer to these questions. First I will mention the most relevant trends and forecasts for the textile industry, including the market for nanotextiles. Next I will explain how nanotechnology works in textiles and what possibilities it creates. The third paragraph will provide an insight in the type of products that can be created with nanotextiles, and what this may mean for the textile industry. I will end with a brief overview of the products that are currently on the market.

3.1 The (nano) textile industry

3.1.1 A move towards technical textiles

Due to new technologies, the textile industry has been expanding to many new areas in the past decade, all belonging to the category of technical textiles. Textiles or textile-based composites are expected to replace many metallic and plastic materials used in for example the automobile industry, construction sector, machinery and machine tools industry, electronics, and to a lesser extent, in wood, leather, and other natural materials in furniture, sport goods and many other smaller application areas (Cientifica, 2006).

The main fields of application for textiles are:

- Agriculture and forestry
- Building and construction
- Clothing
- Defence
- Electronics
- Environmental protection
- Geotextiles and civil engineering materials
- Healthcare
- Home and household
- Industry and machinery
- Mobility and transport
- Packaging
- Sport and leisure

As written by Euratex in the report ‘The future is… Textiles!’ (2006), growth rates for technical textile products in new applications are generally higher than those for clothing and home textiles. But, on the other hand, their markets are often more specialised niches, with low volumes and high levels of quality and performance. Product innovation in these new markets is rapid, but these new developments require extensive know-how in materials, processing options, customer requirements and use scenarios.

The image on the next page shows the estimated consumption of technical textiles in Western Europe in percentages for 2004.
3.1.2 Facts and figures

An important note:
Because of the fact that there are currently no laws or regulations for the use of nanomaterials (for details see chapter 4, paragraph 3), and thus no report duty for products containing them, there are no reliable figures on the presence of nanotechnology in the market today. The nanotechnology figures present are based on estimations.

In the textile industry, one of the most important trends of the past few years is the rise of Asia, which clearly shows in trade figures. In 2006, four trade flows involving Asia grew by more than 10%.

In textiles, exports from Asia to Africa and Europe, for example, increased by 19% and 11% respectively, while those to North America rose by 9%. In clothing alone, Asian exports to Europe grew by 39% while those to North America rose by 15%.

A decline showed in America: Intra North American trade decreased by 9% and exports from South and Central America to North America fell in value by 6% (Textiles Intelligence, 2007).

The world’s biggest textile exporter in 2006 was the EU25*, followed by China. The EU25 was also the biggest importer, followed by the USA and China. In clothing alone, China became the world’s leading exporter, ahead of the EU25 (Textiles Intelligence, 2007).

Figure 3.2 on the next page shows the expected growth of the global textile market. In 2007, the world textile market was estimated to be US$ 4.4 trillion and is expected to rise to US$ 5.3 trillion by 2012. Clothing textiles will still comprise the largest sector (currently 60%) of the total textile market while sports/outdoor textiles and non-conventional technical textiles (used in for example mobility, machinery, agriculture) will exhibit the highest growth rates (Cientifica, 2006).

* EU25 : the 25 countries that belong to the EU since May 1st, 2004, when 10 countries were added : Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.
The next image shows the estimated market for textiles making use of some form of nanotechnology. It is estimated at US$ 13.6 billion for 2007, climbing to reach US$ 115 billion by 2012 (Cientifica, 2006).

Research of the Dutch Food and Goods Authority showed that in June 2007, there were 143 products in the Dutch market in which nanomaterials were suspected to be used. According to Lux Research Inc., in 2007, more than $60 billion of products incorporating nanotechnology were sold globally. By 2014, this figure is expected to grow to almost $3 trillion.
As the image shows, not all markets will be equally affected by nanotechnology. Highest growth rates are expected outside the traditional apparel and home applications, where demand for performance improvements is more important than cost reduction. This will speed up the adoption of nanotechnologies in these applications, which are mainly technical textiles and non-cost sensitive products such as sport or military textiles. Barriers are higher for the fashion clothing market, which makes up about 60% of the world textile market. As the primary pressure on fashion clothing is price rather than performance, penetration will be less in this sector, although in absolute dollar terms it will be the largest market. Nanotechnologies currently account for just 0.38% of the market for clothing, and this is expected to rise to 0.70% by 2012, as new applications and the falling cost of nanomaterials increase market penetration (Cientifica, 2006).

3.2 How nanotechnology works in textiles

The previous chapter described the basic elements of nanotechnology. In this paragraph I will explain more in detail how nanotechnology works in textiles, and what possibilities this creates.

The nanotechnology innovations in the textile industry include both the development of new materials and the improvement of existing materials. The use of nanotechnology allows textiles to become multifunctional. The so-called ‘plasma’ technology for instance, is being used to modify the top nanometre layers of textiles, making them antibacterial, water repellent and able to kill fungus at the same time.

3 types of nanotechnology in textiles can be distinguished:
- Nanotechnology in fibres and yarns (fabrics)
- Nanotechnology in coatings (textile finishing)
- E-textiles

In the following subparagraphs I will briefly describe each of the above subjects.

3.2.1 Nanotechnology in fibres and yarns

Nanotechnology creates many new possibilities in fabrics. Nanofibres make it possible to create new blended yarns and fabrics, enhance or alter the properties of textiles, produce synthetic fibres with properties of natural fibres, etc. The difference with normal fibres is that nanofibres have larger surface areas, that can be used to react with the environment (see paragraph 2.1.3). Molecular (nano) layers and a smaller pore size in the fabrics lead to, for example, self-cleaning and entrapment possibilities.

A different type of nanofibres are nanostructured composite fibres. These fibres contain nanosize fillers such as clay or metal nanoparticles, graphite nanofibres or carbon nanotubes. Another possibility in composite fibres are nano thin coatings around each fibre. The nanosize fillers and coatings are used to increase the mechanical strength and improve the physical properties such as conductivity or antistatic behaviour.

Image 3.4 on the next page shows microscopic views of some examples of nanofibres and nanostructured composite fibres.
Another interesting development are the so-called controlled release polymers. They activate the release of for example antifungals, fragrances or medical growth aids to the fabric. The triggered release systems can be made responsive to stimuli such as changes in temperature, humidity and oxygen levels.

3.2.2 Nanotechnology in coatings
The main advantage of nanotechnology in coatings is that it is no longer visible or perceptible on the product, and can still be made more controllable and more thorough. The separate molecules or nanoparticles of the finishes can be brought individually to specific, designated places on textile materials, which wasn’t possible on such scale before. This means that much less material is needed to create the same effect. Plus, nano-finishes can no longer be washed off, in contrary to previous textile finishes.

Nanoparticles such as metal oxides and ceramics are used in textile finishing to change surface properties and to add functions to the textile. Because of their larger surface area nanoparticles have a higher efficiency compared to larger size particles. Besides, nanosize particles are transparent, and do not blur colour and brightness of the textile substrates. Nanotechnologies for coatings include: self-healing composites, wear and corrosion resistant coatings, cut resistant material and wrinkle resistant fabric.

3.2.3 E-textiles
E (electronic) -textiles are fabrics made from yarns that carry electronic components. Nanotechnology encourages the development of e-textiles in allowing electronic devices to become smaller and more powerful, and creating new electrically conductive fibres and textiles. Nanotechnology treated fibres and fabrics have formed an entire range of smart textiles which can be used in numerous applications, like practical sportswear, medical and safety wear and fashion clothing.

E-textile products include: jackets with integrated audio control systems, heart sensing tops and bras, fabrics containing LEDs (Light Emitting Diodes) that display moving images on textiles, bags containing solar cells for charging mobile phones or iPods, etc.

Image 3.5 on the next page shows Lumalive textiles by Philips. These fabrics containin LEDs that display full colour moving images on textiles. Lumalive is currently used by several companies for advertising and promotion campaigns.
3.3 Opportunities in the textile industry

3.3.1 What nanotechnology can add to the textile industry
Nanotechnology can enrich the textile industry in several ways. First of all, and most obvious, it creates many new possibilities and improved functions in textiles. New materials can be developed, and new properties can be added to existing materials by the use of special-treated fibres, coatings and e-textiles. This will not only benefit the textile industry itself, but many other industries that make use of some form of textiles. Through this, the textile industry will be able to expand to new markets, as is currently already happening (see also paragraph 3.1.1).

Nanotechnology also allows the textile industry to better anticipate to changing consumer needs. More and more, consumers are demanding functions in clothing that go beyond appearance: the quality of products has become more important. Consumers now want the product to smell pleasant, stay fresh, feel comfortable, keep clean and to be simple to care for. Also, information and communication technologies have become very important in daily life.
Nanotechnology offers manufacturers the possibility to combine these changed consumer need with (existing) textile products like sportswear, home textiles and clothing.

But nanotechnology is not just a promising new way of working with textiles, in many cases the step towards nanotechnology is part of the strategy that textile companies hope keeps them surviving in a tough textiles market. Especially in the EU textile production, nanotechnology plays an important role because of this.
Increased competition, particularly from Asia (see also paragraph 3.1.2), combined with the abolition of all import quotas for textiles and clothing in the EU, US, Canada and Norway in 2005, has forced the industry to streamline and modify. It has become clear that manufacturing traditional products may no longer be enough to maintain a profitable business: the industry has to move in the direction of more innovative, high quality products in order to distinguish and compete.
 Much of the focus in the EU is on technical textiles with high added value, in order to develop new markets in construction, protective clothing and medical uses for example. By finding a niche, textile companies will not have to sell lower priced goods that struggle to compete with cheaper textiles from low cost countries.
In this way, nanotechnology offers solutions for keeping the textile industry in Europe competitive with the rest of the world.

3.3.2 Possibilities in textile products
Since there are numerous possibilities with nanotechnology in textiles, which I cannot all describe, I will highlight the most important and promising in this paragraph. I categorised the main fields of application and described the main (future) developments per type of product. Some products are already on the market, which you can read about in paragraph 3.3.3.

Sports/Outdoor wear
- Fibres - Anti-microbial, odour-free, moisture managing and UV-protective properties can be added to fabrics through nanofibres.
- Coatings - Ultra-thin coatings with nano-sized particles can kill bacteria, keep odour out, and make fabrics UV-protective and water and stain repellent.
- E-textiles - Devices such as GPS, solar energy technology, monitoring sensors and electronic gadgets can be integrated into garments, without affecting the flexibility of the sportsman.

All this will enhance comfort and safety of sports and outdoor activities. With more comfort and lightness, athletes are less affected by environmental factors in the game and can focus more on improvement of their performances.

Medical textiles
- Fibres – Medical growth aids and ‘controlled release polymers’ (see paragraph 3.2.1) can be added to fibres. Through this, certain substances or medicines can be released from the fibre at specific times or when circumstances (temperature for example) change.
- Coatings – Anti-bacterial and desinfective coatings can be added to all kinds of textiles used in the medical sector: clothing, bed linen, bandages, etc.
- E-textiles – Textile sensors can monitor and analyse body functions of patients.

All of the above will improve hygiene and ease the working conditions in hospitals, from which both patients and personnel will benefit. It will also help to prevent the spread of illnesses.

Military textiles (and other high-performance/corporate wear)
- Fibres – New and improved fibres can improve strength, durability, flexibility, or make materials change colour with their environment in order to become more invisible to the enemy. Fabrics can also be made self repairing.
- Coatings – Coatings can create a better protection against chemicals and fire (higher melting points), and make fabrics decontaminating, water repellent, tear repellent, self cleaning, and improve strength and durability. Lightweight but super tough bullet proof vests are an example of this.
- E-textiles – E-textiles can improve communication through the use of for example GPS, and security through integrated identification systems.
Nanotechnology can add a lot to safety and protection of the militaries, and improve their working conditions to a large extent. It also improves situational awareness and responding to emergencies. Of course all the benefits of medical textiles can be used in the military sector as well.

**Home textiles**
- Fibres/Coatings – all kinds of textiles (carpets, upholstery, towels, bed linen) can be made stain-free, odour-free, wear-resistant, wrinkle free, UV-protected (curtains), anti-microbial, water repellent and self cleaning through various nano-fibres and coatings.
- E-textiles – electronic operation systems can be integrated in furniture, and access control systems can be used to improve safety.

Nanotechnology can ease and improve daily life by making materials easier to handle and clean, and advance and ease the operation of various electronic systems. Also belonging to this category are commercial interiors, like theatres and public transport, for which these features provide an even larger benefit.

**Clothing textiles**
In clothing most of the above can be used to improve and enrich the functionality of daily clothing, depending on the specific demands of the consumer. The main advantage is of course that these functions can be added to the garment without affecting its physical properties like colour, flexibility, weight, etc.

![Image 3.6: Nano-Tex’ stain and spill resistant fabrics can be used in clothing and home textiles (see also paragraph 3.3.3).](image3.6)
Source: www.sfgate.com and www.textileworld.com

### 3.3.3 Products currently on the market
Of the many promising opportunities described in the previous paragraph, some are already being produced and sold. The products that are on the market today are mostly improved products where some form of nanotechnology enabled materials (such as carbon nanotubes) or nanotechnology process is used in the manufacturing process.

Many of the previously described coatings are already being produced and sold. An example of a company that tries to reach the average consumer already is Nano-Tex (image 3.6). They sell water, stain and wrinkle repellent, ant-static and moisture and odour managing fabrics for different applications in clothing and interior.

As written in Technical Textiles International magazine (May 2008), the integration of sensors into clothing for the control and charging of electronic devices is quite
commonplace in the sportswear market, although, again, still very niche. Companies like Peratech and Fibretronics developed textile touchpads and control systems which are used in the collections of for example O’Neill, Levi’s, Adidas, Samsonite and Oxbow. The integration of sensors for body monitoring is a growing field in both the performance sports and healthcare sectors. The first wearable sensor dates from 1999, which was used for monitoring respiration and cardiac functions. The company Textronics US develops stretchy textile electrodes which can be incorporated into wearable garments, to comfortably monitor the wearer’s heart rate, electrocardiogram (ECG) or other electrical activity of the body (Technical Textiles Intelligence, 2008). According to Technical Textiles Intelligence, these products will be omnipresent in the coming years, though there is still much development work to be done.

3.4 Conclusion

This chapter has shown that nanotechnology has great potential in the textile industry. It will enable growth for the technical textiles market, and provide a stronger competitive position by creating innovative, high performance products. Through this, companies in Europe and the USA can distinguish themselves from the cheaper producing countries, particularly in Asia. Nanotechnology creates many possibilities in fibres, coatings and e-textiles, and is currently mostly present in non-cost sensitive fields like professional sports, military/protective textiles and medical applications, in which performance is more important than cost reduction.
4. Issues in the development process of nanotechnology

Nanotechnology is expected to improve our world and find solutions for many problems in the environment and society. But, as experience shows from the implementation of other technologies in the past, these promises often have a (unexpected) downside.

The development of nanotechnology raises questions and uncertainties, and has to deal with certain issues. Most of these issues are more general for the development of nanotechnology, not specific for nanotechnology in textiles. But they are very important for the future of nanotechnology, and have a large influence on the use of nanotechnology in textiles.

In this chapter I will highlight the most important difficulties around nanotechnology that are playing a role in the adoption process today. For each issue I will describe the problem in general and, if applicable, also more specific for the textile industry.

4.1 Lack of information and knowledge

Though governments and industries are investing millions in nanotechnology research, it appears that the majority of the people still have little idea of what nanotechnology is. An investigation by the Project on Emerging Nanotechnologies (PEN) in 2007 revealed that 70% of the people in the US have heard little or nothing about nanotechnology. When people have heard of the term, they hardly know what it is about. This is partly caused by the complexity of nanotechnology: it requires some studying to understand it.

4.1.1 Information overload

There are thousands of websites and reports on the internet about nanotechnology. This may seem helpful, but actually creates a lot of confusion. This overload of information makes it hard to determine where reliable information on the subject can be found.

Opponents of nanotechnology are spreading horror stories about nanotechnology, creating fear and rejection. These opponents are mainly environmentalist groups who want to protect and conserve the environment. They campaign against nanotechnology because they believe it will have a negative impact on the environment, and compare it to genetic modification.

They write about nanobots (short for nano-robots) for example. According to them, nanobots are able to replicate themselves endlessly and uncontrolled, and in this way they might take over and destroy our world. Since people have no clear view on whether or not this could be true and who is in control here, these stories create fear among the public.

Image 4.1: Visualisations of nanobots.
Source: gearfuse.com, redicecreations.com, bertrijnders.com
4.1.2 Monitoring nanotechnology effects
But the problem is not just that people should be informed better.
More insight in the true issues and risks of nanotechnology is necessary on a short term, otherwise the development process will stagnate. All possible effects of nanotechnology on society and environment need to be monitored and thoroughly researched, as we know little to nothing about this now (see also paragraph 4.2 and 4.3).
In recent years, this problem has been recognised by governments and the EU.

In several reports by EU funded programs like Nanoforum is concluded that not enough research is done to monitor risks and uncertainties.

“Action is required in relation to risk assessment. (...) Some companies are no longer talking about their product development or have stopped their product development because they are not confident about the regulatory environment and are concerned about consumer perception of risk.”

The EU tries to improve and structure the situation by funding a number of nanotechnology R&D initiatives and platforms, and regularly organising debates and dialogues on how to work with the opportunities that nanotechnology offers in a safe and successful way.
One of the conclusions of the ‘First Annual Nano Safety for Success Dialogue’, that took place in October 2007 in Brussels, is that ‘more research is needed on toxicity, exposure, environmental safety and life cycle issues’. Furthermore, the EU recognises that ‘building public confidence in nano products and players is crucial for innovation and market success in Europe’, and ‘Guidance (with clear lines of authority) and a toolbox for good governance should be developed (...)’.

In many countries, especially in Europe, similar initiatives can be found. The Dutch government, for example, started NanoNed, a national nanotechnology R&D initiative.

4.1.3 Similar problems from the past
An example to illustrate the importance of monitoring effects is thalidomide. This was used in the 1950s and 60s as a sedative during pregnancy, but potential side effects were not tested before use. The negative effects on foetal development only became apparent 20 years later, when the damage was already done.

Biotechnology also had many problems with public acceptance. These were, again, mainly caused by a lack of reliable information and horror-stories being told. An example is the creation of some sort of human super-race, artificially developed by putting together the best possible genes. This caused a general rejection by the public.
Though the public concern is not as big as it once was for biotechnology, negative stories and future scenarios about nanotechnology are occurring more frequently, causing concern.

Ing. Teo Stehouwer, Senior Lecturer Textile Technology at Saxion Hogeschool Enschede, sees this more in perspective. He notes that terminology can make quite a difference, which also happened in the case of biotechnology. Biotechnology is also known as genetic manipulation, which in itself already sounds much more negative. Greenpeace used this term,
and linked it to particular negative incidents in biotechnology, which caused many concerns and rejection of genetic manipulation amongst the public. But when using the term biomedical science, the concern is much less of a problem, since it is not linked to all the negativity.

Of course there is a chance that the same thing could happen to nanotechnology, mr. Stehouwer recognises. And that is exactly why it is so important that the risks and rewards of nanotechnology are clearly monitored, and that the public is properly informed and aware of nanotechnology.

Nanotechnology may have the potential to improve the quality of life, but it can only do so with public acceptance of its validity and value. As mr. Henk Gooijer, chairman of the NT (Nederlands Textielinstituut) and specialist in technical textiles, said about this: “Older technologies, driving a car for example, also entail risks, but we are used to them. The problem with nanotechnology is that it is not visible, like radioactivity, which might work against the technology.”

The lack of reliable information on nanotechnology and its risks and rewards is also the main source of the other problems that occur, which I will describe in the following paragraphs.

### 4.2 Effects of nanoparticles on the environment and public health

An important and critical question is what the effects of nanoparticles will be on the environment and public health. Since only little research is done, the consequences of interactions between nanoparticles and the human body or environment are not clear.

Materials on the nanoscale behave different from materials on the bulk scale. These new properties mean that the toxicology of nanoscale materials cannot be determined from the same material in larger form. To make it even more complex: powder or liquid containing nanoparticles is almost never monodisperse. This means that it contains a range of particle sizes, which could all behave differently. Also, nanoparticles have a tendency to aggregate, in which the behaviour could again change. Since only little research is done, the behaviour of nanoparticles inside the body and in the environment is still unpredictable.

#### 4.2.1 Health risks

Nanoparticles are so extremely small that they can enter the bloodstream of the (human) body through the lungs after inhaling or by penetrating the skin. They might enter cells, where they can disturb all kinds of biochemical reactive chains.

Concern was already raised in 1995 when scientists accidentally discovered that rats immediately died after breathing in a small amount of ultra small Teflon (a chemical non-stick coating) parts. It appeared that the Teflon parts were only damaging when they contained nanoparticles, Teflon on microscale was not damaging.

Studies of the health impact of so-called airborne particles (transported through the air) are the closest thing present to determine health risks from nanoparticles. These studies have generally shown that the smaller the particles get the more toxic they become.
Nanotubes are often compared to asbestos, of which the fibres appeared to be very damaging for human health after it was used in thousands of buildings and constructions. A research on mice by the University of Edinburgh, published in May 2008, showed that carbon nanotubes behave in a similar way inside the body.

Image 4.2: Asbestos fibres, from the form in which it was used in constructions to a closer look, and finally a microscopic view.
Source: www.fr.ch, nl.prevent.be, www.amd.uu.nl

4.2.2 Environmental risks
Nanoparticles could also form a problem in the environment. Not only is it important how nanoparticles react with certain elements in the environment, there are also questions about the life-cycle of manufactured nano-materials. It is not clear yet how long nanoparticles will last, and if there are recycle possibilities. It could also be that certain nanoparticles form a complete new class of non-biodegradable pollutant. And if they do, the question is how they could be removed from air or water, because in most traditional filters the pores are too big.

4.2.3 Consequences for the textile industry
According to mr. Gooijer, working with separate nanoparticles or nanotubes forms the largest risk. The problem is that often, especially in nanomaterials, the nanoparticles are not attached well enough to the material. Ing. Stehouwer mentioned a test performed in textiles. Silver and bronze nanoparticles had been attached to socks, in order to oppose smell. But it appeared that after 3 washings, for 7 out of 9 socks, the nanoparticles were no longer attached to the fabric. The question then is where the particles have gone, and whether they could do any damage there. The problem in clothing is that these particles could also be released during wearing, and by penetrating the skin end up inside the body.

Regulatory institutions in the US and EU have concluded that nanoparticles may form an entirely new risk and that it is necessary to carry out an extensive analysis of the risk. The outcome of this analysis can then form the basis for national and international regulations. Some parties, like the British Royal Society, argue that because of these uncertainties, no more nano products should come on the market until this becomes clear. It is obvious that more in-depth investigation is necessary.

4.3 Lack of regulations and laws
At the moment, there are hardly regulations or laws regarding the production, handling or labelling of nanoparticles or the products and materials that contain them. There is an exception to this, in the field of nanomedicine there are strict regulations.
But in other fields, companies can almost do what they want with nanomaterials, regardless of the consequences. Though at November 1st, 2008 an ISO-standard called ‘Health and safety when working with nanotechnology’ (NPR-ISO/TR 12885.2008) became available. Still this is more a guideline than a regulation. The only legally decreed regulation is that products must be safe when entering the market, which is the responsibility of the producer. This has some negative effects, especially on the public’s view on nanotechnology. It seems as though scientists and companies are able to process unchecked by any authority or rule.

4.3.1 Containing nano or not?

At the moment there is no report duty for nanomaterials, and companies don’t have to mention the use of nanoparticles on their product labels. This makes it difficult for authorities to test nanoproducts and their effects, and even impossible to create reliable figures on the use of nanomaterials.

Next to this, it also leads to confusion among the public. The consumer is no longer aware of the contents of the product they are using, it might contain nanoparticles of which the health effects are not yet determined. Who knows, nanoparticles could already be floating inside bodies while people didn’t even know they were running the risk.

Problems also occur the other way around, when the word ‘nano’ is used as a hype word to sell the product. The word ‘nano’ is used to add value to the product, and link it to the promising properties of nanotechnology, while the product has nothing to do with it.

In March 2006, a spray called ‘Magic Nano’ was put on the German market as dirt-repelling coating for glass and ceramics. Over 110 users had experienced difficulty breathing, and six people ended up in hospital with lung oedema. At first, it was feared that nanoparticles in the spray had caused the health problems. But investigations showed that there were no such particles present in the product. The manufacturer then declared that the word ‘nano’ in this case stood for the coating that ‘Magic Nano’ leaves on the sprayed surfaces, which is only a few nanometres thin.

4.3.2 A need for regulations and laws

In ‘Material Safety Data Sheets’, that must be filled in for products containing certain materials, there is no distinction between macro and nanoscale size material, while it is clear that these are not the same. Nanoparticles are now covered by the REACH, the European legislation for chemicals, as are all other chemical substances. But this law is not sufficient in dealing with the new qualities that nanomaterials may have. As this is already causing problems, a legal framework for nanotechnology and its products should be developed by the EU and governments on short term.

Mr. Gooijer believes that the role of EU or government shouldn’t be too large though. “They should focus on monitoring the risks and stimulate research, but be careful with blocking development by creating rules and regulations that are too strict”, he said. He also addressed a different point of view: since there are no restrictions, the lack of rules and regulations also offers opportunities. He mentioned that with new technologies the industry is always ahead of laws. When problems occur, laws will follow. “Laws and regulations form the solution to yesterday’s problems. Sometimes things go wrong in the first phase, but this is something that can hardly be prevented.”

But the EU recognises the need for some form of regulations, and is working on this. In a Nanoforum report from 2007, Nicolas Deliyanakis writes: “The European Union role was
characterised as creating a legislative framework which ensures that the customer is protected.” But before regulations can be established, the behaviour and effects of nanoparticles need to be clear.

4.4 Commercialisation issues

Another issue in the adoption process has to do with the commercialisation of products. Though this problem is also general for nanotechnology, I will look at it from a textile point of view.

The possibilities nanotechnology provides for the textile industry are promising, but have so far resulted in a small amount of commercial products only. Nanotechnology is currently mainly present in non-cost sensitive niches. The main cause of this is cost related.

4.4.1 The vicious circle of commercialisation

Most of the production companies currently working with nanotechnology in textiles are small, and their supply chains are not very robust. These small suppliers have a limited production capacity, which generates a relatively high price. In the fields of military/protective textiles, professional sportswear and medical textiles these high prices do not form a problem, since performance is of higher importance here.

But commercial brands, aiming at the average customer, need high volumes to be able to keep down on costs and sell their products for a reasonable price. What makes the process even more complicated is the fact that the market for nanotechnology products is still quite small. Customers are not familiar with the products and their possible benefits yet. So even when high volumes could be produced in order to achieve a reasonable price, companies would be left with high stock volumes.

As Winston Shih, Advanced Products Manager for outdoor retailer The North Face, says in Technical Textiles International: “(...) in terms of scale, for commercial products, volumes need to be in the hundreds of thousands range, but we are looking at selling between a thousand and five thousand for a new market such as integrated electronics.”

When only low volumes can be produced, the cost price and selling price will rise too much, which customers won’t be willing to pay. In their view, the added value of the coating or integrated device is not in proportion with the price. Winston Shih confirms this: “Right now we have several (integrated electronics) projects we can see coming to the market in the next few years, but there is a list of issues we have to work through first. The big issue is cost, a jacket currently selling for $149 would have to go up to $199 and there is no way the mass market would accept that. Customers only have a certain amount of dollars to allocate
to The North Face. We know that the markets for e-textiles are viable, but right now they’re rather small. The question is how fast they will grow and to what size.” Prices need to be lowered in order for the market to grow faster, which can happen when larger production companies start applying nanotechnology techniques. But since the market is still quite small, it may take some time for them too see the light. As mr. Gooijer said, it is not very likely that this will happen in the coming five years.

4.4.2 Nanotechnology product examples

An example of a commercial nanotechnology product with a similar problem is the first jacket incorporating a television screen in its sleeve by German company Badira. This jacket can receive digital multimedia broadcasting TV programmes and digital audio broadcasting radio stations. But the problem is that Badira partner Bayern Digital Radio is building up its DMB broadcast network gradually, with at present only 5 channels available in around 16 German cities. Because of this, the extra value of the TV screen is out of line with a selling price of 199 euro. As Technical Textiles International writes: ‘This is so loosely integrated it is basically two products: a miniature TV and a jacket.’

An example of a successful cooperation is the Nike+ iPod workout device. This shows how the bigger players in the electronics and sports markets have avoided real integration of devices, but simply used very plain system devices. The Nike+ is a sensor that can be slipped into a shoe or garment, with a receiver that attaches to the iPod. When running, parameters such as distance and pace can be monitored. Winston Shih says about this cooperation: “This simple and elegant device only required the CEOs of Apple and Nike to come together to make it a reality, so it’s easy to imagine the fight those developing products lower down will have in getting something to market. There are lots of projects going on but they have yet to result in products.”

4.5 Investment and funding issues

First a general note on the research nature of nanotechnology: Nanotechnology is science based, which means that it requires theoretical understanding and specialist equipment. This means that research is taking place at universities, research centres and corporate laboratories. The ‘product’ at this stage is intellectual property, which may take the form of a patent (an exclusive right to exploit a technical innovation for a given period of time). This intellectual property is then developed by a company to become a commercial product.

A problem – mainly present in Europe - that stagnates the commercialisation of products is the low level of investments and the low connection of public funding to the industry. Many
reports are written on this subject, for instance by Nanoforum. This paragraph highlights the main problems in this area.

4.5.1 Low investments
Part of the problem lies in the low venture capital (which provides funding and other support to new companies) and industry investment.

Image 4.5 shows that a very low proportion (only 3.5% in 2006) of global nanotechnology venture capital is invested in Europe. Image 4.6 shows that industrial investment is only half of that of the US and Japan, but public funding on the other hand is similar to the US.

Nanoforum believes the reason for the low level of venture capital is ‘a shortage of suitable investment targets.’ The Nanoforum report ‘Commercialisation of Nanotechnology: Key Challenges’ (2006) describes several reasons for this: companies lack focused business models, commercial experience and exit strategies and are thus not attractive investment targets.
The low industry investment in the textile industry has three main reasons, all linked to each other:

- Uncertainties and concerns around nanotechnology
- Small markets (niches)
- The conservative nature of the textile industry

**Uncertainties and concerns around nanotechnology**

Although there are quite some ‘global leaders’ in nanotechnology in the European textile industry, many investors are dissuaded by the challenges and concerns in society. The uncertainties in both the industry and society, caused by the lack of information and knowledge (see previous paragraphs of this chapter) have become more important than the opportunities nanotechnology brings. Companies are afraid to invest in nanotechnology because when the effects of nanotechnology turn out to be damaging, their investments are wasted and the money is thrown away.

**Small markets (niches)**

According to mr. Gooijer, the fields in which nanotechnology is currently mainly present are niches, in which costs are of less importance: professional sports, medical applications and military/protective applications. Nanotechnology is mainly used for technical applications in these fields, the extra functions it brings are of higher importance than the costs. So at the moment, nanotechnology doesn’t really reach the average consumer yet. There are some products on the market, but all on a small scale. This is something that discourages investment as well. For many companies, the benefits of investing are not high enough since mass markets are not yet reached.

Mr. Gooijer expects it will take five to ten years before consumers are reached on a larger scale. The product price is an important factor in this: what amount is a consumer willing to pay for the extra’s nanotechnology brings to the product? At the moment most products are too expensive, and consumers see too little value in the new nanotechnology features. This stagnates the growth of nanotechnology outside the niches.

But mr. Gooijer added: this is the way things usually go with new technologies, in the first phase the results of the technology are more important than costs, and later in the process costs become a focus point and larger markets can be reached.

**The conservative nature of the textile industry**

Mr. Gooijer mentioned an important characteristic of the textile industry, especially in Europe, which forms another reasons for the low investments: its conservative culture. The textile industry is in itself not very innovative, which works against investments in new technologies.

Innovation that does take place mostly comes from the smaller companies, at least that is where it starts. Most of the companies working with technical textiles are relatively small and have a small amount of money to invest. So even though they are investing in innovations, their knowledge often remains limited. In most cases these small companies (or their innovations) will eventually be bought by larger companies or textile conglomerates that have more means to invest. If these larger companies are not dissuaded by the before mentioned reasons of course…

Logically, these three reasons are also partly causing the low level of venture capital.
4.5.2 Public funding

Another problem in the realm of investment is public funding. Though this is quite in balance with the US, the extra value that investors bring is missing here.

Nanoforum (2007): “Whilst public funding sources may take the place of venture capital, the concern is that companies then lose other benefits that investors would bring, such as in-depth industry understanding and networks.”

Besides, the majority of the public funding goes to universities and independent research centres, which causes Europe to lag behind in the number of nanotechnology patents. Figures by Kanama from 2006 show that about 27% of the patents had Europe-based inventors (including Switzerland). There appears to be a gap between universities and the industry. As Cowburn (2006) describes this: ‘The difference between the academic motivation that something can be done and the entrepreneurial motivation that something can be sold.’ Research at universities is simply not aligned to industrial needs. Though the product understanding is very high, different skills are required to manage the commercial potential. Apparently, their inventions have little commercial value, or are too much in the realm of basic science, and thus not worth being protected by patents.

Mr. Gooijer added that the amount of money invested in defence research in the US is very high, which partly causes this difference as well.

4.5.3 Dealing with investment and public funding issues

The solution for this, as Nanoforum describes it, is obvious:

“The investment of public funding in nanotechnology development needs to enable a greater amount of funding from private sources. In order for this to happen, there needs to be an understanding of the industrial or consumer problems which needs to be solved, which then need to be fed back to development and research.” (Nanoforum, 2007)

So funding should focus on projects that meet these problems, and there should be more collaboration between universities and the industry to make this work. Research will then have industrial input and also take into account known factors, such as existing production processes.

Even more important is stimulating investors and companies. The starting point in this is specifying and monitoring the possible effects of nanotechnology. This will provide more security for companies in the industry, so that they can focus more on the opportunities nanotechnology brings. It will also stimulate the growth of other, larger markets like clothing and home textiles. At the same time, governments and EU should cooperate with the industry in investing in nanotechnology.

Research by Nanoforum shows that in countries where specific steps have been taken to activate industry, investment and involvement have increased. An example is Finland, where the National Nanotechnology Programme has resulted in a doubling of the number of companies with nanotechnology strategies or research activities. Nanoforum: “The challenge of nanotechnology commercialisation does not lie in the overall amount of funding, but in deploying it in such a way that it will create a multiplier effect, increasing the amount of private investment. In order for this to happen, there will need to be a move towards a more problem- or need-focused approach.” And when private investment increases, so will the amount of patents and companies, in this way enlarging the nanotechnology industry in Europe.
4.6 The nano-divide

A more general issue often returning in the development of new technologies is ethics.

4.6.1 Limited access

In a report called ‘The future of nanotechnology: We need to talk’ (2006) by Nanologue, a ‘Europe-wide dialogue on social, ethical and legal impacts of nanotechnology’, funded by the European Union, this problem is called ‘access’. They write: “There has been considerable discussion about the potential benefits of nanotechnology in tackling issues affecting developing countries. However, at the early stages of development there is concern that the technology will remain prohibitively expensive, limiting access to those who could benefit the most.” They write about a ‘nanodivide’ that might exclude nations who can’t participate in the nanotechnology business because they can’t afford it.

A returning issue in this is healthcare. The medicine against HIV/AIDS was too expensive for most African countries, but producing cheaper variants was restricted because of patents. So the people that needed it the most had no access to this healthcare breakthrough.

In a report by Greenpeace, ‘Future technologies, today’s choices’ (2005), the concern about a nano-divide is shared. They write about a similar IT divide, ‘which many nations are already witnessing, particularly in reference to Internet usage, that correlates with inequality in the distribution of wealth.’ They expect this existing gap to be enlarged by the rise of nanotechnology, forming the earlier mentioned nano-divide.

In a report called ‘Nano NU’ by the Flemish Institute for Scientific and Technologic Aspects (viWTA), this situation is compared to the promises biotechnology had for developing countries. Some believed the genetically changed crops would be the cure for the food problem in the world. Unfortunately, this was not the case.

4.6.2 A more positive view

The ICS (International Centre for Science and High Technology) in Italy, an international centre for the transfer of knowledge and high technology to Developing Countries, sees the issue differently.

On their website they write: “Nanotechnologies offer a unique chance to bridge the technological gap between industrialised and developing countries due to the fact that nanotechnology represents a convergence of several different sciences and fields of knowledge. (...) ICS has recognised the enormous potential that nanotechnologies could provide to developing countries as an instrument for their growth.” (ICS, 2008)

Unfortunately, ICS doesn’t describe how exactly these countries will gain the funding to work with nanotechnology, or how the technological gap will be bridged.

But there are more positive sounds in this. In several reports, by for example Nanoforum, is argued that the gap will become smaller after some years, when the technologies will become cheaper to produce and thus more accessible for developing countries.

This is already happening in the textiles industry. Since the production of textiles is concentrated in developing, low-wage countries, it is not a surprise that textile producers here want to maintain their position. In many other (technological) fields, western/European countries are much more civilised than these countries, which gives them strategic advances. Since the investment costs are relatively low (compared to for example nanomedicine or electronics), this is a good opportunity for Eastern countries to keep up with
western/European countries in the field of textiles and maintain their position in the textile industry. At the moment, the majority of nano-coatings for textiles are already produced in developing countries (ir. Stehouwer, 2008).

4.7 Conclusion

This chapter showed that there are several large issues in the adoption process of nanotechnology that stagnate further development of the technology and products. The main problem is the lack of information and knowledge. This entails so many uncertainties and risks for public health and environment that many companies have stagnated the development of their products. It is also the main source of the lack of rules and regulations and the fear of the nano-divide, and stagnates the commercialisation of products and a better aligned investment and funding.

It is obvious that these issues need to be tackled before the nanotechnology market can flourish. The EU and individual governments have recognised these issues and are trying to solve them by setting up various research programs.
5. Cultural issues in technology adoption

Nanotechnology is seen as one of the most important (technological) innovations of today and tomorrow. In chapter 4 I describe the issues in the development and adoption process of nanotechnology.

In this chapter I will look at the background of these issues, and try to find out what causes them. When studying the issues, I looked at several innovation and adoption theories and soon found that many adoption problems have to do with culture. I eventually applied the theories of Dany Jacobs and Everett Rogers to the adoption process of nanotechnology in order to find explanations.

I started by looking at the basic innovation theories of Everett Rogers, and took this as a starting point. After studying the innovation theories of Dany Jacobs I found that technology adoption is a far more complex process, in which culture plays an important role. In his book ‘Adding Values: the cultural side of innovation’ (2007) Dany Jacobs describes the process of innovation and the importance of culture in this.

In this chapter I will highlight and describe the most relevant findings of Jacobs, and apply them to nanotechnology. By doing so, I tried to find explanations and causes for the problems in the adoption process.

I will start this chapter with the innovation theories of Everett Rogers. The next paragraphs will explain Dany Jacobs’ theories. Paragraph 2 is an introduction to Dany Jacobs’ view on innovation. The third paragraph describes the two innovation models, followed by a description of cultural and institutional gaps in paragraph 4. Paragraph 5 is about adding cultural value, and paragraph 6 describes selection systems.

5.1 Rogers’ view on innovation

Everett Rogers is one of the best known researchers and writers on the subject of the diffusion of innovation. His book, ‘Diffusion of Innovations’ was first published in 1962. The book deals with the diffusion of innovations of any form in any context.

In this paragraph I will briefly describe his main message.

Rogers defines diffusion as the process by which an innovation is communicated through certain channels among the members of a social system.

His adoption lifecycle model describes the adoption process of an innovation, in which two curves summarise the main message of Rogers’ theories. These curves show the rate of adoption, which is the relative speed with which an innovation is adopted by members of a social system. The rate of adoption is usually measured by the length of time required for a certain percentage of the members of a system to adopt an innovation.

The image on the next page shows both curves in one graph.

At first, only a few individuals adopt the innovation in each time period (a year for example), these are the innovators. But soon the diffusion curve begins to climb, as more and more individuals adopt the innovation in each following time period. Eventually, the trajectory of adoption begins to level off, as fewer individuals remain who have not yet adopted the
innovation. Finally, when the S-shaped curve reaches its asymptote and the bell curve is back on the x-axis, the diffusion process is finished.

Logically, there is variation in the slope of the ‘S’ from innovation to innovation, some ideas diffuse relatively rapidly and the S-curve is quite steep. Other innovations have a slower rate of adoption, and the S-curve is more gradual.

The bell shaped curve shows the relative percentage of adopters during the adoption lifecycle. The S-shaped curve shows the same process, but then cumulative.

Image 5.1: The bell shaped curve represents the relative percentage of adopters; the S-shaped curve shows the cumulative percentage.
Source: www.rubiconsulting.com

Rogers classifies adopters of innovations into various categories, based on the idea that certain individuals (or other decision making units) are relatively earlier in adopting new ideas than other members of a social system. This is depending on their awareness, interest, evaluation, trial and adoption.

Image 5.2: Rogers’ adoption lifecycle model
Source: nl.wikipedia.org

All of these groups go through an adoption process: the process through which an individual (or other decision making unit) passes from first knowledge of an innovation, to forming an attitude toward the innovation, to a decision to adopt or reject, then to implementation of the new idea, and finally to confirmation of this decision.
5.2 Innovation and cultural value

This paragraph will explain the basic elements of Dany Jacobs view on innovation. All quotes are taken from his before mentioned book ‘Adding Values: the cultural side of innovation’ (2007).

Jacobs describes innovation as ‘something new with an added value’ (page 32). This added value is determined by the selectors: the people who decide whether or not to accept an innovation. These selectors must see a certain added value in the new product or service, otherwise they will not purchase it, which means the innovation will fail. To see this added value, the preferences of the selectors must move from existing products towards the particular innovation. As Jacobs describes this: ‘the cultural value systems must be changed’ (page 13). Without this change of preferences and values there is no connection between the innovation and the values of the selectors, and the innovation will be rejected. When the innovation is accepted by the selectors, they apparently recognise their values and preferences in it. In other words: first cultural value should be created, before the innovation can create economic value.

From a technological point of view, nanotechnology is what Jacobs calls a radical innovation. He defines this as ‘a product or process with either unprecedented performance features or familiar features that offer potential for significant improvements or cost. They create such dramatic change in products that they transform existing markets and industries, or create new ones’ (page 61). In general, radical innovations lead to changes in skills, knowledge, designs, plants and equipments. The technology is new to the firms that are working with it and management and business practices often need to be altered because of this.

5.3 Innovation models

There are two types of innovation models: technology (or science) push and market (or demand) pull.

![Image 5.3: Science/technology push versus demand/market pull model of innovation](image)

Demand/market pull
In the case of demand or market pull, which shows in the second scheme, the needs of the potential customer group are the starting point. The first –basic– research is an interpretative research: trying to understand the potential customer group, and the issues and opportunities for which new concepts can be developed. The analysis and problem solving, or applied research, follow when the issues have been clarified. Finally, a solution for a certain problem can be formulated in the form of the development of a new product – an innovation.

Science/technology push
With nanotechnology the process was the other way around, which is better known as science or technology push (see first scheme of image 5.3).
In this case the origin of the innovation lies in new scientific insights, which may later be incorporated in new products or processes. Basic research is not about the customer, but about the new scientific knowledge and its possibilities in general. The results of this basic research are then used in applied research, when investigators combine the new possibilities with solving practical problems. The next phase is product development, the process of putting a new product idea into a form that is expected to meet the needs of potential adopters.

The innovation model of nanotechnology is similar, the first research was focused on the new techniques nanotechnology made possible, instead of the needs of the market. Commercial applications were thought of in the product development stage of the innovation, followed by interpretative research. But obviously, this interpretative research is necessary earlier in the process, to understand and be prepared for social developments and new applications that might emerge because of the innovation.
As Jacobs writes, this is often happening with more radical innovations, and also one of the main problems in the adoption process of nanotechnology. Because little interpretative research has been done early in the process, there is currently not enough knowledge of the values of the potential customer and the possible consequences of nanotechnology. This is forming gaps and stagnating the adoption and further development of nanotechnology.

The next paragraph will describe these gaps, or ‘cognitive distance’ as Jacobs calls it, more in detail and define the gaps for nanotechnology.

5.4 Cognitive distance and cultural and institutional gaps

Different degrees of radicalness are addressed in Jacobs’ book, and from a technology point of view, nanotechnology falls in the category ‘radical innovation’. The actual nanotechnology products are less radical, since nanotechnology is mainly used to improve or add something to existing products, especially in textiles.
The radicalness of an innovation is determined by its cognitive distance from the existing cultural values in the market. The more radical an innovation, the larger the gap with existing norms and values, and the less structured, more complicated and longer the adoption process will be. The risk of rejection is also increasing.

The cognitive distance from existing values can be subdivided into cultural gaps and institutional gaps, both causing different problems in the adoption process, which I will describe in detail in the next two paragraphs.
5.4.1 Cultural gaps
The cultural gap is the most important to bridge in the adoption process, since it is about the recognition of the innovations' values by the selectors. Though nanotechnology is a very revolutionary innovation from a technological point of view, the cultural gap of nanotechnology is not very large. Thanks to the results that micro technology acquired in the past decades, people are used to the fact that things become smaller and smaller. The ongoing search for even smaller levels, now in the form of nanotechnology, will not scare society off. But the possible effects, risks and uncertainties nanotechnology entails may enlarge the gap. As written in paragraph 4.1 there is a lack in knowledge, which discourages the connection with the cultural framework of society. This causes an even larger gap because it also entails societal concerns about nanotechnology and its impact on society and environment. This can put nanotechnology in a bad light and enlarge the gap.

The cognitive distance also quite small for the actual products on the market, especially in the textiles industry. In this case, nanotechnology is mainly used to improve existing materials and add properties to familiar products. So in the end-products, the technology itself is often not the most important factor. It is more about the added properties to the known product, which makes the cognitive distance smaller. Some product examples used in previous chapters can be found in the image below.

<table>
<thead>
<tr>
<th>Cultural gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
</tr>
<tr>
<td>Fibretronic iPod control system</td>
</tr>
<tr>
<td>integrated solar cells for energy supply</td>
</tr>
<tr>
<td>textile sensors for body monitoring</td>
</tr>
<tr>
<td>HIGH</td>
</tr>
<tr>
<td>Lotus effect</td>
</tr>
<tr>
<td>Philips Lumalive textiles</td>
</tr>
<tr>
<td>self healing textiles</td>
</tr>
<tr>
<td>Nokia Morph phone</td>
</tr>
<tr>
<td>controlled release polymers</td>
</tr>
</tbody>
</table>

Image 5.4: some examples of nanotechnology products and their cultural gaps, relative to each other. The more radical the innovation, the higher the cultural gap.

As Jacobs writes: “The most promising ideas on the longer term (...) may be the most difficult to digest by their environment on the shorter term, because they are too radically new and therefore too distant from existing mental frames.” (page 79)

5.4.2 Institutional gaps
Institutional gaps are causing different kinds of problems in the adoption process. In this case the gaps are not formed by a difference in norms and values, but by differences in development, rules and regulations between institutions.

One of the institutional gaps regarding nanotechnology is caused by the lack of rules and regulations, as written in chapter 4.

The fact that there are no regulations or laws regarding the use of nanoparticles causes a large gap between the government and the industry. The government has difficulties in formulating laws and regulations due to the lack of knowledge on the long-term effects of
nanoparticles, and the industry has difficulties in working with nanotechnology since it is not clear what the rules and restrictions are.

The rules and regulations that the EU will prescribe eventually will also largely influence the cultural gap. When producers do have to mention the use of nanotechnology materials on their labels for example, the end-customer will be confronted with the term a lot, and thus more questions and concerns will be raised. But when decided the other way around, the connection of nanotechnology with the societal cultural framework will be less relevant, since it will be mainly the producers who have to deal with it.

Furthermore, as appears from the low number of patents in Europe, the research done at universities, research centres and corporate laboratories does not connect with the demands of the industry (and thus the customer). In many cases, the research is not aligned to industrial needs, so the selectors do not see an added (commercial) value in the research. If more interpretative research would be done, the gaps could become smaller and more commercial products can be developed.

5.5 Creating values and filling the gaps

As written in the second paragraph of this chapter, the connection between the values of the (potential) customer and the innovation is essential for its success. For this to happen, cultural value should be ‘created’ to fill the cultural and institutional gaps.

Important in this process of value creation is what Jacobs calls ‘productive creativity’ (page 13). This means that creativity has to be combined with professionalism and a sense of purpose, otherwise it will not lead to a successful innovation. The invention of nanotechnology sounds very nice and promising, but a useful (commercial) purpose needs to be found first, otherwise nanotechnology will not turn out to be a successful innovation but remain the abstract invention of nanotechnology.

An important part of this ‘professionalism’ is (marketing) research. It is hard to predict how selectors will react to the innovation, so knowing your customer and his norms and values is essential in enlarging the chances for success of the innovation. Eventually, the essential thing is to incorporate the values in the product in such a way that they connect with the values of the potential customers, so that they see an added value in it. The innovation can only be successful when the values are understood and recognised by the potential customers.

To understand the preferences, norms and values of potential customers it is important to know their environment and what influences them in their buying behaviour. Products are bought following our intuition, but the various social groups and subcultures in which we live have a large influence on our buying behaviour. Though we are not aware of it, taste is about individual expression and social adaptation. Markets consist of numerous niches in which different subcultures and ideologies are present. In each niche, customers value products differently and have different selection criteria. Increasing the chances of success of an innovation means interacting with various possible customer groups and getting to know their interests, concerns, preferences, norms and values.
5.6 Selection systems

The value of innovations is determined by its selectors, through so-called selection systems. Each selection system has its own rules and culture on which the product valuation is based. It is very important to take these into account when developing a product, because the better an innovation fits in its environment, the sooner it will be selected.

5.6.1 Forms of selection

There are different forms of selection. Jacobs first makes a distinction between internal and external selection: inside and outside organisations. Innovations are always selected internally first, there has to be decided whether an innovation is worth producing or researching. This is of course influenced by the market and the organisation culture, each organisation has its own norms and values too.

The different forms of external selection (Jacobs took this from Nachoem Wijnberg, 2004):
- market selection: consumers are the selectors, producers the selected.
- peer selection: the opinion of other producers/colleagues determines the outcome of the competitive process.
- expert selection: the success is determined by opinions of experts.
- hierarchical selection: selection by selectors who have received the authority for this. The selectors are often not acting as private persons but as actors within a preset structure (a hierarchy) with preset criteria (the norms and values of the selection system).

Since nanotechnology has so many applications, all selection forms are applicable to some extent. Public regulations are an example of external hierarchical selection. Because of public regulations, some innovations are rejected before they can further develop or enter the market. In nanotechnology this is causing problems the other way around, because of the lack in regulations. There are no restrictions, which causes uncertainties and concern.

In the case of nanotechnology hierarchical selection is also present in a different way. Many nanotechnology investigations get public subsidy. Governments decide which investigations get subsidy and which don’t, in this way filtering research projects.

Public funding is often used to stimulate research of subjects that are undervalued by the market. One of the problems in nanotechnology relates to this. Public funding in Europe is comparable to that of the US, but there is a lack of investment by companies. Apparently, nanotechnology research is undervalued by the market.

Jacobs writes about this as well. “Many public regulations are specifically devised to remedy ‘market failure’ (…). Public hierarchical selection may also stimulate values which are undervalued by the market. In order to be subsidised, for example, (...) research and development has to be ‘fundamental’ and ‘pre-competitive’. In concrete terms this may sometimes mean that (…) R&D may not lead to practical results.” (page 123)

This is clearly happening in nanotechnology, as the lack of patents in Europe shows.

5.6.2 The selection process

The selection process itself can best be explained through an image (see next page), showing the different steps in the process and the relevant influences. The process is also described in paragraph 6.1, applied to the company Royal Ten Cate.
Clearly, it is very important to know who the key players, most important (pre-) selectors, crucial opinion leaders and most relevant subcultures are when bringing an innovation to market. In order to create a successful product, first all the suppliers in the value system (from raw materials to end products) need to see a rewarding value in the product, otherwise the product will not even make it to the market. But ultimately the environment selects, and firms can only try to influence this by applying a certain strategy to the adoption of the product. The more radical the innovation, the harder this is.

In the case of nanotechnology in textiles the products are often not completely new. Most often nanotechnology features are added to existing products. This makes the cognitive distance smaller, so the product is accepted sooner.

Often, as is also the case in nanotechnology, there are many varieties of a product category in an industry, and thus many strategies and focus points for both suppliers and customers.

5.7 Conclusion

This chapter described the innovation theories of Dany Jacobs in combination with the adoption process of nanotechnology.

I briefly described the innovation curve of Everett Rogers, the base of Dany Jacobs’ innovation theories. Jacobs’ theories showed the importance of cultural value in innovations, and through this explained the main issues in the adoption of nanotechnology. These issues that stagnate the adoption process and further development are caused by cultural and institutional gaps. Though the idea of things becoming smaller and smaller is not forming a large cultural gap, the lack in knowledge and the uncertainties this entails forms a large gap between the technology and society. Because of this selection processes are stagnated: the added value does not add up to the possible problems. Institutional gaps, formed by the lack of laws and regulations and bad connection between research and the industry enlarge this problem.

By using Dany Jacobs’ theories, the complexity of the adoption process of nanotechnology became clearer and it showed that many of the obstacles can be linked to events in the adoption process.
6. An example from the industry: Ten Cate

After analysing the adoption process of nanotechnology and the issues that form a problem in this, it is time to take a closer look at a company that actually has to deal with these issues.

In chapter four, in which the issues were described and analysed, I used specialists’ opinions to obtain a better and more realistic view on the issues.

In this chapter I will take a closer look at a company in the textile industry that works with nanotechnology.

I asked the Dutch technical textile company Royal Ten Cate about their experiences with the issues mentioned in chapter four, and used this as a case to identify the true issues in the industry. To further clarify and analyse the selection process of Dany Jacobs, I used Ten Cate as an example as well.

6.1 The selection process applied to Ten Cate

The Dutch company Royal Ten Cate is, as they describe on their website, ‘a multinational company that combines technical textiles with related chemical processes.’ They develop and produce specialist materials with specific properties, that are used in for example protective clothing for fire fighters and lightweight aircraft materials.

Ten Cate is quite an innovative company in the field of technical textiles. The company uses many new and innovative techniques, but does not develop new techniques itself.

The selection process is already shown in image 5.5 (paragraph 5.6), the following paragraph further explains the process.

The enterprise (in this case Royal Ten Cate) has several projects running for improving their weather resistant tent cloth by using nanotechnology coatings. They found possibilities to make the material shape-retaining, more durable, and self-repairing.

After extensive research into the prospects for the three projects, management decides that self-repair and durability are most lucrative and need to be developed further (internal hierarchical selection).

Ten Cate continues these projects and starts developing actual commercial products of these two coatings (supply of innovations). During this process market research continues, and it appears that the majority of Ten Cate’s distributors worldwide sees little commercial value in the self-repairing coating.

Management decides that this project has to be brought to a stand still as well (pre-selection by distributors, experts).

After a process of further research and testing, the more durable coating does make it to the market, in which it has to withstand the next level: market selection. Various customer groups (e.g. different tent selling companies, and finally end consumers) will value the more durable coating differently. Some will see an added value and buy the product, while others are not convinced of the extra value and will reject it. All these customer groups are influenced by the opinions of experts, opinion leaders and peers (for example ANWB reviews, camping fairs, experiences of friends and family).
External hierarchical selection is also part of the system, certain projects may get subsidy from the government for example, which means they will be selected by the enterprise sooner. This can also work the other way around: laws and regulations may forbid the use of certain (nano) materials which means a project has to end before it can be developed further.

By applying the theories of Dany Jacobs to an existing textile company, the process becomes more clear and it shows that his theories can be applied to actual processes in the industry.

6.2 Dealing with the issues

The first and most important issue I addressed is the lack of information and knowledge. Ten Cate confirmed that this forms a large problem within their company. The second issue, the effects of nanoparticles and public health, belongs to the same category in this case.

Ten Cate management has recently (November 2008) decided to stop further development of a number of nanotechnology projects because of the uncertainties and risks this lack of knowledge entails. The company itself does not perform research on the effects of nanotechnology, and thus has to wait until the risks are clearly monitored by cooperating with other companies and/or governments.

As they said, most companies do not have the means to invest in such specialised nanotechnology research, even when they cooperate. Without funding from governments, this is something that cannot be done.

Since they are not willing to take any risks in damaging human health or environment, they have decided to put these projects on hold until a better insight in the effects of nanotechnology is obtained.

Also part of this issue is the public acceptance. For Ten Cate this does not form a problem, since they do not sell products for mass markets, but operate in specialised niches like protective workwear.

The lack of regulations and laws does not form a problem for the company itself, they see this more as a problem for research authorities or governments. Ten Cate mentioned a Quality Label for Nanotechnology, which provides the security that a textile product actually uses nanotechnology. This Quality Label is developed by Hohenstein Institute in Germany, an internationally recognised research and service centre. This label provides manufacturers the opportunity to have their products tested and documented independently. Though it is not really a law, it does bring an end to the insecurity amongst retailers and end users about whether or not a product contains some form of nanotechnology. Many companies, including Ten Cate, use this label as a guideline.

The issue of commercialisation is also not very much a problem for Ten Cate. They aim at more specialised niches, in which price is of less importance than performance. Investment and funding issues form a larger problem, they confirm. Not specifically to Ten Cate, but more for the industry itself. They believe that this forms a vicious circle with the risks and fears existing around nanotechnology. As long as these risks remain, companies will not invest much, and the situation will remain the same. It is an important task of the government and EU to provide funding for research in this, according to Ten Cate.
6.3 Conclusion

This case of Ten Cate made clear what the main issue in the adoption process of nanotechnology in the textile industry is: the lack of information on the effects of nanoparticles in the environment and human health. It showed that it is hard for companies like Ten Cate to cope with this situation, since they often do not have the (financial) means and materials to perform specialised research themselves. They depend other parties, like governments, which causes stagnation in the further development of nanotechnology textiles: projects are now put on hold.
7. Conclusion

When I started my research into the subject of nanotechnology, I soon found that its features and issues are not easy to define. The overload of information, especially on the internet, confused me and I found it hard to gather reliable information on the subject. In a later stage of my research appeared that I wasn’t the only one: this overload of information, but lack of reliable information, appeared to be one of the issues in the adoption process. During my research, I came across the term nanotechnology more and more often in the news and magazines like FHM. In September there was a news item in the RTL news about the possible damaging effects of nanoparticles. Clearly, the subject is very up to date and its continuous development is important in today’s society.

The main question of this report is:

**What are the issues in the adoption process of nanotechnology in the textile industry and (how) can they be solved?**

In order to provide an answer to this question, I questioned companies and specialists in the field of nanotechnology, and searched the internet, textile magazines, books and reports.

The issues in the adoption process are explained in chapter four, and their background is further monitored and researched by applying the innovation theories of Dany Jacobs in chapter five. The analysis in these two chapters made clear that the main problem in the adoption of nanotechnology in the textile industry is the lack of information and knowledge on its possible harmful effects in the environment and public health. The fact that the risks of nanotechnology are not clearly monitored causes stagnation in the development process for various reasons:

- It causes concern among end-users, which might result in problems with public acceptance of nanotechnology products.
- It causes concern among companies working with nanotechnology, which currently already forces companies to put nanotechnology projects on hold and discourages industry investment. These investments are very necessary to stimulate further development of nanotechnology in the textile industry, since there also appears to be a gap between public funding and the needs of the industry.
- It is hard for governments and/or EU to develop laws and regulations regarding the use of nanoparticles, which then again causes uncertainty among end-users and companies about the use of nanoparticles in products.
- It causes fear for a nano-divide between developing countries and the western world.

The analysis of the issues made clear that most of the issues in the adoption of nanotechnology are more general issues, and are quite common in the adoption of new technologies. Radical innovations, as nanotechnology is from a technology point of view, often entail many obstacles in funding, public and industry acceptance, and defining possible effects. Many similarities to the adoption processes of for example biotechnology, asbestos and thalidomide occurred.
Though the issues may be part of the adoption process, steps can be taken to improve the situation and stimulate the adoption and further development of nanotechnology. Governments and the European Union form the main solution for this. They are already trying to improve the situation by funding a large number of nanotechnology R&D initiatives and platforms, but it appears they should put even more effort in this. They are first and foremost in the position to invest, since companies often do not have the financial means to do so. Important in this is that they cooperate with the industry in performing the research, to avoid gaps between the research and the needs of the industry. In addition to this, they should stimulate companies to invest in nanotechnology by focusing on the opportunities and benefits of nanotechnology.

When the effects of nanotechnology are monitored, governments and EU are also in the position to link laws and regulations to working with nanotechnology and nanoparticles in order to protect public health and environment and through this stimulate public acceptance.

The textile industry wants to move forward with the possibilities that nanotechnology offers, but is not given the chance yet because of the existing uncertainties and risks.

Another problem, in a different realm, are the issues in the commercialisation of textile products. Nanotechnology is currently mainly present in non cost sensitive, specialised niches like protective workwear, medical textiles, military textiles and professional sports. Since the cost price of products is still high, the mass market is not yet reached. But it appeared that this is not forming a very large problem, since it is quite common for new technologies to develop this way. In about five to ten years, the mass market is expected to be reached.

Especially in times of financial crises, the keyword often is investment. This perfectly aligns with the critical situation nanotechnology is stuck in at the moment.

In order to let nanotechnology flourish in the textile industry and receive the benefits it offers, I advise both companies, EU and governments to do one main thing: invest!
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