AMIR, ASAD. Industry Technology Roadmapping of Nonwoven Medical Textiles. (Under the direction of Dr. Helmut H Hergeth).

This research is a collaboration between Wake County Economic Development, NCSU Economic Development, and the College of Textiles. The overall purpose of this research is to examine the process by which an Industry Technology Roadmap (ITR) is developed, to start the development of an elementary roadmap for the medical nonwovens industry, and finally to identify the role of the College of Textiles, NCSU in effectively implementing this roadmap. The scope of this thesis covers the examination of Industry Technology Roadmapping process, including the selection process for panel members and preliminary identification of goals and challenges for the nonwoven medical textiles. Compiling the roadmap itself goes beyond the scope and time frame of this masters thesis.

A mixed methods method is employed for data collection and analysis. Experts affiliated with the nonwovens industry, personnel from the Association of Nonwovens Fabrics Industry (INDA), Nonwovens Cooperative Research Centre (NCRC), and faculty from NC State University were surveyed. An attempt was also made to conduct an industry wide survey to collect data about Industry location factors.

The results of this research provide insight into the road-mapping process that can be employed for the nonwovens industry. A pilot roadmap for the nonwovens medical industry identifies the process/product performance targets of medical textiles, technology barriers/challenges for achieving these targets and the priorities related to research and development for achieving the targets. Finally the research proposes an
action plan for the College of Textiles in the areas of (i) types of collaborations with the nonwoven industry and (ii) allocation of research and development resources to better serve nonwoven industry.
BIOGRAPHY

The author, Asad Amir was born in Karachi, Pakistan on June 21, 1979. His parents are Amir Jan Baig and Afroz Iqbal Fatima and he has an elder sister Sarwat Amir.

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CHAPTER I

Introduction

This research is a collaboration between the Wake County Economic Development Commission, North Carolina State University Economic Development Partnership, and the College of Textiles. Based on empirical findings from Porter’s Industry Cluster Analysis report, the Research Triangle Park (RTP), North Carolina was identified as the optimal location for a medical textile cluster (Porter, 2001). Porter, however, identified weak technology commercialization structure & lack of collaboration among & within clusters as the major challenges faced by this region.

According to Dr. Pourdeyhimi of North Carolina State University, medical textiles are primarily made up of nonwovens (Pourdeyhimi, 2004). Nonwovens Report International (2006) quotes Dr. Behnam Pourdeyhimi as saying “In this country (USA), we have saturated areas such as medical, and hygiene. Over 90% of all such products are nonwovens” (Nonwovens Report International, 2006). The nonwoven fabrics industry is one of the fastest developing sectors of the textile business with a growth rate of 7.6 % (Pourdeyhimi, 2004). The primary reason behind nonwovens’ increasing market share is that they are manufactured by very high-speed and low cost processes compared to the traditional woven and knitted fabrics. Moreover nonwovens are also finding end uses in non-traditional textile markets such as automotives. United States continues to lead the world in nonwoven’s technology, production and consumption. The US industry is composed of over 550 firms; employing 160,000 (Pourdeyhimi, 2004).
Based upon Michael E. Porters’ recommendations and due to relative infancy of this growing industry, it is crucial to identify the current situation of its market and assess the future technological, workforce, innovation, and infrastructure requirements needed to sustain the growth and longevity of the industry. Having competitiveness issues and being an innovation driven industry, industry technology roadmaps can serve as a solid framework for this process. It can also serve as a tool for partnership between government, nonwoven companies, industry associations, and universities to understand
market needs and collaboratively develop technologies and innovations to meet these needs.

An Industry Technology Roadmap (ITR) is a structured, multi-dimensional, technology planning process to support development, communication, and implementation, linking technology and business needs by using series of simple charts or graphs. The process brings together people from different parts of the business, providing an opportunity for sharing information and perspectives.

Purpose of the Study

The purpose of this study is to examine the process by which an Industry Technology Roadmap (ITR) is developed, to develop an elementary roadmap for the medical nonwoven industry, and finally to identify the role of College of Textiles at North Carolina State University in the effective implementation of this roadmap.

Specific objectives were to collect information on the nonwovens industry to

1. Provide an overview of the process/product performance targets of the nonwovens industry.
2. Determine the barriers/challenges for achieving these targets.
3. Determine the priorities related to research and development for achieving targets.
4. Identify the types of collaborations needed between industry and the College of Textiles for achieving the targets.
Significance of This Study

The aim of this study is to contribute to the body of knowledge by providing appropriate literature for studying the development of industry technology roadmaps for the nonwovens industry and avenues of partnership between industry and university.

This study provides insight into the nonwovens market and presents information about process/product performance targets of the nonwoven industry, technology barriers/challenges for achieving these targets and the priorities related to research and development for achieving the targets. Rather than relying solely on secondary data sources such as INDA reports, this research uses a mixed method approach to data collection and analysis. The results are generated based upon the recommendations of the panel of experts that includes personnel from the nonwovens industry, INDA, NCRC, NC State University Faculty and economic development committees at NC State University and Wake County, NC. Finally, the research proposes an action plan for the College of Textiles in the areas of (i) types of collaborations with the nonwoven industry and (ii) allocation of research and development resources to better serve nonwoven industry. The outcome of this research will provide a framework that can be applied to other sectors within the industry in the development of clusters.

Limitations of This Study

The limitations of this study related to sample size, time frame and scope of study.
Sample Size

Due to constraints of time and resources, the panel of experts constituted of a limited number of people from industry, regulatory authorities and academia. Thus, the resulting roadmap may not be representative of the whole medical nonwovens industry.

Timeframe

Data were collected over the course of 4 months in July 2006 - October 2006.

Scope of Study

Deliberately a focus is maintained in interviews and surveys on identifying the role of the College of Textiles at North Carolina State University to better serve industry achieve the performance targets.
Definition of Terms

**Nonwovens:** Nonwoven fabrics are broadly defined as sheet or web structures bonded together by entangling fiber or filaments (and by perforating films) mechanically, thermally or chemically. They are flat, porous sheets that are made directly from separate fibers or from molten plastic or plastic film. They are not made by weaving or knitting and do not require converting the fibers to yarn (INDA, 2006).

**Medical Textiles:** Medical textiles, also known as biomedical textiles, are textile products and constructions, for medical and biological uses used for first aid, clinical, or hygienic purposes (“What are Medical,” 2001).

**Technology Roadmapping:** A technology roadmap is a plan (document) that defines the critical Roadmapping requirements, performance targets and timeframes for a given set of needs, and identifies the technology alternatives (‘paths’ or ‘roads’) and milestones to meet those targets (Ronald, Kostoff & Schaller, 2001). Technology roadmapping is the needs-driven technology planning process that delivers technology roadmaps (Albright, Richard E, 1998). In other words, the essence of technology roadmapping is exploring possible future scenarios and at the same time identifying, quantifying and
minimizing the risks and uncertainties of that future view. It captures the common view of a group of people about their future and what they want to achieve in that future (Garcia and Bray, 1997).

**Process / Product Targets:** Process or product related goals identified by nonwoven companies, academics and the industry associations.
Chapter II

Literature Review

This chapter describes existing literature on the process of technology roadmapping. In addition, literature that describes the relationship between industry and university and the benefit of collaboration between the two is also reviewed.

Technology Roadmapping

Introduction

Technology planning is becoming increasingly important for many reasons. Since investment in technologies is a costly affair, it must be carefully considered; not all investments in technologies have potential pay-off (Hassan, Ahsan, Mahfar & Elamvazuthi, 2004). Today companies are facing many problems. Products are becoming more complex and customized. Times-to-market are shrinking. Product life cycles are shortening. A short-term focus is reducing investment funding to enhance returns on investment ratios. Competition is increasing, resulting in cutbacks of profit margins. These problems enhance the need for companies to be more focused and to better understand both their industry and their markets. Better technology planning can help deal with this increasingly competitive environment. Once identified, technology enhancements or new technologies may be developed internally or collaboratively with external partners (Garcia & Bray, 1997).
Technology roadmaps are being used as a technology-planning tool by a growing number of organizations including corporations, government agencies and research institutes. Roadmaps are used for many purposes, in domains as varied as foreign policy, corporate strategy, and fundamental scientific research (Bruce & Fine, 2004).

Technology roadmapping helps to identify product needs, map them into technology alternatives, and develop project plans to ensure the availability of the required technologies upon need. It is an important tool for collaborative technology planning and coordination for corporations as well as for entire industries. It is a specific technique for technology planning, which fits within a more general set of planning activities (Garcia & Bray, 1997).

Technology roadmapping allows companies to make better investment decisions because it provides better information to:

- Identify critical product needs that will drive technology selection and development decisions.
- Determine the technology alternatives that can satisfy critical product needs.
- Select the appropriate technology alternatives.
- Generate and implement a plan to develop and deploy appropriate technology alternatives.

However, this roadmap is only a high level strategy for developing these technologies. A more detailed plan is then needed to specify the actual projects and activities (Garcia & Bray, 1997).

The technology roadmapping process is driven by a need, not a solution. For example, if the need exists for an energy efficient vehicle that gets better miles per
gallon, then lightweight composite materials is a possible solution. There may be other more appropriate solutions. Therefore, you must start with the need, not a pre-defined solution. It is a fundamentally different approach to start with a solution and look for needs (Garcia & Bray, 1997).

**Background**

The approach was originally developed by Motorola more than 25 years ago, to support integrated product-technology planning (Phaal, 2003). Bob Galvin of Motorola is widely considered the father of the practice of technology roadmapping (Schaller, 1999). Groups of people in the company would come together to develop a consensus vision for the future of technology areas that affected their business. Motorola discovered that the establishment of this pervasive culture of technology roadmapping enabled the company to produce roadmaps that “…communicate visions, attract resources from business and government, stimulate investigations, and monitor progress. They [Roadmaps] become the inventory of possibilities for a particular field, thus stimulating earlier, more targeted investigations (Galvin, 1998).” Technology roadmapping represents a powerful technique for supporting technology management and planning in the firm. Roadmapping has been widely adopted in industry (Willyard & McClees, 1987; Barker & Smith, 1995; Bray & Garcia, 1997; EIRMA, 1997; Groenveld, 1997; Strauss et al., 1998; Albright & Kappel, 2003; McMillan, 2003).

**What is Technology Roadmapping?**

Different people use the term roadmapping (or even technology roadmapping) to mean different things.
**Definition of Technology Roadmapping**

Technology roadmapping is a needs-driven technology planning process to help identify, select, and develop technology alternatives to satisfy a set of product needs. It brings together a team of experts to develop a framework for organizing and presenting the critical technology-planning information to make the appropriate technology investment decisions and to leverage those investments. (For an example of this teaming process at the industry level see Garcia, Introduction to Technology Roadmapping: The Semiconductor Industry Association’s Technology Roadmapping Process.)

Given a set of needs, the technology roadmapping process presents a way to develop, organize, and present information about the critical system requirements and performance targets that must be satisfied by certain time frames. It also identifies technologies that need to be developed to meet those targets. Finally, it provides the information needed to make trade-offs among different technology alternatives.

**What is a Technology Roadmap?**

A technology roadmap is the document that is produced by the technology roadmapping process. A technology roadmap identifies alternate technology “roads” for meeting certain performance objectives (Garcia & Bray, 1997).
**Figure 2: A Generic Roadmap**

**Roadmapping Scope**

Roadmapping can be done at either industry or corporate levels. These levels require different pledges in terms of time, cost, level of effort, and complexity. However, for both levels the resulting roadmaps have the same structure — needs, critical system requirements and targets, technology areas, technology drivers and targets, technology alternatives, recommended alternatives or paths, and a roadmap report — although with different levels of detail (Garcia & Bray, 1997).

**Uniqueness of Technology Roadmaps**

Technology roadmapping can be confused with certain methods of technological forecasting, such as scenario planning, trend extrapolation and historical analogy. These
methods make projections of technological capabilities and predict the invention and
diffusion of technological innovations into the future (Schaller, 1999). Similarly,
technology foresight aims to identify new areas of science and technology research over
an extended period of time.

Roadmaps differ from these methods in one important respect. In the above-
mentioned techniques the end-point is forecast, whereas the roadmapping process starts
with the end-point or vision clearly in mind and then draws the different technology paths
to achieve it (Scheer, 2001). Roadmapping is a tool for companies to predict future
market demands and to determine the technological processes and products required to
satisfy them. This process is unique in that it encourages firms, R&D organizations,
governments and industries to develop a shared vision of the future and explore the
opportunities and pathways to achieve it. Other exclusive attributes of Technology
Roadmapping includes

It is driven by “market pull,” that is, the technological innovations needed if
companies are to serve anticipated future markets. Roadmapping is NOT driven by
“technology push,” what can be done with the existing stock of technologies.
It builds on a vision of where a company or industry wishes to go and what technologies
are needed to get there.

It provides a route for achieving the vision, going from today to tomorrow, by
helping companies or organizations identify, select and develop the right technology
alternatives needed to create the right products for future markets (Industry Canada,
2006).
*Types of Technology Roadmapping*

Roadmaps can be developed at three broad levels of resolution: industry, technology and product.

- **Industry roadmaps** define broader market goals that are applicable across an entire sector and provide focus for industry to identify and address market, regulatory and other barriers to growth and define a clear set of industry actions.

- **Technology roadmaps** identify, evaluate and promote the development of collaborative projects within and between industries to fill technology gaps and/or capture technology related opportunities.

- **Product level** roadmaps provide business managers with a comprehensive, long-range technology assessment of their future product needs. This type of roadmap provides a complete description of the product line, division or operating group of an organization.

(Technology Planning for Business Competitiveness, A Guide to Developing Technology Roadmaps, Australian Government or the Department of Industry, Science and Resources, 2001)

![Figure 3: Types of Roadmaps](http://roadmap.itap.purdue.edu/CTR/default.htm)

**Technology Roadmapping Approaches**

**Purpose**

Garcia and Bray (1997) identified that at both the levels—corporate and industry, technology roadmapping has several potential purposes and resulting benefits. Three major uses are:

- First, technology roadmapping can help develop a consensus about a set of needs and the technologies required to satisfy those needs.
- Second, it provides a mechanism to help experts forecast technology developments in targeted areas.
- Third, it can provide a framework to help plan and coordinate technology developments both within a company or an entire industry.

The technology roadmapping approach is very flexible, and the terms ‘product’ or ‘business’ roadmapping may be more appropriate for many of its potential uses. Phaal’s examination of 40 roadmaps revealed a range of different aims, clustered into the following eight broad areas, based on observed structure and content (Phaal, 2003):

1. **Product Planning**

*Description:* This is by far the most common type of technology roadmap, relating to the insertion of technology into manufactured products, often including more than one generation of product.

*Example:* A Philips roadmap, where the approach has been widely adopted (Groenveld, 1997). Product roadmaps are used to link planned technology and product developments.
2. Service / Capability Planning

*Description*: It is similar to product planning, but more suited to service-based enterprises, focusing on how technology supports organizational capabilities.

*Example*: A Post Office roadmap used to investigate the impact of technology developments on the business. This roadmap focuses on organizational capabilities as the bridge between technology and the business, rather than products.

3. Strategic Planning

*Description*: Includes a strategic dimension, in terms of supporting the evaluation of different opportunities or threats, typically at the business level.

*Example*: The roadmap focuses on the development of a vision of the future business, in terms of markets, business, products, technologies, skills, culture, etc. Gaps are identified, by comparing the future vision with the current position, and strategic options explored to bridge the gaps.

4. Long-range Planning

*Description*: Extends the planning time horizon, and is often performed at the sector or national level (‘foresight’).

*Example*: A roadmap developed within the US Integrated Manufacturing Technology Roadmapping (IMTR) Initiative8 (one of a series). This example focuses on information systems, showing how technology developments are likely to converge towards the ‘information driven seamless enterprise’.
5. Knowledge Asset Planning

_Description_: Aligning knowledge assets and _knowledge management_ initiatives with business objectives.

_Example_: This form of roadmap has been developed by the Artificial Intelligence Applications Unit at the University of Edinburgh enabling organizations to visualize their critical knowledge assets, and the linkages to the skills, technologies and competences required to meet future market demands.

6. Programmed Planning

_Description_: Implementation of strategy and more directly relates to project planning (for example R&D programs).

_Example_: A NASA roadmap, used to explore how the universe and life within it has developed. This particular roadmap focuses on the management of the development program for the Next Generation Space Telescope (NGST), showing the relationships between technology development and program phases and milestones.

7. Process Planning

_Description_: Supports the management of knowledge, focusing on a particular process area (for example, new product development).

_Example_: A type of technology roadmap to support product planning, focusing on the knowledge flows that are needed to facilitate effective new product development and introduction, incorporating both technical and commercial perspectives.
8. Integration Planning

Description: Integration and/or evolution of technology, in terms of how different technologies combine within products and systems, or to form new technologies (often without showing the time dimension explicitly).

Example: A NASA roadmap, relating to the management of the development program, focusing on ‘technology flow’, showing how technology feeds into test and demonstration systems, to support scientific missions.

Format

Roadmaps are communicated with the help of following eight graphs (Phaal, 2003):

a. Multiple layers

Description: The most common format of technology roadmap comprises a number of layers, such as technology, product, and market. The roadmap allows the evolution within each layer to be explored, together with the inter-layer dependencies, facilitating the integration of technology into products, services and business systems.

Figure 4: Roadmapping Format - Multiple layers

b. Bars

Description: Many roadmaps are expressed in the form of a set of ‘bars’, for each layer or sub-layer. This has the advantage of simplifying and unifying the required outputs, which facilitates communication, integration of roadmaps, and the development of software to support roadmapping.

![Figure 5: Roadmapping Format – Bars](source)


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c. Tables

Description: In some cases, entire roadmaps, or layers within the roadmap, are expressed as tables (e.g. time vs. performance). This type of approach is particularly suited to situations where performance can be readily quantified, or if activities are clustered in specific time periods.

![Figure 6: Roadmapping Format - Tables](source)

d. Graphs

Description: Where product or technology performance can be quantified, a roadmap can be expressed as a simple graph or plot - typically one for each sub-layer. This type of graph is sometimes called ‘experience curve’, and is closely related to technology ‘S-curves’.

![Figure 7: Roadmapping Format – Graphs](http://www.unido.org/file-storage/download/?file%5fid=16963)


e. Pictorial representations

Description: Some roadmaps use more creative pictorial representations to communicate technology integration and plans. Sometimes metaphors are used to support the objective (e.g., a ‘tree’).

![Figure 8: Roadmapping Format - Pictorial Representation](http://www.unido.org/file-storage/download/?file%5fid=16963)

f. Flow charts

Description: A particular type of pictorial representation is the flow chart, which is typically used to relate objectives, actions and outcomes.

![Flow Chart Image]


g. Single layer

Description: This form is a subset of type ‘a’, focusing on a single layer of the multiple layer roadmaps. While less complex, the disadvantage of this type is that the linkages between the layers are not generally shown.

h. Text

Description: Some roadmaps are entirely or mostly text-based, describing the same issues that are included in more conventional graphical roadmaps (which often have text-based reports associated with them).

**Benefits of Technology Roadmapping**

The benefits of roadmapping are often derived directly from participating in the roadmapping process itself, rather than merely consuming a roadmap document produced as a final report (Bruce & Fine, 2004). Garcia & Bray (1997) propose the main benefits
of technology roadmapping are that it provides information to help make better
technology investment decisions. It does this by:

1- Identifying critical technologies or technology gaps that must be filled to meet product
performance targets.

2- Identifying ways to leverage R&D investments through coordinating research
activities either within a single company or among alliance members.

3- Bruce & Fine, point out that roadmapping provides a better understanding of the
potential paths for innovation, helping to visualize new opportunities for future
generations of product developments. Practitioners often assert that the roadmapping
“process” is at least as valuable, as the output, the roadmap itself. (Bruce & Fine, 2004)

4- Roadmap can serve as a marketing tool. It can show that a company really understands
customer needs and has access to or is developing (either internally or through alliances)
the technologies to meet their needs (Garcia & Bray, 1997).

5- Enhance prospects for economic growth for an entire industry sector through
collaborative efforts at innovation and technological development (Bruce & Fine, 2004).

6- Roadmap allows industry to collaboratively develop the key underlying technologies.
It helps the industry because a certain technology may be too expensive for a single
company to support or take too long to develop, given the resources that can be justified.
(Garcia & Bray, 1997).

7- Roadmaps guide fundamental scientific research and government funding. Roadmaps
can be used to convince the government funding agencies regarding support of scientific
research that will address long-term technology barriers (Kostoff & Schaller, 2001).
“Government participation in the generation of industrial technology roadmaps is a particularly valuable way to gather intelligence regarding impending changes in innovation patterns. Roadmaps...generally represent a collective vision of the technological future that serves as a template for ways to integrate core capabilities, complementary assets, and learning in the context of rapid change (Department of Industry, Science and Resources, Government of Australia, 2001).”

**When Should an Industry Produce a Technology Roadmap?**

Industry Canada’s guide to roadmapping identifies some of the indications that an industry needs to produce a roadmap: (Industry Canada, 2006)

- Dramatically changing market demands
- The industry has reached a strategic juncture with regard to entering new markets, seeking out new technologies or acquiring new skills.
- Decreasing market share and increased competition from other industries
- Companies within the industry have a vision of their place in future markets but no strategy for making that vision tomorrow’s reality.
- Companies, or the industry, are facing uncertainty about what technologies and applications future markets will demand, and when new technologies will be needed.
• Lack of consensus among companies or within the industry on technology choices

• Each company within the industry is conducting separate R&D efforts devoted to technology problems, that all have in common.

• Individual companies within an industry sector lack the resources and skills needed to boost innovation, and would benefit from joint efforts in R&D, sourcing, or supply-chain arrangements.

---

Figure 10: Change, Complexity and Competition in Industries

Technology Roadmapping Process

Data Collection Approaches

Two major approaches to development of technology roadmaps are:

Expert Based Approach:
A team of experts comes together to identify the structural relationships within the industry and specify the quantitative and qualitative attributes of the roadmap.

Workshop Based Approach:
This technique is used to engage a wider group of industry, research, academic, government and other stakeholders to draw on their knowledge and experiences.

Garcia & Bray developed a three-phase roadmap development model. The first phase involves preliminary activity without which the roadmapping probably should not be done. The second phase is the development of the technology roadmap. The third phase is the follow-up and use of the technology roadmap. (Garcia & Bray, 1997).
The Technology Roadmapping Process

<table>
<thead>
<tr>
<th>Phase I: Preliminary Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Satisfy essential conditions</td>
</tr>
<tr>
<td>2. Provide leadership/spONSorship</td>
</tr>
<tr>
<td>3. Define the scope and boundaries for technology roadmap</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase II: Development of the Technology Roadmap</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Identify the &quot;product&quot; that will be the focus of the roadmap</td>
</tr>
<tr>
<td>2. Identify the critical system requirements and their targets</td>
</tr>
<tr>
<td>3. Specify the major technology areas</td>
</tr>
<tr>
<td>4. Specify the technology drivers and their targets</td>
</tr>
<tr>
<td>5. Identify technology alternatives and their time lines</td>
</tr>
<tr>
<td>6. Recommend the technology alternatives that should be pursued</td>
</tr>
<tr>
<td>7. Create the technology roadmap report</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase III: Follow-Up Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Critique and validate the roadmap</td>
</tr>
<tr>
<td>2. Develop an implementation plan</td>
</tr>
</tbody>
</table>

Figure 11: Three Phase Technology Roadmapping Process


The Department of Industry, Science and Resources, Australia, proposes a similar six-step workshop based process for development of Technology roadmaps.
The standard T-Plan process, developed by Institute for Manufacturing, University Of Cambridge (Phaal, Farrukh, & Probert, 2001) comprises four facilitated workshops – the first three focusing on the three key layers of the roadmap (market /
business, product/service, and technology), with the final workshop bringing the layers together on a time-basis to construct the chart.

![Diagram of T-Plan Roadmapping Process]

**Figure 13: T-Plan Roadmapping Process**


**Post Development Challenges**

There are two key challenges to overcome if roadmapping is to be adopted widely within a company:

**Keeping the Roadmap Alive:**

The full value of roadmapping can be obtained only if its information is kept current and kept up-to-date as events unfold. In practice, this means updating the
roadmap on a periodic basis, at least once a year, or perhaps linked to budget or strategy cycles.

**Roll-out:**

Once the first roadmap is developed in an organization, it may be desired to facilitate the adoption of the method in other parts of the organization. Essentially there are two approaches to rolling-out the method:

– **Top-down**, where senior management prescribes the requirement for roadmaps – the particular format may or may not be specified.

– **Bottom-up** (‘organic’), where the benefits of using the method are communicated and support provided for application of the method where a potential fit with a business issue problem is identified (Phaal, 2003).

**Roadmapping Success Factors**

Bruce & Fine (2004) report that a successful roadmap draws upon the following factors:

- Should be an iterative process.
- Requires commitment from the participants, in terms of both time and resources.
- Depends on the competence of roadmap participants.
- Should be led by the stakeholders.

The department of Industry, Science and Resources, Australia, emphasize that success of the roadmap depends on the following:

– Participation of the right people.

– Partnerships building.

– Designing of a manageable process, and

– Careful plan and a review cycle.
Industry and University Partnerships

Introduction

Rapid technological changes, shorter product life cycles, and increasingly intense global competition are transforming the current competitive environment for most firms. As a result, the timely development and commercialization of new technologies are critically important for firm growth and survival (Ali, 1994). Though until recently firms had been relying on in-house R&D efforts for developing new products and technologies, now it is increasingly more difficult for firms to rely solely on internal organizational units due to limited expertise and resources (Hamel & Prahalad, 1994).

Partnership between university and industry has been receiving considerable attention because of its potential benefits for all parties. Powers suggest that the increasing number of collaborations is an indication that all parties are benefiting. Academic institutions and industry interact and enter into collaborative relationships for many different reasons (Powers, Betz, & Aslanian, 1988). According to a survey conducted by Peters and Fusfeld, companies collaborate in order to obtain access to manpower, obtain a window on science and technology, and gain access to university facilities (Peters & Fusfeld, 1983).

Universities collaborate in order to obtain access to industry as a new source of funding, to provide student exposure to real-world research problems, to work on intellectually challenging problems of tangible relevance to society, and to gain access to company research facilities and equipment. A document by US General Accounting Office outlines how higher education services can help foster industrial innovation (U.S. General Accounting Office, 1983).
**Nature of Relationship**

Today, both industry and universities seek to establish close ties with one another for a number of reasons. Industrial firms gain access to highly trained students, professors, university facilities, and leading-edge technologies. Additionally, firms can often enhance their image and reputation by associating with a prominent institution. Powers et al. (1988) noted, “The most fundamental reason that institutions of higher education want to collaborate with businesses is to improve their financial situations. Another reason educational institutions seek collaborative relationships with businesses is to promote advancement of knowledge by improving the quality of instruction and research. Businesses enter cooperative relationships first of all to meet corporate product, service, or management needs.”

Industry–University (I/U) collaboration can provide new opportunities for advancing new technologies. For example, I/U partnerships in biotechnology have helped advance basic research in microbiology (Pisano, 1990). Additionally, manufacturing firms like Chrysler Corporation have worked with university partners to address applied engineering projects (Frye, 1993).

EIRMA 1972, reports the justification for seeking industry university collaboration is because of the very real benefits that the study has shown to accrue to both parties from fruitful collaboration, such as:

a) For industry, in mobilizing the scientific and intellectual potential of universities to help increase its effectiveness and productivity.

b) For the universities, by the stimulation of having to relate their work to real-life activities, by contact with applications and people problems.
c) For society as a whole, by the enhanced levels of effectiveness and responsibility of the industrial and educational worlds in their services to the community.

Santoro and Chakrabarti’s (2001) research revealed seven key factors as being especially important to industrial firms in establishing industry university relationships:

1) Strengthening skills, knowledge, and gaining access to university facilities for advancing core technologies;
2) Strengthening skills, knowledge, and gaining access to university facilities for advancing noncore technologies;
3) Organic and adaptable corporate culture;
4) Flexible university policies for intellectual property rights (IPR), patents, and licenses;
5) Presence of an I/U champion at the firm;
6) Firm’s level of personal interactions and resource commitments in their I/U relationships;
7) Level of tangible outcomes generated from I/U relationships.

(Santoro & Chakrabarti, 2001).
Chapter III
Research Methodology

Determination of an Industry Relevant to NC

In his Clusters of Innovation Initiative study on Research Triangle Park, Michael E. Porter identified Textiles as an established cluster and the College of Textile, NCSU among the world’s best with the Textile Protection and Comfort Research Center and the Nonwovens Cooperative Research Center (Porter, 2001). He also emphasized the possibility of several cross-clustering opportunities, between textiles and pharmaceuticals / biotechnology cluster.

The United State is a net exporter of nonwovens. During the period June 2004 to June 2005, domestic manufacturers exported nonwovens goods worth $1.37 billion compared with imports of $0.73 billion (OTEXA, 2005). See Table A-4 in Appendix A.

Forty of North Carolina’s 100 counties have at least one commercial nonwoven related facility located in them (Pourdeyhimi, 2004). In addition, eight of the top 40 largest nonwoven firms in the world have plants in North Carolina (Duke University, 2005):

In August 2004, Dr. Behnam Pourdeyhimi, a professor at College of Textile, North Carolina State University, reported 29 companies making nonwoven products in North Carolina, as well as 70 that support them, such as distributors and packagers. Overall, the nonwovens industry generates about $3 billion in annual economic activity for the state, and it is growing at a rate of up to 8 percent a year (The News & Observer, 2004). According to the North Carolina Office of the Governor, in May 2005 the number of core nonwoven firms rose to 35 (Easley, 2005).
Selection of Nonwovens Industry

David L. Barkley & Mark S. Henry of Regional Economic Development Research Laboratory (REDRL), Clemson University, South Carolina used the following 5-point screening criteria to identify promising manufacturing clusters (Berkley & Henry, 2005):

1. Five or more establishments in the S.C. Upstate in 1996.
2. Upstate industry employment was greater than 1000 in 1996.
3. Industry employment in the Upstate counties increased from 1988 to 1996.
4. Industry Location Quotient (LQ) for the Upstate counties exceeded 1.00 in 1996 or increased from 1988 to 1996. A location quotient greater than one indicates that the region has been, over time, relatively successful in attracting or nurturing employment in a specific industry.
5. Industry Competitiveness Differential (CD) of Shift-Share Analysis for Upstate counties was positive for the period 1988 to 1996. A positive competitiveness differential indicates that industry employment in the area grew at a more rapid rate than for the nation, or area industry employment declined at a less rapid rate than for the nation.

Applying the same criteria to North Carolina Nonwoven industry we find that:

1- In May 2005 there were 35 nonwovens fabric mills in North Carolina (Easley, 2005)
2- State employment in year 2003 was 2480. (See Table A-5 in Appendix A)
3- During 1993 to 2003 the employment in nonwovens fabric mills increased by 9% (see Table A-5 Appendix A).
4- The number of nonwovens firms increased from 23 to 35 during 1993-2005 (see Table A-5 Appendix A). This is a 52% increase.

5- The fact that today North Carolina has more than twice the number of nonwoven textile mills than its nearest competitor shows that
   i) It is doing better than the rest of the nation in maintaining & attracting employment in nonwovens, and
   ii) Nonwoven industry employment in the area grew at a more rapid rate than the national average, or industry employment declined at a less rapid rate than for the nation.

Implication of the Clusters of Competitiveness Theory

After having established that nonwovens industry is a growing cluster with substantial impact on North Carolina Economy, it is important to analyze how this cluster can be used for betterment of NC. Porter identifies three implications of clusters for a region’s competitiveness.

i) An Explicit Cluster Development Program: Although chance events play a role in the formation and development of clusters, conscious efforts to raise cluster competitiveness and innovative capacity can meaningfully influence the trajectory of cluster development (Porter, 1998).

ii) Recruiting for Clusters: Recruitment strategies at the regional level should target clusters in which the region has strength, or clusters which overlap with other clusters. This allows the region to market its unique assets rather than compete on subsidies. In recruiting efforts, regions should also identify gaps within clusters, and seek to attract companies to fill them (Porter, 1998).
iii) Opportunities at the Intersection of Clusters: Opportunities for growth often arise at the intersection of clusters where a region has strength (Porter, 1998).

As per Porter’s recommendation a conscious effort is needed for development and recruitment of clusters. Such an effort would also assist in identifying the opportunities at the intersection of clusters.

Technology roadmapping of the nonwovens industry will provide insight into existing and future needs of the nonwovens industry. Given the substantial economic importance of nonwovens industry to North Carolina, this roadmap would enable the economic development committees of Wake County, NC, and NC State University to allocate resources for meeting these needs. The roadmap would further allow the College of Textiles to identify (i) the types of collaborations with the nonwoven industry and (ii) the research areas for allocation of R&D to better serve nonwoven industry.

Development of Industry Technology Roadmaps

Research Design – Approach 1

The research for this study uses a mixed methods approach. Primary sources of qualitative data include interviews of COT faculty members and NCSU economic development officials. Quantitative data was collected through a survey of nonwoven firms. The secondary data sources included INDA outlook report, data from the Employment Security Commission of North Carolina, Duke University, Durham, NC, NCRC, and the Council of Competitiveness report on Research Triangle Park.
This research was composed of three parts. Part I included data collection through secondary sources and interviews of NC State Faculty, industry experts and a survey of nonwoven companies. Firms having stakes in the nonwovens industry, such as nonwovens roll goods producers; converters, raw material and services suppliers were the potential respondents for the survey. Survey instrument was distributed to the nonwovens firms at the Nonwovens Cooperative Research Center’s (NCRC) semi annual meeting held on November 2 & 3, 2005, in the College of Textiles. This survey was conducted to identify the (i) location factors of nonwovens plant and (ii) to identify a growing & challenging segment of nonwovens industry. Part II involved gathering of data through subsequent questionnaires about challenges faced by the industry in the “growing” nonwovens segments and possible solutions. And finally with the help of data from Part II, a roadmap would be compiled in Part III.

The interviews with the industry experts and NC State faculty were used in development and for validation of survey instrument in Part I. Please see Appendix B for details about development of survey instrument (B1), Institutional Review Board approval (B2), survey instrument (B3), and Appendix B4 for sample selection, product category, size, pre-test method, and location selection & data collection.

Data Analysis

Descriptive statistics analysis would be conducted to determine factors most important for nonwoven industry in relocating to North Carolina and their expectation from the college of textiles.
Results

Until February 28, 2006, only three replies were received. None of the respondents were core manufactures of nonwovens. Survey Respondents were sent appreciation letters. Reminder letters (see Appendix B6) were sent to attendees who had given their contact information. Moreover, the survey instrument was also posted on NCRC’s website to remind the participants. These reminding efforts could only fetch one additional response from a core manufacture, who citing company policy, declined to participate in the survey. Due to the low response rate in general and absence of core manufacturers in particular, results from this survey were not deemed useful for identifying a nonwovens segment with high growth potential. This approach had to be discarded in favor of a more result oriented one.

Data gathered through these responses was nonetheless analyzed using descriptive statistics (see Appendix B5).
Research Design- Approach 1 Schema

Part I - Environmental Scan

<table>
<thead>
<tr>
<th>Environmental Scan Of Nonwovens Sources Qualitative</th>
<th>Survey Instrument For Identification of growing segment of nonwovens</th>
<th>Validation &amp; Pretest Survey Instrument validation and pretest through faculty, NCRC and nonwovens firm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualitative INDAs Reports Nonwovens Journals Duke University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qualitative INDAs reports Interviews NC State Faculty Industry Experts INDAs Officials</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Part II - Identification of a growing Sector in Nonwovens

<table>
<thead>
<tr>
<th>Data Gathering Data gathering from Industry</th>
<th>Data Analysis Analysis of Data using descriptive statistics to identify the growing segment</th>
</tr>
</thead>
</table>

Part III - Roadmap development

<table>
<thead>
<tr>
<th>Instrument Development Development of survey instrument to gather industry opinion on the identified are</th>
<th>Data Gathering Gathering the date from Industry, academia &amp; Industry Associations</th>
<th>Data Analysis and Assembly Analyzing the data and putting it in the form of a roadmap</th>
</tr>
</thead>
</table>

Figure 14: Research Design- Approach 1 Schema
Problems With Research Design-Approach 1

Part I

**Environmental Scan Of Nonwovens Sources**
Qualitative
INDA Reports
Nonwovens Journals
Duke University
Qualitative
INDA reports
Interviews
NC State Faculty
Industry Experts
INDA Officials

**Survey Instrument**
For Identification of growing segment of nonwovens

**Validation & Pretest**
Survey Instrument validation and pretest through faculty, NCRC and nonwovens firm

Part II

**Data Gathering**
Data gathering from Industry

**Data Analysis**
Analysis of Data using descriptive statistics to identify the growing segment

---

**Surveys Sent**
1 2 3 4 40

**Responses Received**
1 2 3

Low response rate + absence of core nonwovens mills

**Reminders**
1
One reply citing company policy for their inability to respond

**Approach Changed/ Abandoned**
Because of low response rate + Absence of core nonwovens companies, results from this survey were not deemed credible.

Figure 15: Problems with Research Design-Approach 1
Research Design – Approach 1 Analysis of Problems

It is important to note that the nonwovens industry is more reserved about sharing information than other segments of the textile industry. This diffidence may be attributed to the fact that due to high growth rates of this industry, nonwovens firms invest heavily in research and development to come up with new products and processes. The industry is sensitive about exposure of high investment nonwovens technologies to low-cost importers. Sedef Uncu, a former NC State student, could achieve 10% response rate (1 response from the 10 surveys sent) from the nonwovens firms while researching on investment decisions (Uncu, 2003).

Low response rate from the industry for the questionnaire-survey based approach highlighted the importance of creating increased awareness about the technology road-mapping process and its benefits for the industry. Though the reservations of nonwovens firms in sharing their technology paths due to market competition is understandable, the industry can still find common ground for a joint effort that benefit all of them. Identification of challenges such as workforce and infrastructure requirements, opportunities available of basic and applied research at universities, mutually beneficial partnerships with state and university economic development committees and regulatory authorities has potential to be advantageous for all stakeholders, without conceding any of the trade secrets.
Research Design - Approach 2

It was decided to adopt a new approach to bring the nonwovens industry onboard for the NITR effort. The new research design consists of five parts. The research for this study also uses a mixed methods approach. Primary sources of qualitative data include interviews of COT faculty members, NCSU economic development officials and a panel of nonwovens industry experts from industry, academia, and industry organizations. The secondary data sources included INDA outlook report, data from the Employment Security Commission of North Carolina, Duke University, Durham, NC, NCRC, and the Council of Competitiveness report on Research Triangle Park.

Part I calls for an environmental scan of nonwovens industry. The sources identified are INDA reports, nonwovens journals, faculty and industry expert interviews and NC State library web database.

In Part II includes development of a proposal for NITR, presentation of this proposal to potential partners, and finally recruitment of experts from industry, academia, industry associations and economic development committees to serve on the NITR panel.

Data collection from the panel starts from Part III. In this step panel would be asked to identify the goals of the industry and challenges it faces. Depending on the preference and availability of panel members, data may be collected through workshop, internet based communication or conference calls.

Part IV consists of collecting data from the panel for responses to these challenges identified in Part III. The panel would identify possible rejoinders from the angle of work force, physical infrastructure, basic and applied research at Universities & research centers to deal with challenges.
Part V comprises of data compilation into a roadmap document.

**Data Analysis & Compilation**

Descriptive statistics and opinions of experts at the College of Textile would be used in Part III of the research to identify and prioritize a limited number of targets. These targets would be used for Part IV.

In Part IV, the NITR panel would be asked to propose solutions for the challenges identified in Part III. These proposed solutions would then be compiled by section, using Alignent’s ‘Vision Strategist’ software in Part V. The first draft of the roadmap would be sent to the panel members along with plans for the next teleconference or email correspondence, with an agenda to discuss the draft section by section. Written comments on the first draft would also be requested.

This would be critical stage in the process and the potential exists for separation of interests. Strong leadership is required to hold the panel together.
Research Design – Approach 2 Schema

Part I

**Environmental Scan Of**
Nonwovens
Medical Textile
Roadmapping Process

**Sources**
Qualitative
INDA Reports
Nonwovens Journals
Duke University
Qualitative
INDA reports
Interviews
NC State Faculty
Industry Experts
INDA Officials

Part II

**NITR Proposal**
Proposal
Development
Presentation to potential partners

**Recruitment**
Recruitment for expert panel for
from Industry, Industry
Associations, Academia, University
and State Economic Development
Committees

Part III

**Identification of Challenges**
Data collection from the Panel
about:
Challenges faced by the industry

Part IV

**Identification of Solutions**
Data collection from the Panel
about:
Possible technology alternatives
that satisfy industry needs

Part V

**Compilation of Roadmap**
Compilation of the roadmap
document based upon the
recommendations of the panel of
experts

---

Figure 16: Research Design- Approach 2 Schema
Chapter VI

Results

Environmental Scan of Nonwovens & Medical Textile

This section describes the results of the environmental scan of Nonwovens and Medical Textiles. Data was gathered from the INDA reports, Nonwovens Journals, the Employment commission of North Carolina, Duke university website, and faculty interview. See Appendix C for faculty interviews.

Overview of the US Market Place

The U.S. is by far the largest economy in the world. In 1998 it included more than 270 million consumers and 20 million businesses. The United States consumers purchase more than $5.5 trillion of goods and services annually, and businesses invest over a trillion dollars more for factories and equipment. In addition to spending by private households and businesses, government agencies at all levels (federal, state, and local) spend roughly an additional $1.5 trillion a year. Today the U.S. population is over 300 million (Census Bureau, 2005a). The national average per capita income of US is $37,500, only behind Luxemburg (Success-and-culture.net, 2005). Luxemburg is however slightly smaller in area than the state of Rhode Island, with a population of 468,571 (The World Fact Book, 2005).

Over 80 percent of the goods and services purchased by U.S. consumers each year are made in the United States; the rest are imported from other nations (Encarta.com, 2005). The 20% slice of this huge economy is reason enough for exporters around the globe to focus on US market. In the case of textiles and apparel, the interest is further
aroused because the US imports more goods in this sector than it produces locally. Today apparel imports account for an astronomical 96% of the total US market size. The production and shipments for apparel for the first quarter of 2005 are valued at $3,678.9 million dollars (Census Bureau, 2005b) (see Table A-1 in Appendix A). US apparel sales exceeded 182 billion dollars in 2000 (NPD Group, 2005). The North American 2003 GDP was $11.8 trillions, equaling 34% of the world GDP. The annual growth rate forecast for North America from 2004-2008 is 3.7% (INDA, 2004b).

Overview of the Nonwoven Industry

History and Background

The nonwoven fabrics industry is international in scope. The concept of making fabrics directly from fibres on needlepunch machinery achieved commercial viability in North America and Europe more than 75 years ago. Much of the early work with nonwovens was done by cotton mills, which were seeking to upgrade cotton waste into salable products such as furniture stuffing and wipes. Some of the mills then working with nonwoven technology were Avondale Mills, Callaway Mills, Dan River and WestPoint Manufacturing (Mansfield, 2002). Facilities for producing commercial quantities of fabrics using wet-laid technology were established in the United States during the 1930s. Large-scale commercial production facilities for chemically bonded nonwovens were placed in operation in the United States during the early 1940s and in Europe and Japan following World War II. The earliest identifiable nonwoven consumer products were wipes, developed by Chicopee's in the mid-1950s. During this time, Pellon Corp., owned by Freudenberg Nonwovens Group of Germany, became an important U.S. producer of nonwovens, specializing in inner linings and interfacings for the apparel
trades (Mansfield, 2002). During this initial phase, proprietary technology was used not only to produce fabric structures that performed better than the items they were designed to replace, but it also was used when traditional fabrics could not be used. As a result, new applications and markets were established and the industry expanded.

Up until the 1960s, the major technology for nonwovens was based on drylaid technology. The 1960s, however, saw the introduction of spunbonded, meltblown, needlepunch and wetlaid nonwoven technology. By the 1970s, the establishment of a trade association for nonwovens, the Association for the Nonwoven Fabrics Industry (INDA), provided a focal point for nonwovens as useful and distinct materials differentiated from conventional textile materials (Mansfield, 2002).

The 1980s was a decade of increasing growth in nonwovens activity throughout the world, particularly in spunbonded and meltblown products. Factors influencing spunbonded and meltblown growth included the expiration of patents, which led to the development of turnkey plants from companies like Germany-based Reifenhäuser, as well as lower-cost and higher-quality polyolefin and polyester resins (Mansfield, 2002).

The 1990s marked the era of widespread acceptance of nonwovens as performance and problem solving materials for industries as diverse as civil engineering and healthcare. Many of the products that came into use during this time were based on composites made by combining different types of nonwovens and/or nonwovens with other materials, such as films and foams (Mansfield, 2002). By the mid-1990s about half of the worldwide nonwoven fabric production capacity was located in North America, a third in Europe, and an eighth in Japan. Capacities in these areas were expanding at annual growth rates ranging 6 to 10 percent through both productivity improvements and
the installation of new facilities. In addition, new nonwoven enterprises were being launched throughout Asia and South America. At that time about two-thirds of all nonwovens were made directly from fibres and one-third were made directly from polymers. Some portions of the nonwovens industry were technology driven while others were market driven. A number of firms were proprietary technology-based while others were turnkey plant operations. Some were commodity roll-goods producers while others were more oriented to niche markets with high value-added products. Many nonwovens producers continued the quest for new markets and more opportunities to compete with traditional textiles, papers, and plastics. But recently, nonwoven roll good producers and converters are reducing R&D costs as a cost saving measure perhaps suggesting a negative impact on future industry development. Commodity materials definitely have their place in nonwovens, but in order for the industry to remain competitive, special value-added products and unique technology are crucial (Mansfield, 2002).

**Market Description**

The nonwoven fabrics industry is one of the fastest growing sectors of the textile business, becoming an integral part of the American economy and everyday life. The nonwoven industry has grown to present a broad array of “engineered” products that are driven by high-speed, low-cost, innovative, value-added processes. Nonwovens have barriers to imports because of high capital & low labor requirements. The high volume and low cost of the nonwoven goods make imports economically quite unattractive (Pourdeyhimi, 2004). The production of nonwoven fabrics requires a substantial capital investment and a relatively small workforce; therefore, it is not an attractive industry for
developing countries where finding employment for numerous people is a prime objective.

This industry requires sophisticated, electronically controlled machinery and highly trained fabric engineers. Environmental performance has improved due to significant reductions in material usage. This results from the use of high performance materials or new processing technologies. Also, the industry has reported no history of pollution problems in terms of air pollution. Product design also continues to improve, which has a significant impact on environmental performance. The most evident societal impact from nonwovens is the significant improvements in hygiene and medical applications worldwide. This will continue to improve as nonwovens become more innovative in terms of production and overall product characteristics (Chapas, 2002).

In almost all cases where nonwoven fabrics can be substituted for woven and knitted fabrics, the result is a less expensive product. Today nonwovens are recognized as viable replacements to certain wovens and knits (Holliday, 1997). They are proving to be sustainable products. In 2002, Chapas studied nonwovens and determined the characteristics of a sustainable product. He observed that nonwovens are environmentally responsible, economically viable, and serve a social need (Chapas, 2002).

The most noted challenges that the nonwovens industry is currently facing are:

- Disposability of the products – disposable nonwovens are not reusable and must be thrown away, which contributes to the increase in the levels of trash in community landfills. Products need to be disposable and biodegradable.

- Dependency on petroleum – most nonwovens are made from synthetic fibers, which are composed of petroleum based fibers, which may become a concern during any oil crisis,
when oil prices increase as a result of war or other political instability in petroleum producing countries.

- Societal dislocations of wovens as they are replaced by nonwovens – is society ready to replace woven products with nonwoven products. This shift to nonwoven production will affect the employment that exists for woven and knitted goods (Chapas, 2002).

**US Nonwovens Market**

The US is the largest market for nonwovens production. The US industry leads the world in nonwovens technology, production and consumption. It is composed of over 550 firms that employ more than 160,000 people (Pourdeyhimi, 2004). The typical US nonwovens firm is small, has a median employment of about 75, and annual sales of about 7.5 million dollars (Pourdeyhimi, 2004). Nonwovens manufacturing firms are located primarily in 32 states and the District of Columbia. However, manufacturing of nonwoven fabrics is segmented by geographical areas within the US, indicated by the table below. It is also apparent from Table A-2 (in Appendix A) that the state of North Carolina is dominant in the nonwovens industry (Pourdeyhimi, 2004).
Table 1: Nonwoven Fabrics (NAICS 3132301). Value of Product Shipments

<table>
<thead>
<tr>
<th></th>
<th>United states</th>
<th>California</th>
<th>Georgia</th>
<th>Massachusetts</th>
<th>New York</th>
<th>North Carolina</th>
<th>Ohio</th>
<th>Pennsylvania</th>
<th>South Carolina</th>
<th>Wisconsin</th>
</tr>
</thead>
</table>


Figure 15 shows that North Carolina has the largest number of core nonwovens firms in the US, doubling the amount of firms the next ranked state has. Forty of North Carolina’s 100 counties have at least one commercial nonwoven related facility located in them (Pourdeyhimi, 2004).
Production and Consumption

Nonwovens are consumed globally, but a great deal of this consumption is concentrated right here in the United States, as shown in Table 2. However, as developing countries become more developed it is to be expected that more nonwovens production and consumption shift into these regions.

Table 2: Nonwovens Consumption by Region

<table>
<thead>
<tr>
<th>Year</th>
<th>USA</th>
<th>West Europe</th>
<th>Japan</th>
<th>China</th>
<th>Rest of the World</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>52</td>
<td>31</td>
<td>8</td>
<td>-</td>
<td>9</td>
</tr>
<tr>
<td>1988</td>
<td>48</td>
<td>30</td>
<td>9</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>1995</td>
<td>38</td>
<td>30</td>
<td>9</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>1998</td>
<td>35</td>
<td>30</td>
<td>10</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>1999</td>
<td>34</td>
<td>30</td>
<td>9</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>2000</td>
<td>33</td>
<td>30</td>
<td>9</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>2005</td>
<td>31</td>
<td>31</td>
<td>9</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>2007</td>
<td>30</td>
<td>30</td>
<td>9</td>
<td>12</td>
<td>19</td>
</tr>
</tbody>
</table>


Like consumption, nonwoven’s production is found worldwide, but is mainly concentrated in North America, Europe, and Japan. (Due to its sheer market size, Japan is considered separate from the rest of Asian-Pacific nonwovens market.)

![Figure 18: Worldwide Nonwovens Production](http://www.tx.ncsu.edu/ncrc/presentations/directions_in_nonwovens_technology.pdf)


The concentration of production in the western hemisphere and Japan may decline as developing countries advance their technology. More production will be seen in Latin
America, Asia-Pacific, and the Middle East. In terms of nonwoven roll goods production, production has increased since 1991 and is expected to increase over the next few years.

Table 3: Nonwovens Production by Region

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N. America, Europe, Japan</td>
<td>1.5</td>
<td>1.8</td>
<td>2.6</td>
<td>3.6</td>
<td>6.4%</td>
<td>6.2%</td>
</tr>
<tr>
<td>Latin America</td>
<td>.09</td>
<td>.17</td>
<td>.24</td>
<td>.04</td>
<td>10.3%</td>
<td>8.5%</td>
</tr>
<tr>
<td>Asia Pacific</td>
<td>.22</td>
<td>.46</td>
<td>.64</td>
<td>1.1</td>
<td>11.2%</td>
<td>10.7%</td>
</tr>
<tr>
<td>Middle East</td>
<td>.04</td>
<td>.08</td>
<td>.17</td>
<td>0.4</td>
<td>15.6%</td>
<td>15.0%</td>
</tr>
<tr>
<td>Rest of World</td>
<td>.06</td>
<td>.11</td>
<td>.16</td>
<td>0.3</td>
<td>10.3%</td>
<td>11.3%</td>
</tr>
<tr>
<td>Total</td>
<td>1.9</td>
<td>2.6</td>
<td>3.9</td>
<td>5.6</td>
<td>7.5%</td>
<td>7.6%</td>
</tr>
</tbody>
</table>


North American nonwoven fabric consumption reached 23.9 billion square meters during 2003. This volume was equivalent to 1.1 million metric tonnes with a value of $4.1 billion.

Table 4: American Nonwoven Consumption

<table>
<thead>
<tr>
<th>Roll Goods sales (billion, $)</th>
<th>Tonnes (thousands)</th>
<th>2002-2003 Growth (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>2003</td>
<td>2002</td>
</tr>
<tr>
<td>4.103</td>
<td>4.123</td>
<td>1,074</td>
</tr>
</tbody>
</table>


Nonwovens can be classified into short life and long life products. Table 5 shows that for 2003, almost 2/3 of the industry’s total was short life nonwovens with a volume of 738,000 tons. Two segments that are driving the short life markets’ growth are the wipes industry and an increase in usage of airlaid pulp nonwovens in the core absorbent hygiene products.
Growth in the industry are expected to be driven by incontinence products, filters and protective apparel. Total demand is forecasted to reach nearly $5 billion in 2007 (Table 6).

### Table 5: American Sales of Nonwoven Fabrics 2002, 2003-2008

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Short Life</strong></td>
<td>2,449</td>
<td>2,509</td>
<td>3,189</td>
<td>2.50%</td>
<td>5.90%</td>
</tr>
<tr>
<td><strong>Long Life</strong></td>
<td>654</td>
<td>1,614</td>
<td>2,023</td>
<td>2.40%</td>
<td>1.80%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4,103</td>
<td>4,123</td>
<td>5,212</td>
<td>0.50%</td>
<td>3.20%</td>
</tr>
</tbody>
</table>


The nation’s average age is rising, driven in part by the baby boomers reaching the retirement age and nation’s low birth rate. This demographic shift in population will have a positive effect on growth of medical textiles, adult incontinence products, and personal convenience items. A longer life span of population will increase consumption of nonwovens in the healthcare sector. Disposable nonwovens apparel and related surgical products are expected to increase their share of the total medical market versus reusable products (INDA, 2004b).
Fiber / Raw Material Consumption

At present, the nonwovens industry is dominated by manmade fibers and resins.

Figure 19 shows that polypropylene and polyester make up majority of nonwoven raw material consumption.

**2003 Staple Fibers and Spunlaid Resins Consumption in North America (in million tonnes) (see Table A-3 in Appendix)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Consumption (in million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Consumption of Resins</td>
<td>490</td>
</tr>
<tr>
<td>Total Consumption of Staple Fiber</td>
<td>460</td>
</tr>
<tr>
<td>Wood Pulp</td>
<td>141</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>17</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1108 million tonnes</strong></td>
</tr>
</tbody>
</table>

![Pie chart showing 2003 Staple Fibers and Spunlaid Resins consumption in North America](chart.png)

**Figure 19: 2003 Staple Fibers and Spunlaid Resins consumption in North America**

Figure 20: Spundlaid Resins Distribution


Figure 21: Staple Fibers Distribution as Follows


Trends in Materials, Process and New Products
Nonwoven products usually have a short life span. Consumption of nonwovens is proportional to disposable income to households. Demand for nonwovens will increase as middle classes grow in developing countries (INDA, 2004b).

As of January 1, 2005, the decades-old global system of imposing quotas on textile and apparel goods has come to an end.

INDA reports that hydroentangling will become more prevalent as the process continues to become more energy efficient and economies of scale are realized. Process changes will be required as the cost and shortage of inexpensive water increases. Focus is increasing on composite fabric made by combining processes or different fabric and value added treatments will become more prominent. Public and government concerns regarding flushability, dispersability and biodegradability are expected to become more prevalent. Manufacturers would have to find suitable wipes construction to meet these requirements.

Nonwovens industry is affected by globalization, which has allowed spread of new technologies rapidly around the world. INDA emphasizes the need for enforcement of Intellectual Property (IP) regulations throughout the world, especially China.

The technical activity in the industry is focused on higher value markets; e.g. textile substitution and value added applications. The industry is exerting strong pressure for faster to market tactics and value addition and reduction in manufacturing costs. Product differentiation is identified as the key to competition.

Innovation is the key for growth within the nonwovens industry. Below are just a few trends developing within the nonwovens production arena, indicated by INDA (2004).
<table>
<thead>
<tr>
<th>Materials</th>
<th>Process</th>
<th>New Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>New polymers</td>
<td>New web formation technologies</td>
<td>Nano technology</td>
</tr>
<tr>
<td>Move toward finer denier fibers</td>
<td>New combinations of web forming and web bonding systems</td>
<td>“Smart” fabric</td>
</tr>
<tr>
<td>Increased development of nonwovens made of bicomponent fibers.</td>
<td>Hydroentangling would continue to grow</td>
<td>Unusual composites</td>
</tr>
<tr>
<td>Airlaid pulp would continue to expand</td>
<td>Environment friendly products that are flushable, dispersible &amp; biodegradable</td>
<td></td>
</tr>
<tr>
<td>Further development of composites</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


According to a new report from INDA, Nonwovens growth was 7.5% a year during the 1990s. The Global annual nonwovens volume growth was 8.5% per year during 2000-2005 (Nonwovens.com, 2005).
Overview of the Medical Textile Industry

Introduction
While many US textile firms relocated manufacturing units to Mexico and Asia to take advantage of low wages, the specialty textile market remains a growth area in North America. Besides high investment in research and development, one of the most critical reasons is adherence to stringent quality standards, which results in low product liability. Because high liability is a known risk, steps must be taken to ensure only the highest quality, defect-free products leave the mill. The medical and automotive markets are examples of such high-liability sectors (Ziegenfus, 2005).

Definition
Medical textiles, also known as biomedical textiles, are textile products and constructions for medical and biological uses, e.g., first aid, clinical, or hygienic purposes (“What are Biomedical,” 2005).

Medical Textiles Classification
Medical textiles may be divided into two categories: disposable products made of nonwoven materials; and reusable products made of woven or knitted fabrics. No matter what these products are made of, they have to perform 100 percent of the time (Ziegenfus, 2005). The design of a biomedical textile is driven by its end use. The main factors in designing a biomedical include:

• Function: the textile needs to fulfill the purpose for which it was designed

• Biocompatibility: the compatibility of textile with blood and an implantable material.

• Cost: this depends on the raw materials and manufacturing process
• Product approval: each country has its own regulations and standards for the approval of biomedical textiles” (“What are Biomedical,” 2003)

Applications

Medical textile uses are wide ranging. Medical textiles can be anything from implantable devices used in surgery to simple bandages used for cuts and scrapes. Medical textiles represent a very diverse market in terms of uses & production (Frei, 1999). Because the products and uses are so different, the methods of manufacturing are varied as well. In addition, the materials used vary a great deal. Materials used can be basic cotton to complex synthetics. All production and material decisions are driven by the end use of the textile. Examples of applications include:

• Protective and healthcare textiles: surgeons’ wear, operating drapes, and gowns
• External devices: wound dressings, bandages, pressure garments, prosthetics
• Implantable materials: sutures, vascular grafts, artificial ligaments
• Hygiene products: incontinence pads, nappies, tampons, sanitary towels
• Extracorporeal devices: artificial liver, artificial kidney, artificial lung” (Frei, 1999)

Nonwovens are low cost products and can replaced readily as opposed to woven products. This property is one of the main reasons hospitals and operating rooms prefer nonwovens over woven fabrics (Frei, 1999). Disposables used in a hospital offer a freshness quality that reusable textiles cannot offer. Reusable textiles, even after washing, can retain stains (Frei, 1999). Other manufacturers feel nonwovens offer more possibilities than wovens, allowing them to better adjust their product lines to potential customers (Frei, 1999). However, the conversion of wovens to nonwovens has been
slower than anticipated due to corporate red tape, along with the time needed for R&D, lab and clinical trials, and FDA approvals (Frei, 1999). A critical focus for medical disposables producers is pollution due to an increase in the amount of waste associated these disposable products (Frei, 1999).

**Medical Textiles and Nonwovens**

Nonwovens are a major player in the medical textiles field. Nonwovens are beginning to take the place of wovens and knits as they offer disposability at a time when fear of disease contraction is at its height (Rodie, 2001). Medical textiles are proving to be just as important as the medicines that are used today. These textile products act in the same capacity as they treat and prevent medical problems with patients. Businesses and scientists are combining efforts to develop new medical textiles that optimize biocompatibility, sterility, leak resistance, and wear of medical products (“Wear and Care,” Textile Month, 2001).

The use of nonwoven fabrics in medical textiles has grown over the past 25 years. The main growth area is single use disposable medical products. The acceptability of these products has resulted from the significant improvements made in properties and cost of the materials (“Wear and Care,” Textile Month, 2001).

Nonwoven fabrics have brought “better medicine” to healthcare in terms of improved wound care, lower patient infection rate, better staff/worker protection, cost/benefit improvements, and sterility assurance (McDowell, 1991). With the widely accepted use of these nonwovens materials comes the definite concern, which has already been discussed: disposability. The chief concerns with the disposal of these single use
products are fear of AIDS, environmental pollution, decreasing numbers of landfills, increasing costs, and regulatory/legislative actions (McDowell, 1991).

Surgical applications include operating room drapes, OR gowns, head coverings, face masks, scrub apparel, CSR wrap, and shoe coverings. More than three quarters of the fabrics used in these applications are nonwovens. General care applications include uniforms and bed linens. These are mainly reusable textiles.

The desired properties for medical nonwoven products are as follows:

- Repellant vs. breathable comfortable
- Strong vs. lightweight
- Laser and electrocautery safe
- Low lint/abrasion resistant vs. softness
- Environmentally compatible
- Fluid control
- Antimicrobial activity
- Sterility assurance
- Non-toxic
- Non-allergic
- Non-carcinogenic
- Antistatic in nature
- Optimum fatigue endurance
- Flame proof
- Dyes must be fast and non-irritant (McDowell, 1991)

Categories of Medical Textiles Include:

- Non-implantable materials
- Implantable materials
- Extracorporeal devices
- Healthcare and hygiene products
Table 8: Non-implantable Materials

<table>
<thead>
<tr>
<th>Fibre Type</th>
<th>Fabric Structure</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton, viscose, lyocell</td>
<td>Nonwoven</td>
<td>Absorbent pad</td>
</tr>
<tr>
<td>Alginate fibre, chitosan, silk, viscose, lyocell, cotton</td>
<td>Woven, nonwoven, knitted</td>
<td>Wound-contact layer</td>
</tr>
<tr>
<td>Viscose, lyocell, plastics film</td>
<td>Woven, nonwoven</td>
<td>Base material</td>
</tr>
<tr>
<td>Cotton, viscose, lyocell, polyamide fibre, elastomeric-fibre yarns</td>
<td>Woven, nonwoven, knitted</td>
<td>Simple non-elastic and elastic bandages</td>
</tr>
<tr>
<td>Cotton, viscose, lyocell, elastomeric-fibre yarns,</td>
<td>Woven, nonwoven, knitted</td>
<td>High-support bandages</td>
</tr>
<tr>
<td>Cotton, viscose, lyocell, elastomeric-fibre yarns,</td>
<td>Woven, knitted</td>
<td>Compression bandages</td>
</tr>
<tr>
<td>Cotton, viscose, lyocell, polyester fibre, polypropylene fibre, polyurethane foam</td>
<td>Woven, nonwoven</td>
<td>Orthopaedic bandages</td>
</tr>
<tr>
<td>Cotton, viscose, plastics film, polyester fibre, glass fibre, polypropylene fibre,</td>
<td>Woven, nonwoven, knitted</td>
<td>Plasters</td>
</tr>
<tr>
<td>Cotton, viscose, lyocell, alginate fibre, chitosan</td>
<td>Woven, nonwoven, knitted</td>
<td>Gauze dressing</td>
</tr>
<tr>
<td>Cotton</td>
<td>Woven</td>
<td>Lint</td>
</tr>
<tr>
<td>Viscose, cotton linters, wood pulp,</td>
<td>Nonwoven</td>
<td>Wadding</td>
</tr>
<tr>
<td>Polylactide fibre, polyglycolide fibre, carbon</td>
<td>Spunlaid, needle-punched nonwoven</td>
<td>Scaffold</td>
</tr>
</tbody>
</table>

Table 9: Implantable Materials.

<table>
<thead>
<tr>
<th>Fibre Type</th>
<th>Fabric Structure</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collagen, catgut, polyglycolide fibre, polylactide fibre</td>
<td>Monofilament, braided</td>
<td>Biodegradable sutures</td>
</tr>
<tr>
<td>Polyester fibre, polyamide fibre, PTFE fibre, polypropylene fibre, polyethylene fibre</td>
<td>Monofilament, braided</td>
<td>Non-biodegradable sutures</td>
</tr>
<tr>
<td>PTFE fibre, polyester fibre, silk, collagen, polyethylene fibre, polyamide fibre</td>
<td>Woven, braided</td>
<td>Artificial tendon</td>
</tr>
<tr>
<td>Polyester fibre, carbon fibre, collagen</td>
<td>Braided</td>
<td>Artificial ligament</td>
</tr>
<tr>
<td>Low-density polyethylene fibre</td>
<td></td>
<td>Artificial cartilage</td>
</tr>
<tr>
<td>Chitin</td>
<td>Nonwoven</td>
<td>Artificial skin</td>
</tr>
<tr>
<td>Poly (methyl methacrylate) fibre, silicon fibre, collagen</td>
<td></td>
<td>Eye-contact lenses and artificial cornea</td>
</tr>
<tr>
<td>Silicone, polyacetylene fibre</td>
<td></td>
<td>Artificial joints/bones</td>
</tr>
<tr>
<td>PTFE fibre, polyester fibre</td>
<td>Woven, knitted</td>
<td>Vascular grafts</td>
</tr>
<tr>
<td>Polyester fibre</td>
<td>Woven, knitted</td>
<td>Heart valves</td>
</tr>
</tbody>
</table>


Table 10: Extracorporeal Devices

<table>
<thead>
<tr>
<th>Type Fibre</th>
<th>Application</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hollow polyester fibre, hollow viscose</td>
<td>Artificial kidney</td>
<td>Remove waste products from patients’ blood</td>
</tr>
<tr>
<td>Hollow viscose</td>
<td>Artificial liver</td>
<td>Separate and dispose of patients’ plasma and supply fresh plasma</td>
</tr>
<tr>
<td>Hollow polypropylene fibre, hollow silicone membrane</td>
<td>Mechanical lung</td>
<td>Remove carbon dioxide from patients’ blood and supply fresh oxygen</td>
</tr>
</tbody>
</table>

Table 11: Healthcare/ Hygiene Products

<table>
<thead>
<tr>
<th>Fibre Type</th>
<th>Fabric Structure</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton, polyester fibre, polypropylene fibre.</td>
<td>Woven, nonwoven</td>
<td>Surgical gowns</td>
</tr>
<tr>
<td>Viscose</td>
<td>Nonwoven</td>
<td>Surgical caps</td>
</tr>
<tr>
<td>Viscose, polyester fibre, glass fibre</td>
<td>Nonwoven</td>
<td>Surgical masks</td>
</tr>
<tr>
<td>Polyester fibre, polyethylene fibre,</td>
<td>Woven, nonwoven</td>
<td>Surgical drapes, cloths</td>
</tr>
<tr>
<td>Cotton, polyester fibre, polyamide fibre,</td>
<td>Knitted</td>
<td>Surgical hosiery</td>
</tr>
<tr>
<td>Cotton, polyester fibre, polyamide fibre yarns</td>
<td>Woven, knitted</td>
<td>Blankets</td>
</tr>
<tr>
<td>Cotton</td>
<td>Woven</td>
<td>Sheets, pillowcases</td>
</tr>
<tr>
<td>Cotton, polyester fibre</td>
<td>Woven</td>
<td>Uniforms</td>
</tr>
<tr>
<td>Polyester fibre, polypropylene fibre</td>
<td>Nonwoven</td>
<td>Protective clothing, incontinence, diaper/sheet, coverstock</td>
</tr>
<tr>
<td>Superabsorbent fibres, wood pulp,</td>
<td>Nonwoven</td>
<td>Absorbent layer</td>
</tr>
<tr>
<td>Polyethylene fibre,</td>
<td>Nonwoven</td>
<td>Outer layer</td>
</tr>
<tr>
<td>Viscose, lyocell</td>
<td>Nonwoven</td>
<td>Cloths/wipes</td>
</tr>
</tbody>
</table>


Tables 9, 10 and 12 show that nonwovens are the primary fabric structures for medical textile applications.

In total, over 1.5 million tons of textile materials, with a value of US$5.4 billion, were consumed worldwide in the manufacture of medical and hygiene products in 2000 (David Rigby Associates, 2003).

The US demand for medical textiles is expected to increase over the next few years. Today the global market for medical textiles is worth around US$ 6.3 billion, consuming 1.8 million metric tons of fiber (Kilduff, 2004).

This is forecast of increase in volume terms by over 4% per annum to 2010 to reach 2.4 million tons with a value of US$8.2 billion. In developed countries, the medical textiles sector offers strong growth potential based on an ageing, longer-living and more
affluent population that has an increased interest in healthcare issues. Incontinence goods will generate the strongest gains amongst medical/hygiene disposables. In developing countries, demand for medical textiles, and especially for disposable absorbent product is also expected to rise significantly as a result of a fast-growing, increasingly urbanized, young, brand-conscious population. Feminine hygiene products are rapidly becoming accepted in these regions. The uptake of disposable bed sheets and surgical drapes, gowns and caps is also increasing gradually and these are now widely used in hospital wards in countries such as China. However, baby diapers and adult incontinence pads are yet to see full market penetration, especially in relatively poor countries.

Dr. Peter Kilduff reported that medicare’s spending as a share of GDP could more than triple by 2050. Total federal budget spending on health care will soar according to a government forecast. Home care grew 6% in 1992, 11% in 2000, and is expected to grow 35% in 2012 (Kilduff, 2004).

According to David Rigby Associates’ estimates, world consumption of technical textiles in 2000 amounted to just over 16.7 million tons of fiber and polymer with a finished textile product value of US$92.9 billion. Medical Textiles enjoy 9% of this market in terms of volume (David Rigby Associates, 2003).
Figure 22: Share of Medical Textiles in Technical Technical Textiles Market (by volume)


Table 12: Forecast World Technical Textiles Consumption, 1995-2010, Volume (000 tons)

<table>
<thead>
<tr>
<th>Application Area</th>
<th>Years</th>
<th>Compound Annual Growth Rate %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1995</td>
<td>2000</td>
</tr>
<tr>
<td>Agrotech</td>
<td>1,173</td>
<td>1,381</td>
</tr>
<tr>
<td>Buildtech</td>
<td>1,261</td>
<td>1,648</td>
</tr>
<tr>
<td>Clothtech</td>
<td>1,072</td>
<td>1,238</td>
</tr>
<tr>
<td>Geotech</td>
<td>196</td>
<td>255</td>
</tr>
<tr>
<td>Hometech</td>
<td>1,864</td>
<td>2,186</td>
</tr>
<tr>
<td>Indutech</td>
<td>1,846</td>
<td>2,205</td>
</tr>
<tr>
<td>Medtech</td>
<td>1,228</td>
<td>1,543</td>
</tr>
<tr>
<td>Mobiltech</td>
<td>2,117</td>
<td>2,479</td>
</tr>
<tr>
<td>Packtech</td>
<td>2,189</td>
<td>2,552</td>
</tr>
<tr>
<td>Protech</td>
<td>184</td>
<td>238</td>
</tr>
<tr>
<td>Sporttech</td>
<td>841</td>
<td>989</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>13,971</strong></td>
<td><strong>16,714</strong></td>
</tr>
<tr>
<td><strong>Of which Oekote</strong></td>
<td><strong>161</strong></td>
<td><strong>214</strong></td>
</tr>
</tbody>
</table>

Trends in World Trade of Medical Textiles

Mironov (2004) states that the market for medical textiles is being driven by a number of factors which includes:

- Population growth rates, particularly in newly developing global regions,
- Changes in demographics, including the ageing of the population in the Western European market,
- Changes in living standards,
- Attitude to health risks; increased awareness of the risks to health workers from health threats from blood-borne diseases and airborne pathogens,
- The continuing dominance of the leading suppliers and brands (especially in the consumer market),
- Ongoing enhancement in product performance,
- The growing dominance of purchasing which demands increasing value for money,
- The increasing share of nonwovens on the medical world market in relation to traditional textile materials.

These trends will be further fed by the increasing development of the medical textile market and industry (Mironov, 2004).
NITR Proposal Development

A Nonwovens Industry Technology Roadmap (NITR) proposal was developed with help of the environmental scan shown in Part I. Please see Appendix D for the NITR proposal. One of the benefits of developing this proposal is gaining the support of Alignent® Software Company, based in Carlsbad, CA (Alignent.com, 2005). Alignent® claims to be the first and only software company to support the powerful process of roadmapping. Their flagship product, Vision Strategist, helps organizations to collaborate on strategic plans, share real-time information and communicate across geographically dispersed teams.

Dr. Hergeth and the author were in contact with Alignent® from the beginning of January 2006 to discuss the NITR project. Alignent® showed interest and Mr. Carl Dietz, founder of Aligent® and now President of Roadmapping Professional Inc. generously gave his feedback on multiple versions of NITR proposal for the Industry. Appreciating our seriousness in pursuing this project, Alignent® agreed to donate the use of Vision Strategist, which sells for $1 million and up (Balint, 2005).

On June 20, the NITR proposal was presented to INDA, represented by Mr. Cos Camelio, Director of Technical Affairs & NC State Economic Development committee, represented by Dr. Ted Morris, Director, Economic Development Partnership & Ms. Ruthann Cage, Director of Marketing & Public Affairs. Mr. Yusuf Shirazi, co-founder of Alignent®, also attended the meeting in which he explained in detail the purpose and benefits of road-mapping. It was decided in the meeting that NITR should start with focusing on one specific segment of nonwovens industry. Because of high growth rate of nonwovens medical textiles and North Carolina’s strong bio medical cluster, it was
agreed that NITR should begin with a pilot roadmap for nonwovens medical textiles, which would be later expanded into other areas of industry.

**Recruiting for Panel**

Emails were sent to determine nonwoven academics, industry experts and user (hospitals) who may be willing to be a part of NITR panel (See Appendix F for email text). Eight stake holders in medical nonwovens expressed their interest in the project (see Appendix G for initials and functions of panel members).
Identification of Challenges faced by Nonwoven Medical Textiles

Panel members were asked to identify the challenges faced by the nonwovens medical that are necessary to overcome for continued growth of this industry. Data from the panel members was gathered through interviews and emails. Following are the challenges identified by the panel members.

Rising Raw Material Costs

The industry heavily uses petroleum based synthetic fibres and resins as the basic raw material. The problem with this raw material is oil prices. Due to an increase in demand worldwide, especially from growing economies of China and India, and instability in the Middle East, oil prices are above $60/barrel and hit a maximum of $78.40/barrel (Foss, 2006). The major problem, threatening to disrupt the global supply chain of the nonwoven industry is surging oil prices, which in turn makes it expensive to produce raw material. The increase in oil prices could possibly slow nonwoven’s growth rate. Nonwovens have to invest in research and development to develop alternate sources for raw materials.

Sustainability of Environment

Government regulations and consumer awareness are forcing companies to come up with technologies that are environment friendly, including the capability of producing biodegradable, flushable and disperseable products. To meet these requirements nonwovens medical industry needs to make investment in:

1) New, more efficient and economical and energy conserving processing technologies
2) Use of new types of composite nonwovens and laminates, and
3) New finishing techniques and novel additives
4) Design of products from renewable sources

Life Cycle Study of Nonwovens

NC State is engaged in research on biocidal surface coatings for hospital garments and textiles. Biocidal compositions are useful in controlling the growth of bacteria and fungi in aqueous surface-coating compositions. This study involves life cycle studies of woven and nonwovens as well as various other supply chain dimensions. One Industry Roadmap challenge is the need for information requested by customers and suppliers, usually life cycle information. There is a growing demand in the field of sustainability for quantitative information of the environmental footprint as measured by life cycle inventory and analysis. Companies are repeatedly asked for this information, particularly in regards to exports. Not having this information can lead to a lack of competitiveness as these are no-go criteria for some green purchasers and States.

FDA Approvals

It is very important to design products that meet regulatory requirements before they could be launched in the market. The total time required to bring a single drug to market, from synthesis of the molecule to marketing approval, has more than doubled from 6.5 years to 15 years since 1964. An important reason is that the highly risk-averse FDA keeps raising the bar for approval, especially for innovative high-tech products (Miller, 2004). The challenge for medical nonwovens is to work out a strategy for faster approval of nonwovens medical textiles from FDA. Shorter times to market would allow
firms to earn profit and improve their cash flow positions. Profits then turn into investments again, promoting innovation and bring useful products to end-users.

**Public Awareness**

One of the challenges is to communicate to masses that while single use disposable gowns can be more expensive than repeat use garments, the savings in hospital re-admittance far outweighs this cost difference. People go into a hospital with one disease and pick up something else. The cost comparison is minor compared to the cost of people remaining in the hospital for longer. Nonwoven medical textiles have to embark upon a public awareness campaign to justify their seemingly higher price in comparison to their woven and knitted counterparts.

**New Uses for Nonwovens**

Medical nonwovens have replaced many products previously provided by woven or knitted structures. These days nonwovens are finding increased uses in wound management, an area earlier controlled by woven structures. It is important for the medical nonwovens firms to continue to find new areas where nonwovens can replace woven and knitted structure by providing better quality and lower price.

**Truly Functional & Comfortable Medical Nonwovens**

While hydroentangled carded or spunlaced fabric are very comfortable for the wearer, offering optimal breathability, drape, moisture vapor permeability and other comfort related. Their barrier properties, however, compare less favorably with other types of nonwoven fabrics. Spun bound- Melt Blown- Spun bound (SMS) structures, on
the hand, have sound barrier properties but they lack the comfort offered by hydroentangled fabrics.

Medical nonwovens need to come up with a nonwovens construction that should offer both the comfort of a hydroentangled fabric and superior barrier properties of a SMS fabric.

**Sterilization**

Preferred method of sterilization for hospitals has been steam or ethylene oxide gas. Ethylene oxide is used in hospital sterilization of surgical equipment and plastic devices that cannot be sterilized by steam. These methods are not considered very healthy and EPA is trying to reduce the use of ethylene as its acute inhalation exposure has resulted in nausea, vomiting, neurological disorders, bronchitis, pulmonary edema, and emphysema at high concentrations. Gamma radiation and E-beam sterilization are some of the solutions that can be used to replace the traditional environment unfriendly methods of sterilization. Gamma radiations and E-beam are expensive processes, requiring huge installations. Moreover gamma rays cannot be applied to all substrates. Exposure to gamma ray irradiation is a frequent, clean, and superior method used to prevent bacterial contamination of sterilized biomedical end products. However, the potential damage induced by gamma ray irradiation of polypropylene is of concern because of the decay of bioactivity, which correlates with considerable structural alterations.

Medical textiles face the challenge of i) coming up with environment friendly sterilization methods ii) and to develop fibers that are damage resistant to gamma radiation.
**Reusable vs. Disposable Materials**

In United States, so far the cost of disposing a single use product isn’t the concern of the manufacturer. In Europe, however the cost of disposing single use products is built in the price. There is a need for the industry to prepare itself for a change in public policy requiring manufacturers to take the responsibility for disposal of the single use products.

**Anti Microbial Treatments**

Microbial problems associated with nonwovens can be found in all segments of the nonwovens industry. Problems range from control of germs on surgical nonwoven fabrics, to control of microbial levels on wet wipes, towels, and baby diapers. Microbes cause problems in the form of degradation, defacement, odor, and health related problems. Proper control of microbial levels is important to the safety and market acceptance of the finished product.

In the past we relied on antibiotics to kill the germs at the hospitals. It was effective until the germs became immune. There is a need for research into newer technologies to address this problem.

**Clothing and Textiles for Disabled and Elderly People**

The populations of most of the industrialized countries are both growing slowly and aging rapidly, implying that ratios of retirees to workers will rise sharply in coming decades. For example, in the United States, for every 100 people between the ages of 20 and 64, there are currently about 21 people aged 65 or older. By 2030 the population of the United States will include about 34 people aged 65 or over for each 100 people in the 20-64 age range; for the Euro area and Japan, the analogous numbers in 2030 will be 46
and 57, respectively. In 2050, for example, the number of retirees for each 100 working-age people in the United States should be about the same as in 2030, about 34, but the number of retirees per 100 working-age people is projected to increase to about 60 in the Euro area and about 78 in Japan (Bernanke, 2005).

The expected aged population would have higher medical needs. The quality of life for disabled and elderly people can in many cases be substantially improved by a better choice of good looking and functional clothing and other textile products. A basic requirement of clothing is that it must not cause discomfort for the wearer (Meinander & Minna, 2002).

For an individual who is lying in bed for prolonged times, his body contacts bed textiles such as sheets, pillows, blankets and quilts, bed protectors and pile pads. Comfort properties of textile products are very important for such an individual, as permanent or prolonged stay in bed entails high bedsores risk. It is therefore essential to design softer medical textiles in which surface roughness, raw material and finishing agents must not cause mechanical nor physiological allergic reactions

**Online Quality Inspections**

Nonwovens are made at a very high speed. More research is needed to device satisfactory inspection systems for critical medical textile applications.
Chapter V

Summary

The overall purpose of this research was to examine the process by which an Industry Technology Roadmap (ITR) is developed, to start the development of an elementary roadmap for the medical nonwovens industry, and finally to identify the role of the College of Textiles, NCSU in effectively implementing this roadmap. The scope of this thesis covered the examination of Industry Technology Roadmapping process, including the selection process for panel members and preliminary identification of goals and challenges for the nonwoven medical textiles. Compiling the roadmap itself goes beyond the scope and time frame of this masters thesis.

Review of literature in part II of thesis showed that successful and forward-looking companies invest in research and development to gain and maintain a competitive edge. Since investment in technologies is a costly affair, it must be carefully carried out; not all investments in technologies generate expected benefits. Investments in technologies could fail due several reasons: a lack of understanding of the potential evolution of the technology or failure to update oneself on issues and implications from various angles prior to further investment.

It is important for industries to plan for technological innovation in accordance with changing market conditions and customer preferences. Technology Roadmapping is a consensus-driven process to identify, evaluate and select technology alternatives to satisfy the needs of a particular group of people. It serves as a high-level planning tool to
support the development, implementation and communication of technology development strategies and plans.

The literature review shows that an industry should develop an industry technology roadmap when:

- It is facing dramatically changing market demands
- The industry has reached a strategic juncture with regard to entering new markets, seeking out new technologies or acquiring new skills.
- Companies within the industry have a vision of their place in future markets but no strategy for making that vision tomorrow’s reality.
- Companies, or the industry, are facing uncertainty about what technologies and applications future markets will demand, and when new technologies will be needed.
- Lack of consensus among companies or within the industry on technology choices
- Each company within the industry is conducting separate R&D efforts devoted to technology problems, that all have in common.
- Individual companies within an industry sector lack the resources and skills needed to boost innovation, and would benefit from joint efforts in R&D, sourcing, or supply-chain arrangements.

Environmental scan showed that all of the above criteria fit to the nonwovens industry. USA is the currently the largest producer as well the consumer of nonwovens.
According to a new report from INDA, nonwovens production grew at an average of 7.5% a year during the 1990s. The global nonwovens production is forecasted to increase by 8.5% annually until 2006. Nonwovens are particularly important for the economy of North Carolina. This state has the more than twice the number of firms then its nearest competitor.

Two research designs were used to start the technology roadmapping process for nonwovens industry.

Research Design – Approach 1 consisted of two parts. Part I included data collection through secondary sources & interviews of NC State Faculty, industry experts and a survey of nonwoven companies. Survey instrument was distributed to the nonwovens firms at the Nonwovens Cooperative Research Center’s (NCRC) semi annual meeting. This survey was conducted to identify the (i) location factors of nonwovens plant to identify and (ii) a growing & challenging segment of nonwovens industry. Part II involved gathering of data through subsequent questionnaires about challenges faced by the industry in the “growing” nonwovens segments and possible solutions. Due to the low response rate in general and absence of core manufacturers in particular, results from this survey were not deemed useful for identifying a nonwovens segment with high growth potential. This approach had to be discarded in favor of a more result oriented one.

Research design - Approach 2 consists of five parts. Part I called for an environmental scan of nonwovens industry. Part II included development of a proposal for NITR, presentation of this proposal to potential partners, and finally recruitment of experts from industry, academia, industry associations and economic development committees to serve on the NITR panel. Data collection from the panel started from Part
III. In this step panel was asked to identify the challenges that nonwoven medical industry faces. Part IV consists of collecting data from the panel for responses to these challenges identified in Part III. The panel would identify possible rejoinders from the angle of work force, physical infrastructure, basic and applied research at Universities & research centers to deal with challenges. Part V comprises of data compilation into a roadmap document.

As per the scope of this thesis, Part I, II are completed whereas Part III is partially complete. Due to the presence of strong bio-medical cluster in North Carolina and because of a higher growth rate compared to other segments of nonwovens, members of the panel, formed in Part II, identified nonwovens medical textiles for pilot roadmapping effort.

Challenges identified by the panel are as follows:

- Rising raw material costs
- Sustainability of environment (Bio-degradability & Flushability)
- Life Cycle Study of Nonwovens
- Product Differentiation
- FDA Approval delays (cautions in product design)
- Public Awareness (promotion of the use of single use products)
- Exploration of new markets for Nonwovens
- Development of truly comfortable nonwovens attire
- Sterilization (reduction in use of Ethylene oxide)
- Reusable vs. Disposable materials
- Anti Microbial Treatments
- Clothing and textiles for disabled and elderly people
- Online Quality Inspections
Nonwovens Industry Technology Roadmapping Research Process

Part I
Environmental Scan Of Nonwovens Medical Textile Roadmapping Process

Part II
NITR Proposal Development & Presentation Recruitment for expert panel

Iterative process to keep the roadmap alive

Part III
Identification of Challenges Data collection from the Panel about challenges faced by the industry

Identification of Challenges
Academics

Part IV
Identification of Solutions Data collection from the Panel about possible technology alternatives.

Challenges Sent
Solutions Sent
Hospitals
Academics

Part V
Compilation of Roadmap Compilation of the roadmap document.

Roadmap Distribution to participants
Hospitals

Vision Strategic Software for Compilation

Iterative process to keep the roadmap alive

Figure 23: NITR-Research Process
Conclusion & Recommendations for Future Work

This study has been successful in achieving its stated purpose of examining the process by which an Industry Technology Roadmap (ITR) is developed and to start development of an elementary roadmap for the medical nonwoven industry. We have shown that roadmapping is very much relevant to nonwovens medical textiles and this technique can be applied as a collaborative planning tool for nonwovens industry. NITR panel consists of nonwovens industry and academic experts.

One of our finding was that the questionnaire survey technique does not work very well in soliciting the expert opinion from industry. A case study technique with selected nonwovens firms could be more beneficial.

Though the responses received so far from the NITR panel members are highly valuable, it is recommended to include and increase representation from health-centers (hospitals) and industry associations (INDA & EDANA) in the NITR panel. Active participation from hospitals, which are the major customers of nonwovens medical textiles, would provide an incentive for nonwovens firms to participate in the NITR panel, allowing them easy access to the voice of the customer. It is very important to gain industry championship for the roadmapping effort. The pilot roadmap resulting from future work could be presented to Industry Associations (INDA & EDANA) to request their active cooperation in preparing full fledge ITR for nonwovens.

In terms of the more specific objectives, the environmental scan of the nonwovens and medical textile industry enabled to achieve objective 1 of providing an overview of the process/product performance targets of the nonwovens industry. Some of the key points learned from achieving objective 1 i.e., environmental scan of nonwovens and medical textiles, are: i) increased consumer awareness & demand for environment
friendly products that are flushable, dispersible and biodegradable, ii) the effect on changing population demographics on the demand of nonwovens medical textile products and, iii) rising raw material prices and threats to the growth of nonwovens. Being the facilitator of the NITR, the College of Textile’s nonwovens roadmapping research team is recommended to remain current with on going developments in the nonwovens sector.

Objective 2 asks for determination of barriers /challenges for nonwovens industry. This objective was achieved through environmental scan of the nonwovens, and challenges identified by the NITR panel members. Some of the key points learned from this objective have been i) need for new, more efficient and economical and energy conserving processing technologies and design of products from renewable sources, ii) research requirements for developments of truly comfortable nonwovens attire and clothing and textiles for disabled and elderly people and, iii) research needs for developments of non petroleum based fibers. It is recommended to seek input from customers (hospitals) on their unmet requirements from medical nonwovens.

While environmental scan of nonwovens and medical textiles gave a good idea about general research requirements of nonwovens medical textiles, Objective 3, calling for prioritization of research and developments activities is achieved by inferring from the major challenges identified by the NITR panel members. A key learning from this objective is the importance of environmental scan of medical nonwovens and literature review of technology roadmapping. Firm knowledge about roadmapping process helps in soliciting the support of industry experts to be a part of the NITR panel. Moreover, an industry expert, willing to share his opinion expects the listener to have a good general knowledge about his area of expertise for effective and efficient communication. It is
recommended to the challenges identified by different NITR panel members be sent to them for mutually agreed prioritization.

Objective 4 calls for identification of the types of collaboration needed between the College of Textile and Nonwovens industry. This objective is achieved by inferring from the NITR panel responses. Problems identified by panel the NITR members can be research opportunities for the College of Textiles at North Carolina State University. Basic & applied research opportunities available at the College of Textiles offers the prospects of mutually beneficial partnerships with industry on challenges identified by the NITR panel. The roadmap document would help the College of Textiles with allocation of research funds on projects most desired by industry. A key learning form this objective is that while the College of Textile should facilitate the nonwovens technology roadmapping effort, the roadmapping should be championed by a nonwovens industry or research association (NCRC), enjoying greater influence with the nonwovens stake holders. It is recommended to approach Association of Nonwovens Fabric Industry (INDA) and Nonwovens Cooperative Research Center (NCRC) for roadmapping leadership.
Thesis Objectives and Learning

Objective 1
Overview of the process/product performance targets of the nonwoven industry

Objective Accomplishment
Objective 1 is achieved through Environmental scan of Nonwoven & Medical Textiles.

Key Learning

Future Work
Being the facilitator of the NITR, the College of Textile’s nonwoven roadmapping research team is recommended to remain current with on going developments in the nonwoven sector.

Objective 2
Determine the barriers/challenges for achieving these targets.

Objective Accomplishment
Objective 2 is achieved through Environmental scan of Nonwoven & Identification of challenges by NITR panel of experts.

Key Learning
Need for efficient & economical energy conservational processing technologies. Need for truly comfortable nonwovens attire for disabled & elderly people. Need for development of non-petroleum based fibers.

Future Work
It is recommended to seek inputs from customers (hospitals) on their insurer requirements from medical nonwovens.

Objective 3
Determine the priorities related to research and development for achieving targets.

Objective Accomplishment
Objective 3 is achieved by inferring from the major challenges identified by the NITR panel members

Key Learning
The importance of environmental scan of medical nonwovens and literature review of technology roadmapping in panel recruitment and communicating with industry experts.

Future Work
It is recommended that the challenges identified by NITR panel be compiled and sent back to them for mutually agreed prioritization of challenges.

Objective 4
Identify the types of collaborations needed between industry and the College of Textiles for achieving the targets.

Objective Accomplishment
Problems identified by the panel and the NITR members can be research opportunities for the College of Textiles at North Carolina State University.

Key Learning
While the College of Textiles should facilitate the nonwovens technology roadmapping effort, the roadmapping should be championed by a nonwovens industry research association such as INDA and/or NERC, ensuring greater influence with the nonwovens stake holders.

Future Work
It is recommended to approach Association of Nonwovens Fabric Industry (INDA) and Nonwoven Cooperative Research Center (NCRC) for roadmapping leadership.
Other Recommendations for Future Work

- It is recommended to use descriptive statistics and opinions of experts at the College of Textile to prioritize a limited number of challenges identified in Part III. These prioritized targets can be used for Part IV.

- In Part IV, it is suggested to ask the panel for the solutions of the challenges identified in Part III.

- The solutions from the panel can be compiled by section, using Alignent’s ‘Vision Strategist’ software. The first draft of the roadmap would be sent to the panel members along with plans for the next teleconference or email correspondence, with an agenda to discuss the draft section by section. Written comments on the first draft would also be requested. This would be critical stage in the process and the potential exists for separation of interests. Strong leadership is required to hold the panel together.

- Learning from this pilot roadmap for medical nonwovens can be applied to create roadmaps for other segments of textile in general and nonwovens in particular.
References


Appendix
## Appendix A- Tables

### Table A-1: US Apparel Production and shipment Data

<table>
<thead>
<tr>
<th>Product description</th>
<th>Quantity**</th>
<th>Value***</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>616,013</td>
<td>4,784.1</td>
</tr>
<tr>
<td><strong>Men's and boys' apparel:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suits</td>
<td>745</td>
<td>91.4</td>
</tr>
<tr>
<td>Coats</td>
<td>5,739</td>
<td>213.1</td>
</tr>
<tr>
<td>Tops</td>
<td>167,737</td>
<td>644.3</td>
</tr>
<tr>
<td>Bottoms (D*)</td>
<td>(D)</td>
<td>(D)</td>
</tr>
<tr>
<td>Underwear and nightwear.</td>
<td>33,405</td>
<td>63.8</td>
</tr>
<tr>
<td>Other garments</td>
<td>14,181</td>
<td>183.1</td>
</tr>
<tr>
<td><strong>Women's and girls' apparel:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dresses</td>
<td>26,190</td>
<td>596.4</td>
</tr>
<tr>
<td>Coats</td>
<td>2,453</td>
<td>86.9</td>
</tr>
<tr>
<td>Tops</td>
<td>94,083</td>
<td>755.2</td>
</tr>
<tr>
<td>Bottoms (D)</td>
<td>(D)</td>
<td>(D)</td>
</tr>
<tr>
<td>Underwear and nightwear.</td>
<td>56,032</td>
<td>664.3</td>
</tr>
<tr>
<td>Other garments</td>
<td>23,260</td>
<td>344.8</td>
</tr>
<tr>
<td><strong>Infants' apparel</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coats, jackets, vests, swimwear,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>And sweaters (D)</td>
<td>(D)</td>
<td>(D)</td>
</tr>
<tr>
<td>Dresses</td>
<td>477</td>
<td>6.3</td>
</tr>
<tr>
<td>Shirts, knit or woven</td>
<td>(D)</td>
<td>(D)</td>
</tr>
<tr>
<td>Sets</td>
<td>182</td>
<td>1.2</td>
</tr>
<tr>
<td>Pants and shorts (D)</td>
<td>(D)</td>
<td>(D)</td>
</tr>
<tr>
<td>Play clothing</td>
<td>1,454</td>
<td>4.3</td>
</tr>
<tr>
<td>Underwear (D)</td>
<td>(D)</td>
<td>(D)</td>
</tr>
<tr>
<td>Nightwear (D)</td>
<td>(D)</td>
<td>(D)</td>
</tr>
<tr>
<td><strong>Total Value of Production and shipments for Apparel</strong></td>
<td></td>
<td>3,678.9</td>
</tr>
</tbody>
</table>

Source: Census Bureau, retrieved on Sep 7, 2005 from http://www.census.gov/cir/www/315/mq315a.html

*D Withheld to avoid disclosing data for individual companies.

**Quantity in thousands of units. ***Value in millions of dollars.
<table>
<thead>
<tr>
<th>State</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Carolina</td>
<td>35</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>17</td>
</tr>
<tr>
<td>Georgia</td>
<td>12</td>
</tr>
<tr>
<td>New York</td>
<td>12</td>
</tr>
<tr>
<td>South Carolina</td>
<td>10</td>
</tr>
<tr>
<td>New Jersey</td>
<td>8</td>
</tr>
<tr>
<td>Michigan</td>
<td>6</td>
</tr>
<tr>
<td>Virginia</td>
<td>3</td>
</tr>
</tbody>
</table>


Note: For North Carolina, the number of firm are referenced from Easley, 2005, while Pourdeyhimi, 2004 is the reference for all other states.
Table A-3: 2003 Staple Fibre and Spunlaid Resins consumption

<table>
<thead>
<tr>
<th>Spunlaid Resins</th>
<th>Volume (Million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>344</td>
</tr>
<tr>
<td>Polyester</td>
<td>94</td>
</tr>
<tr>
<td>Polyethylene and Nylon</td>
<td>52</td>
</tr>
<tr>
<td><strong>Total Resins</strong></td>
<td><strong>490</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Staple Fibers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>199</td>
</tr>
<tr>
<td>Polyester</td>
<td>152</td>
</tr>
<tr>
<td>Rayon</td>
<td>40</td>
</tr>
<tr>
<td>Bicomponent, Nylon, other</td>
<td>69</td>
</tr>
<tr>
<td><strong>Total staple fiber</strong></td>
<td><strong>460</strong></td>
</tr>
</tbody>
</table>

| Wood pulp                    | 141                      |
| Miscellaneous                | 17                       |

| **Total All Fibers and Spinning Resins** | **1108** |

### Table A-4: Import Export Analysis for US nonwovens

(Billion Dollars)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Imports</td>
<td>0.73</td>
</tr>
<tr>
<td>Total Exports</td>
<td>1.37</td>
</tr>
<tr>
<td>Trade Balance</td>
<td>0.63</td>
</tr>
<tr>
<td>Exports as a % of imports</td>
<td>187.49%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technical Textile</th>
<th>NAICS</th>
<th>Number of Plants</th>
<th>Annual Average Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonwoven Fabric Mills</td>
<td>31323</td>
<td>23</td>
<td>30%</td>
</tr>
<tr>
<td>Fabric Coating Mills</td>
<td>31332</td>
<td>17</td>
<td>12%</td>
</tr>
</tbody>
</table>

Appendix B: Research Design Details for Approach 1

Appendix B1: Instrument development

The interviews with the industry, COT faculty members, and North Carolina State economic development committee officials led to development and validation of the survey instrument. An extensive literature review was conducted in order to develop the plant location survey instrument for Part II of the research. This led to identification of factors important to plant location decision from a nonwoven company’s perspective. By location factor we mean an advantage which is gained when an economic activity takes place at a particular point or at several such points rather than elsewhere” (Weber, 1929). Weber continued his argument by stating that an advantage was a saving of cost of any kind. Today, the definition of advantage has changed drastically. Many other evaluation criteria have evolved other than cost, like quality, lead-time, etc.

INDA identifies six major end market groups for short-life nonwovens materials, which include: absorbent hygiene, wipes (wet and dry), medical, air filtration, wet filtration and disposable apparel (INDA Estimates, 2004). Because of limited time and resources it was difficult to do a industry wide technology roadmap. So it was decided to identify and focus on a specific segment of nonwovens industry through the survey instrument.

**Appendix B2: Institutional Review Board (IRB) Approval**

Institutional Review Board (IRB) of NC State University works for Protection of Human Subjects in Research. It is obligatory for all researchers to gain IRB’s approval before contacting firms or individuals for data collection. After administrative review, the IRB office determined that the study is exempt from the federal regulations outlined in 45CFR46, which relate to the protection of human subjects, and qualifies for administrative approval. The study does not require further IRB review.

The official letter declaring the study exempt from 45CFR46, and administratively approving the study, is pasted on the next page.
From: Debra A. Paxton, Regulatory Compliance Administrator
North Carolina State University
Institutional Review Board

Date: November 8, 2005

Project Title: Technology Roadmap of Nonwovens Industry
IRB#: 243-05-11

Dear Mr. Amir:

The research proposal named above has received administrative review and has been approved as exempt from the policy as outlined in the Code of Federal Regulations (Exemption: 46.101.b.2). Provided that the only participation of the subjects is as described in the proposal narrative, this project is exempt from further review.

NOTE:
1. This committee complies with requirements found in Title 45 part 46 of The Code of Federal Regulations. For NCSU projects, the Assurance Number is: M1263; the IRB Number is: 01XM.

2. Review de novo of this proposal is necessary if any significant alterations/additions are made.

Please provide your faculty sponsor with a copy of this letter. Thank you.

Sincerely,

Debra Paxton
NCSU IRB
Appendix B3: Survey Instrument

Survey for Business Location Factors

Company Name: Date:

1Q- Please select the appropriate box that best describes the position of your firm in the Nonwovens supply chain

- Raw material suppliers
- Roll goods manufacturer
- Converter
- Machinery Manufacturer
- Others

Q2- R&D Percentage of Total Expenditures (%):

- 0-5
- 6-10
- 11-15
- 16 & more

Q3- Which techniques does the firm use for plant location decisions? (Select all that apply)

- Customer / Market Research Decision Trees
- Scaling Scoring Ranking / Delphi Methods / Scenario Analysis
- Analytic Hierarchy Process / Mathematical Programming
- Other (please, specify)

Q4- Thinking about your company's most recent plant location decisions, how effective were your company's techniques?

- Not effective
- Somewhat effective
- Effective
- Very effective
Please recall your company's NC plant location decision, and answer questions 5-7 based on that project.

Q5- Who gave the final decision about the final location?

<table>
<thead>
<tr>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project group and CEO</td>
</tr>
<tr>
<td>CEO</td>
</tr>
<tr>
<td>CEO and board members</td>
</tr>
<tr>
<td>All of the above</td>
</tr>
<tr>
<td>Others: Please list:</td>
</tr>
</tbody>
</table>

Q6- Companies generally commission a project report to achieve consensus of top management on plant location decisions. If your company used such a report, how would you gauge its contribution to final decision?

<table>
<thead>
<tr>
<th>Contribution Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
</tr>
<tr>
<td>Only slightly contributed</td>
</tr>
<tr>
<td>Somewhat contributed</td>
</tr>
<tr>
<td>Very much contributed</td>
</tr>
</tbody>
</table>

Q7- Was there a specific organizational value, belief and/or principle that affected the decision?

<table>
<thead>
<tr>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>If yes, please specify</td>
</tr>
</tbody>
</table>

On a scale from one to four, with "4" being very important and "1" being unimportant, please specify the importance of the following location factors in your company's NC plant location decision

<table>
<thead>
<tr>
<th>Infrastructure Factors</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>State local industrial climate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land availability / Room for expansion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of labor and construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity availability/ Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public welfare treatment capacity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scientific and technological infrastructure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximity to markets</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q9-</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Market Factors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximity to suppliers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access / Availability to raw material</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing similar businesses</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength of local demand</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximity to Services</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximity to markets</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q10-</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transportation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roads/HW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Transportation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability of Sea Port</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q11-</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Environmental Laws</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental regulations/Permit process</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid hazardous waste treatment facilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q12-</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Labor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor productivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled labor availability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unskilled labor availability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability of middle management</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability of technical training programs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q13-</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Law &amp; Regulations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business taxation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State financial incentives</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Administrative infrastructure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Admin/Bureaucracy, permits, etc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q14-</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quality of Life</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability of universities, colleges, schools</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Q15- Please specify, if there were any other reasons for your choice of North Carolina for plant location.

Q16- On a scale from one to four, with "4" highly valuable and "1" being worthless, Please specify if you think it is of value for your company to have other nonwoven companies establish in the same region where your plant is located?

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Q17- Which other states did you consider for plant location?

Q18- Please specify the nonwovens sector which, in your view, has the highest potential for growth (please feel free to elaborate)

| Automotive                  |
| Filters                     |
| Home Applications           |
| Health Care – Hospital      |
| Health Care – Consumer      |
| Industrial                  |
| Wipes                       |
| Others (please specify)     |

Thank you very much for your consideration.
Appendix B4: Data Gathering

Sample Selection

The sample for this research was the nonwoven firms located in USA.

Product Category

Data would be gathered from Nonwoven mills engaged in production of raw material, roll goods, finished goods, and other supplies.

Size

The sample size is 40, made up of nonwoven firms that are members firms of Nonwovens Cooperative Research Center\(^1\). NCRC’s present membership stands at 53 and this include the Nonwoven firms located in North Carolina. To avoid duplication, each firm would only be surveyed once.

Pre Test

Besides survey instrument validation for the instrument was obtained from Dr. Hergeth, Dr. Pourdeyhimi, Dr. Ted Morris of NCSU development committee. A nonwovens converter based in Hickory North Carolina, was approached for the pre-test of the survey instrument. Certain changes were made to the survey based upon the recommendation gathered during instrument validation and pre-test.

Location Selection & Data Collection

Two main strategies were used to approach the nonwovens companies.

\(^1\) The Nonwovens Cooperative Research Center (NCRC) was established as a State/Industry-University Cooperative Research Center (State/IUCRC) in 1991 as a result of a grant from the National Science Foundation (NSF). NCRC is located in Centennial campus of NCSU.
i) Survey instrument was mailed to nonwovens companies satisfying the sample criteria of having a production plant in NC or USA.

ii) Nonwovens companies were approached at the semiannual Nonwovens Cooperative Research Center meeting. This meeting was held on November 2 & 3, 2005, in the College of Textiles.
Appendix B5: Survey Results

Sample Description

Despite sending reminder letter to potential participants, only three responses were received. Reminder cover letter included at the end of results. The sample comprised of two raw material suppliers and a product development company of nonwoven industry. Information about the survey respondents is shown in Table 1. Company names are masked to ensure the confidentiality of the participated companies.

Table 1: Sample Description of Survey Respondents

<table>
<thead>
<tr>
<th>Company Name</th>
<th>Position in nonwovens supply chain</th>
<th>Plant Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Product Development &amp; IP management</td>
<td>NC</td>
</tr>
<tr>
<td>B</td>
<td>Raw Material Supplier</td>
<td>SC</td>
</tr>
<tr>
<td>C</td>
<td>Raw Material Supplier</td>
<td>TN</td>
</tr>
</tbody>
</table>

Results

Responses were analyzed according to the research objectives of the study. The Objectives are to determine the effects of different dimensions on location factors for nonwovens industry, ascertaining

i) The existing appeals which motivate nonwovens companies to chose North Carolina as the site for plant location; &

ii) How North Carolina can be made further attractive for relocation of nonwoven industries

The first seven questions of the survey instruments were designed to identify the firm’s position in nonwoven supply chain, its commitment to R & D and techniques & effectiveness of its location decision-making process. Due to small size this data is reported in tabular form. With
the expected increase in number of responses, author plans to use descriptive statistics for identification of location decision-making process trends in nonwoven industry.

**Survey Results**

**Position in Nonwovens supply chain & commitment to R & D.**

1Q- Please select the appropriate box that best describes the position of your firm in the Nonwovens supply chain

<table>
<thead>
<tr>
<th>Position</th>
<th>A – NC</th>
<th>B – SC</th>
<th>C - TN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material suppliers</td>
<td>Others</td>
<td>Raw Material Suppliers</td>
<td>Raw Material Suppliers</td>
</tr>
<tr>
<td>Roll goods manufacturer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Converter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machinery Manufacturer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Company Responses**

- A – NC: Others- Product Development & IP management
- B – SC: Raw Material Suppliers
- C - TN: Raw Material Suppliers

2Q- R&D Percentage of Total Expenditures (%):  

<table>
<thead>
<tr>
<th>Percentage</th>
<th>A - NC</th>
<th>B - SC</th>
<th>C - TN</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>16 or more</td>
<td>6 - 10% of sales</td>
<td>16 or more</td>
</tr>
<tr>
<td>6-10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11-15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 &amp; more</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Techniques, responsibilities & effectiveness of location decision-making process**

3Q- Which techniques does the firm use for plant location decisions? (Select all that apply)

<table>
<thead>
<tr>
<th>Technique</th>
<th>A - NC</th>
<th>B - SC</th>
<th>C - TN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer / Market Research Decision Trees</td>
<td>16 or more</td>
<td>6 - 10% of sales</td>
<td>16 or more</td>
</tr>
<tr>
<td>Scaling Scoring Ranking/ Delphi Methods / Scenario Analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analytic Hierarchy Process / Mathematical Programming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (please, specify)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Q4**- Thinking about your company's most recent plant location decisions, how effective were your company's techniques?

<table>
<thead>
<tr>
<th>Not effective</th>
<th>Somewhat effective</th>
<th>Effective</th>
<th>Very effective</th>
</tr>
</thead>
</table>

**Company Responses**

<table>
<thead>
<tr>
<th>A - NC</th>
<th>NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>B - Sc</td>
<td>Other - Company property</td>
</tr>
<tr>
<td>C - TN</td>
<td>Scaling Scoring Ranking/ Delphi Methods / Scenario Analysis</td>
</tr>
</tbody>
</table>

Please recall your company's plant location decision, and answer questions 5-7 based on that project.

**Q5**- Who gave the final decision about the final location?

<table>
<thead>
<tr>
<th>Project group and CEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEO</td>
</tr>
<tr>
<td>CEO and board members</td>
</tr>
<tr>
<td>All of the above</td>
</tr>
<tr>
<td>Others: Please list:-</td>
</tr>
</tbody>
</table>

**Company Responses**

<table>
<thead>
<tr>
<th>A - NC</th>
<th>NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>B - SC</td>
<td>All of the above</td>
</tr>
<tr>
<td>C - TN</td>
<td>Project group &amp; CEO</td>
</tr>
</tbody>
</table>
Q6- Companies generally commission a project report to achieve consensus of top management on plant location decisions. If your company used such a report, how would you gauge its contribution to final decision?

<table>
<thead>
<tr>
<th>Contribution Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
</tr>
<tr>
<td>Only slightly contributed</td>
</tr>
<tr>
<td>Somewhat contributed</td>
</tr>
<tr>
<td>Very much contributed</td>
</tr>
</tbody>
</table>

**Company Responses**

<table>
<thead>
<tr>
<th>Company</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>A – NC</td>
<td>NA</td>
</tr>
<tr>
<td>B – SC</td>
<td>Somewhat contributed</td>
</tr>
<tr>
<td>C – TN</td>
<td>NA</td>
</tr>
</tbody>
</table>

Q7- Was there a specific organizational value, belief and/or principle that affected the decision?

<table>
<thead>
<tr>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>If yes, please specify</td>
</tr>
</tbody>
</table>

**Company Responses**

<table>
<thead>
<tr>
<th>Company</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>A – NC</td>
<td>NA</td>
</tr>
<tr>
<td>B – SC</td>
<td>Yes—did not specify</td>
</tr>
<tr>
<td>C – TN</td>
<td>No</td>
</tr>
</tbody>
</table>

Questions 8 to 14 were designed to determine the preferences of nonwovens industry for site location factors. Location factors that are grouped under the following seven categories: Infrastructure Factors, Market Factors, Transportation, Environmental Laws, Labor, Law & Regulations, and Quality of Life cost. Again due to small sample size, data is reported in the form of radar charts and firm’s plant location is used for classification of nonwoven firms. With the expected increase in number of responses, author also plans to classify location factors on the basis of Nonwovens firm’s position in the supply chain. Furthermore, mean comparison of plant
location factors would also be conducted based site location and position in supply chain of the nonwoven firms.

On a scale from one to four, with "4" being very important and "1" being unimportant, participants were asked to specify the importance of the location factors in their company's recent plant location decision.

The scores of each variable affecting a location factor is depicted using a radar (spider) chart. This graphical representation is selected because one can easily see the overall inclination of the sample and the specific values of the variables and their difference from the maximum and the minimum value in one chart. In this chart, the value increases from the center to the outer layers of the chart. The value differs from 0 to 4 since this scale was used to rank the variables in the survey (1 = UNIMPORTANT, 2 = LESS IMPORTANT, 3 = IMPORTANT, 4 = VERY IMPORTANT). The number of the corners of the chart is equal to the number of the variables in a group. In other words, the corners of the chart represent the variables.
Site location Factors

Q. 8 - Infrastructure Factors

Figure 1: Infrastructure Factors

Q9 - Market Factors

Figure 2: Market Factors
Q10 - Transportation

Figure 3: Transportation

Q11- Environmental Laws

Figure 4: Environmental Laws
Q12 – Labor

Figure 5: Labor

Q13 - Law & Regulations

Figure 6: Law & Regulations
Other Reasons

Question 15 is designed to uncover if there were any other reasons for participants choice of a particular location. The results would help understand the factors, if any, beyond the classical decision location theory. Following are the results

Company Responses

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A- NC</td>
<td>Proximity to family</td>
</tr>
<tr>
<td>B - SC</td>
<td>Existing company complex</td>
</tr>
<tr>
<td>C – TN</td>
<td>No</td>
</tr>
</tbody>
</table>

Existing Industry as a Marketing Tool

Question 16 is intended to determine the participation of the existing industry in attracting more firms in a region. On a scale from one to four, with "4" highly valuable and "1" being worthless, Participants were asked to specify if they think it is of value for their company to have other nonwoven companies establish in the same region where their plant is located. This
question would also provide an insight on the understanding of Nonwoven industry on the importance of clusters.

**Figure 8: Nonwoven's Industry - Importance of Cluster**

![Bar chart showing the importance of clusters in nonwoven industry with values 4 for A-NC, 3 for B-SC, and 2 for C-TN]

**Competitors States**

**Question 17** attempts to determine what other states firms considered for site location. Results would help Wake County and NC State economic development committees to understand their competitors in attracting nonwovens industry. Following are the results:

<table>
<thead>
<tr>
<th>States</th>
<th>Competitors</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-NC</td>
<td>NA</td>
</tr>
<tr>
<td>B-SC</td>
<td>TX---another company complex</td>
</tr>
<tr>
<td>C-TN</td>
<td>SC, NC</td>
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**Identification of Product Category for Product Technology Roadmap**

**Question 18** seeks to determine the nonwovens product category that is most valued by the nonwovens industry. Participants were asked to specify the nonwovens sector, which, in their view, has the highest potential for growth. Result of this question would help College of Textile, NCSU allocate resources to better serve the nonwoven industry. Results would also provide a
product category for the purpose of starting research on a product technology roadmap for Nonwoven Industry.

<table>
<thead>
<tr>
<th>Product Category</th>
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<tbody>
<tr>
<td>Automotive</td>
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<tr>
<td>Filters</td>
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<tr>
<td>Home Applications</td>
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<tr>
<td>Health Care – Hospital</td>
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<tr>
<td>Health Care – Consumer</td>
</tr>
<tr>
<td>Industrial</td>
</tr>
<tr>
<td>Wipes</td>
</tr>
<tr>
<td>Others (please specify)</td>
</tr>
</tbody>
</table>

**Company Responses**

- A - NC  Automotive & Industrial
- B - SC  Apparel & Filters
- C – TN  Consumer Health Care
October 25, 2005

Ladies and Gentlemen:

Since you are one of the primary decision makers for (company name), we would like to request your participation in a research study about plant location decisions. This research is a collaboration between Wake County Economic Development, NCSU Economic Development, and the College of Textiles. Results of this study would help to develop a comprehensive “plant location factors list” categorized according to the strategies of the nonwoven companies, thus enabling

- Wake County and NCSU economic development committees to focus on the factors most relevant to the Nonwovens industry to develop existing and recruit potential clusters.
- The College of Textiles to identify the types of collaborations with the Nonwovens industry and allocation of research and development resources to better serve nonwoven industry.

This scale of decision-making often involves the input of several department leaders. Therefore, if you feel someone else in your company might be better suited to complete this survey, we request that you forward this survey to someone in your company who you consider the most appropriate respondent.

Your responses will be treated completely confidential. All data will be reported in aggregate form to ensure that no individual companies can be identified. An executive summary of the survey results will be sent to you after completion of the project. If for some reason you prefer not to respond, please let us know by sending a brief note to the contact address.

Thank you very much for helping this important project.

Sincerely,

Asad Amir
MS. Student & Research Assistant
aamir@ncsu.edu
(919) 413-5506

Helmut H. Hergeth, Ph.D.
Associate Professor
hhh@ncsu.edu
(919) 515-6574
College of Textile Faculty Interviews Summary

This paper is the summary of interviews of select College of Textiles (COT) faculty members. Ms. Sang Won Chung, MS graduate student previously assigned to the Wake County Economic Development Project, conducted these interviews during Fall 2004. The aim of the questions were to assess the value that the College of Textiles brings in marketing Wake County to prospective nonwoven firms, and in particular, nonwoven firms associated with the medical textile industry.

The list below constitutes interview participants:

- Dr. Pamela Banks-Lee
- Dr. Bhupender Gupta
- Dr. Martin King
- Dr. Wendy Krause
- Dr. Stephen Michielsen
- Dr. Behnam Pourdeyhimi

Five standard questions were put to the faculty members. Following is the synopsis of their replies:

Q1. **What are the strong points of College of Textiles that could be used as a selling point for collaboration? What do we do best? / What can we offer?**

- The largest textiles college in the U.S. in terms of number of students, research budget, mass activities and publications.

- Medical Textiles
  - Highest experienced faculty in medical textiles
  - New curriculum for ‘Medical Textiles’. At least 14 courses are being offered.
  - Bio Medical Textile Initiative- An on going research effort.

- NCRC-52 industrial partners: World’s leading research centre for non-wovens focused on research, product development and training aimed for the industry with facilities (pilot) located only here for the partners to use. There are already trained operators; the companies only have to pay the fee per hour of usage. The benefits for the Industry are
  - Research Cost Avoidance.
  - Research Amplification
  - Non-core Research Cost Reduction
Q2. In terms of research, are there pieces in your own research that could encourage this collaboration?

**Medical Textiles**
Efforts are underway to collaborate with the department of Biomedical Engineering/Vet school of NCSU and hospitals of Duke and UNC & Wake Med Hospital. Research is being carried out in the following areas:

- Surgical sutures
- Tissue engineering
- Prosthetic ligaments
- Vascular grafts

**Non-wovens**
Research is being carried out in the following areas:

- Performance properties and modelling of nonwoven materials (insulates)
- Product development and Characterization
- Surface modification.
- The development of new materials
- The modification of existing materials
- Basic studies that lead to a better understanding of technologies
- Applied research directed at process material - property relationships
- The development of instrumentation and test methods for nonwoven fabrics

Q3. What is your perception of how this collaboration would actually look like? How do you envision the collaboration? (Ex. Education/Research/Extension collaboration)

**Education**

- Currently 6 courses, leading to a certificate, are offered related to nonwoven materials.
- New courses and presentations targeted to the industry’s interest.
- Education-internships
- Extension-courses for the industry in medical textiles.
- Teaching/Present seminars targeted to the industry’s interest

**Research**

- Joint project (company being the sponsor)
- Sponsoring student projects
Helping industry in applied research, giving them long-term answers in basic research.
Technology transfer and consultation services.

**Bio Medical Textile Initiative**
Research Consortium (Medical textile initiative)-School acting as a coordinator like NCRC to form an industry-university partnership. In addition, it will generate new company/company interactions and liaisons. It will be attractive in terms of putting the whole supply chain together, combining variety of different expertise, being industry driven and monitored. The goal of the consortium will be to undertake fundamental and applied research on the basic technologies and business decision-making processes, and to support the industries, needs.

**Q4. What kind of resources will be needed to facilitate this kind of collaboration?**
- Release time-Reducing the teaching loads to have time for research
- Laboratory space & Lab facilities
- Money to sponsor more student projects
- Pilot facilities
  - More faculties specializing in nonwovens

**Medical Textiles**
- New books (Literature)
- Equipments for testing to establish medical textiles evaluation lab.
- Pilot facility with clean room, fabrication, sterilization and packaging line creating a medical textiles incubator to make novel prototype will be wonderful.
- FDA in the campus

**Q5. Are there other people or institutions you think could be involved in this collaboration?**
- Department of Biomedical Engineering
- Department of Wood & Paper science
- Department of Chemical/Mechanical Engineering
- Department of Industrial Engineering
- Department of Chemistry
- Physics Engineering
- VET School & Duke/UNC/Wake Med Hospital
- Animal lab, Clinical work
- Dr. Russell Gorga
- Dr. Juan Hinestroza
- Dr. Hudson (Textile Chemistry)
- Dr. McCord (Surface modification)
- Dr. Gary Smith (Knitting)
Appendix D: Nonwovens Industry Technology Roadmapping Proposal

The nonwoven fabrics industry is one of the fastest growing sectors of the textile business. Today this trade is challenged with problems with landfills and waste disposal, the development of environmentally friendly, multi functional and non-petroleum based raw materials and rising international competition to name a few. It is crucial to identify the current situation of this industry and assess the future technological, workforce, innovation, and infrastructure requirements needed to sustain the growth and longevity of the industry. An increasing number of firms and industries are using Industry Technology Roadmaps (ITR) to obtain an assessment of their technological needs.

What is Technology Roadmapping?
Technology roadmaps are strategic plans that help to align research, development, and the application of technology with business goals. Through the process of roadmapping, organizations can collaborate on their vision for future products, technologies and capabilities. Unlike scenario planning, trend extrapolation and historical analogy where the end-point is forecast, road-mapping starts with a goal or vision clearly in mind and then draws different technology paths to achieve it.

Uses of a Technology Roadmap
Technology roadmaps are used by forward-looking companies and industries to:

- Foster collaborative solutions to complex scientific and technological challenges
- Draw upon the collective knowledge and expertise of science, business, and policy leaders
- Uncover critical R&D and knowledge gaps
- Prioritize promising technology solutions within distinct time frames
- Outline strategies for supporting multiple solutions and pathways
- Initiate partnerships that align and focus resources
- Communicate clear science and technology priorities to a broad community

Benefits of a Technology Roadmap for Individual Companies and Complete Industries

- Roadmaps can serve as a marketing tool. They can show if a company really understands customer needs and has access to or is developing the technologies (internally or through alliances) to meet their customers’ needs.
- Roadmapping integrates the talents of diverse stakeholders to solve some of today's most challenging science and technology problems. Practitioners often assert that the roadmapping “process” is at least as valuable as the roadmap itself.
- Roadmapping helps the industry work collaboratively, e.g., when a technology is too expensive to be supported by a single company or if it is taking too long to develop an objective with justifiable resources.
Roadmaps guide basic scientific research and government funding. Roadmaps can also be used to convince government funding agencies to support scientific research that will address long term technology barriers or to remove infrastructure barriers.

How to develop an Industry Technology Roadmap for Nonwovens

Roadmaps can be developed on a corporate as well as an industrial level. In either case a team of experts from industry, research institutes, academic entities, and government come together to identify:

- The process/product performance targets of the industry
- What the technology barriers/challenges are for achieving these targets
- What the priorities related to Research and Development are for achieving targets
- What types of collaboration are needed between industry, academia, government, and other stakeholders

Roadmapping can help enhance prospects for economic growth for an entire industry sector through collaborative efforts at innovation and technological development.

To create a Nonwovens Industry Technology Roadmap, industrial cooperation is needed in the following way

- Identify 1 or 2 key people in your corporation as a link to the Nonwovens ITR who can share in the product, technology, and marketing areas.
- Identify areas of relevance in the sciences for the nonwovens industry.
- Identify aspects of infrastructure relevant to the nonwovens industry.
- Allow for the participation in 1 to 2 day workshops and occasional follow-up questions via e-mails or phone calls over a period of one year. A second workshop could be via conference calls if preferred.
- All NITR members will be updated regularly via e-communication.

Contact Information:
Dr. Helmut H. Hergeth & Asad Amir, Box 8301 College of Textiles, Raleigh, NC 27695, hhh@ncsu.edu, 919-515-6574
Appendix E: Medical Textiles Conference 2004

Key Points
Asad Amir, Graduate Student
Submitted: April 26, 2005

To address market demand and new textile applications in surgery and medicine, Medical Textiles Conference 2004 was held in conjunction with IFAI Expo 2004 at the David L. Lawrence Convention Center in Pittsburgh, Pennsylvania, USA, from 26-27 October 2004. The theme of the conference was ‘Advances in Biomedical Textiles and Healthcare Products’. Following is the summary of conference proceedings from the presentations of the participants. References alongside each heading can be traced to the presentations and authors listed at the end of this document.

Trends [Ref: 1, 20]

- Today the Global market for medical textiles is worth around US$ 6.3 billion. Consuming 1.8 million metric tons of fiber. Source: David Rigby Associates Data.
- Medicare’s spending as a share of GDP could more than treble by 2050. Total federal budget spending on health care will soar according to a government forecast. Source: Peter Kilduff, PhD, UNC
- Home care is growing. Six percent in 1992, 11% Eleven percent in 2000 and 35% in 2012.
- Primary drivers in health care cost hike are: Technology changes (product and process innovation) 47% and Medical product inflation 19%.
- Because of aging population, rise in disposable income and trend towards home care medical textiles and bio-textiles are growing markets in USA. Technology for medical textiles is expensive and still evolving but profit margins are high.
**Work Force Requirement [Ref: 1]**

Professional and management occupations combined will account for 40% of all new jobs. Thirty five percent of jobs in fastest growing occupations require college degrees. Unemployment rate for college-educated workers is already 3.4% and for hospital workers it is 1.4%. Where will workers come from?

**Globalization of US health care [Ref: 1, 3]**

Consequences of domestic skill shortage of college-educated workers would increase the probability of health care professional to be foreign born of trained. So there would be less homogenous skill base and a heterogeneous workforce. Health care industry would be more culturally diverse. Product standards are expected to move to international stage. Because of skill shortage older workers would be in demand and they would be resistant to new technology adoption.

Products should be designed for self-administered settings and for lower skilled delivery and/or follow-up.

**Institute of Healthcare Improvement (IHI) [Ref: 2, 23]**

Quality issues are emphasized in healthcare. The Institute for Healthcare Improvement (IHI) is a not-for-profit organization driving the improvement of health by advancing the quality and value of health care. Founded in 1991 and based in Cambridge, Massachusetts, IHI offers comprehensive products and services. IHI holds an Annual National Forum that is the best way to learn of trends in healthcare in a week. The 17th National Forum would be held in Orlando, FL, USA through 11 to 14 of December 2005.
College of Textiles, NCSU [Ref: 2, 6, 7, 8, 14, 23, 24]

T-PACC, NCSU

- NC State houses Textile Protection and Comfort Center (T-PACC) that recently unveiled the new generation of firefighter’s turnout gear. It offers not only the protection from fire but also provides protection from chemical and biological weapons.

Medical and bio-textiles at COT, NC State

- New medical textiles and bio-textiles concentrations are introduced in almost all undergraduate degrees.
- Graduate programs in medical textiles and bio-textiles are being developed
- New research facilities are being added – some joint with new Biomedical Engineering Department.
- Joint research programs with outside originations are being created.
- Close tie with Biotech Center are being created
- Internships with healthcare organizations started

Medical Textile Grant

- The College of Textiles received an industry testing contract in Oct 2004.
- A major medical device company approached the college of Textiles and solicited faculty research expertise in converting a novel biomedical polymer into fibrous/textile structure for bio-textile application.

Current Medical textiles and Bio-textiles Research at NC State

- Surgical Sutures
- Vascular Grafts
- Ligaments
- Prostheses based on natural tissues
- Micro denier fiber for use in prostheses
- Cardiovascular Implants
- Antimicrobial fabric technologies

**Nonwovens Cooperative Research Center (NCRC), NCSU**

- NCRC has received a new grant from the Air Force to develop large area deployable structures (large tents) from Nonwovens. The structures will be made from novel Nonwovens that will have very specific properties including high tear resistance and environmental resistance.

- NCSU worked closely with the researchers of DuPont in development of Suprel™, a highly protective and comfortable fabric used for hospital operating gowns and patient drapes. Comfort studies conducted on operating room nurses were carried out in NCSU.

- Freudenberg Nonwovens’ Novolon Dimensional Fabric Division will manufacture three-dimensional nonwoven fabrics utilizing a patent pending technology developed by NCSU.

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**Other Opportunities [Ref: 2, 4, 6, 7, 8, 11, 21, 22]**

- Manikin design and application of new quality methodologies
- Transportation
- Electro-textiles and sports-textiles
- Environmental Textiles
- New fibers and Fabrics: Super strong nylon fibers created at NC State.
- New finishing methods.
- Nano and Conductive fibers
References and Contacts

1- Future Trends in the Delivery of Medical and Healthcare Services
Presenter: Richard O’ Sullivan, Center for Civil Society Studies, John Hopkins University

2- Quality Management in the Healthcare Sector
Presenter: Dr. Blanton Godfrey, College of Textiles, North Carolina State University

3- Regulatory Issues: FDA and International Requirements
Presenter: Elaine Duncan, Paladin Medical Inc.

4- Performance of Polymers, Fibers and Textiles in Medicine
Author: Dr. Bhupender Gupta, North Carolina State University

5- Novel Materials, Biopolymers and Resorbables
Author: Dr. Shalaby W. Shalaby, Poly-Med Inc.

6- Clinical Performance of Suture Materials
Author: Dennis Jamiołkowski, Ethicon Inc.

7- Recent Developments in Suture for Healing
Author: Dr. C.C. Cu, Cornell University

8- Barbed Suture Technology: Recent Advancements
Author: Dr. Jeffery Lueng, Quill Medical

9- Historical Perspective of Vascular Prostheses, Structures and Coatings
Authors: Dr. Robert Guidoin, Lavall University, Quebec and Dr. Martin King, NCSU

10- Endovascular Stent-Graft Developments
Author: Dr. Roy Greenberg, Cleveland Clinic

11- Vascular Scaffolds Using Biomimetic Design
Author: Dr. Vladimir Mironov, Medical University of South Carolina

12- Smart Bandages for Orthopedic Support
Author: Dr. Volkmar Bartels, The Hohenstien Institutes, Germany

13- Prosthetic and Orthotic for Repair and Rehabilitation of Sports Injuries
Author: Shitij Chabba, BSN Medical Inc.

14- Antimicrobial Strategies for Woundcare Products
Author: W. Curtis White, Aegis Environments

15- Approaches to Controlling Micro-organisms in Hospital Trends
Author: Dr. Stephen Micheilson, North Carolina State University

16- Future Structures and Properties of Mechanism of Wound Dressing
Dr. Vincent Edwards, U.S. Department of Agriculture, Southern Regional Research Center

17- Standards and Specifications for Protective Barrier Fabrics
Author: Bradley Bushman, Standard Textile Inc.
18- *Hospital Requirements for Infection Control*
Author: Dr. Sylvie Trottier, Center de Research en Infetiology, Quebec, Canada

19- *Market Segmentation: Disposable vs. Reusable*
Author: Bradley Bushman, Standard Textile Inc.

20- Market Status and Growth Opportunities for Hygiene and Healthcare Products
Author: Dr. Peter Kilduff, University of North Carolina

21- *Wearable Healthcare Systems*
Author: Dr. Rita Paradiso, Smartex srl., Italy

22- *The Next Generation of Materials – Genetically Engineered, Nano- and Conductive Fibers*
Authors: Dr. Steve Warner, University of Massachusetts – Dartmouth; Dr. Jaffe, New Jersey Institute of Technology


24- College of Textiles, NCSU Website: www.tx.ncsu.edu

25- *Nonwovens Cooperative Research Center (NCRC)*
Behnam Pourdeyhimi
Director
2401 Research Drive
College of Textiles
North Carolina State University
Raleigh, NC 27695-8301
Phone (919) 515-6551

26- *Textile Protection and Comfort Center (T-PACC)*
Dr. Roger L. Barker
Director
North Carolina State University
College of Textiles
Center for Research on Textile Protection and Comfort (T-PACC)
Box 8301
Raleigh, NC 27695-8301

27- *Bio/Medical Textiles Initiative*
Dr. Bhupender S. Gupta & Dr. Martin King.
College of Textiles
North Carolina State University.
Appendix F: NITR Invitation

Dear ____________:

In collaboration with Wake County’s Office of Economic Development and the NC State Office of Economic Development, the College of Textiles is working on a Nonwovens Industrial Technology Roadmap project. The nonwovens industry is one of the fastest growing sectors of the textile business. As a fairly new industry, it is crucial to identify the current situation of its market and assess the future technological, workforce, innovation, and infrastructure requirements needed to sustain the growth and longevity of the industry.

Industry Technology Roadmaps (ITR) are a type of strategic plan for the industry as a whole that help align research, development, and application of technology with business goals. Through the process of roadmapping, organizations and industries can collaborate on their vision for future products, technologies and capabilities. The process brings together people from different parts of the business, providing an opportunity for sharing information and perspectives.

In the first phase of the project we will work on Medical Nonwoven Textiles. You are invited to please share your views about the influencing factors and challenges facing this sector in the areas of technology, markets (market expansion, competitive threats), infrastructure, workforce and/or any other area.

We will compile the views of all participants and get back to you for prioritization and finally solutions to these challenges.

Please e-mail your suggestions to hhh@ncsu.edu or aamir@ncsu.edu or fax them to 919-515-3733.

Thanks for your consideration.

Helmut H. Hergeth, Ph.D.          Asad Amir
Associate Professor              Graduate Student (RA)
Appendix G : List of NITR Panel Members

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<th>No.</th>
<th>Initials</th>
<th>Function</th>
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<tbody>
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<td>MK</td>
<td>Nonwoven - Academic Expert</td>
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<td>2</td>
<td>MM</td>
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