Australian Nonwovens Manufacturing Technology Roadmap
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Preface

Enterprise Connect commissioned CSIRO through its SME Engagement Centre to develop a Technology Roadmap for the nonwovens manufacturing industry. Initially the request was to develop a Technology Roadmap for the whole TCF Industries sector but feedback from the TCF Innovation Council was that the sector was too diverse for one Technology Roadmap to encompass all the relevant issues. Subsequent discussions with Enterprise Connect led to the decision to develop a Roadmap for the nonwovens manufacturing sector as a pilot activity. It is hoped the methodology developed can be easily used in the future for other components of the TCF Industries and a series of Roadmaps can be developed to cover the whole TCF sector.

As many industries have developed Technology Roadmaps the coordinators of this Roadmapping activity sought advice on methodologies and structures which were considered best practice. The Alumina Industry Roadmap was almost universally nominated as an excellent example of an industry Technology Roadmap. It was therefore decided that The Australian Nonwovens Manufacturing Technology Roadmap would use a similar methodology and structure.

Although companies must be market driven, technology is crucial to the nonwovens manufacturing industry being able to compete in the global marketplace. A Technology Roadmap is therefore an important element in planning the future of this industry. With the sponsorship of Enterprise Connect, this project sought to create an industry aligned Technology Roadmap to help ensure the industry has the technical capability to be globally competitive. This Roadmap compliments the TCF Innovation Council’s Strategic Roadmap and Capability Map.
1. Introduction

Much has been written about the decline of the TCF industries but they still make up a substantial industry sector worth $2.8 billion with exports of $1.6 billion. These industries also employ over 45,000 workers. When TCF retailing and wholesaling are included, value add increases by a further $7.5 billion and employment by around 160,000, increasing again when growth sectors such as design and business services are counted in the total.

The industry has been the subject of two major reviews in the last 7 years which provide a useful background and context to this Roadmap. The Productivity Commission Post 2005 Inquiry concluded that the Australian TCF industries could not compete in the labour intensive, commodity segment of the industry. Other developed countries have come to similar conclusions, in particular, European Union countries, and developed strategies based on growing technology intensive sectors of the industry. It was also pointed out by the Productivity Commission that segments of the Australian TCF industries had already adjusted to the new global environment and were finding competitive niches.

The recent Commonwealth Government Review was in broad agreement with the previous Productivity Commission Inquiry. Evidence to this Review demonstrates that the key success factor for the TCF industries is the development of innovative capability at the level of the enterprise and workplace, which is driven not only by research and technology development but also by an increasing emphasis on business model transformation, market-led organisational changes and the integration of firms into collaborative networks and supply chains. The Review maintains that Australia’s TCF industries have a promising future, but this can only be achieved through a concerted effort to differentiate their products through uniqueness, product quality and design.

Product uniqueness and quality are particularly relevant to the nonwovens sector. Nonwovens are often highly specified but commodity products with little differentiation between products supplied by different manufacturers. To survive in the global marketplace Australian nonwovens manufacturers need to produce products which customers are prepared to pay a premium for rather than a simple dollars per kilogram for a commodity which can be purchased from anywhere in the world. With increasing oil prices and greater concern over the environmental impacts of shipping, local manufacturing may become more competitive with imports even for commodity products but transportation is also an impediment to exports. The low density of and difficulties in packing some nonwovens exacerbates this issue.

In addition to the two inquiries the TCF Innovation Council has recently developed a Strategic Roadmap for the period 2009 - 2014. This Roadmap lists the desired outcomes in 2014 as:

- “Brand Australia” – Certified, Innovative, Ethical, Green
- Innovative Products& Processes
- Global & Local Competitive Specialised Niches
Establish Strategic Imperatives
Define Key Technology Areas
Identify Development Priorities
Construct Roadmap

Most of these outcomes depend on the industry having a sophisticated technology base producing knowledge intensive, environmentally sustainable products.

Competitive pressures on the industry, particularly the manufacturing sector, however will not stand still; they will only increase as low wage economies, where most of the world’s textile manufacturing is based, attempt to move up the value chain. The nonwovens sector is particularly dependent on technology and the industry must therefore make intelligent decisions on investment in technology to ensure that Australian nonwoven manufacturing is globally competitive. The Technology Roadmap is a tool to help make these decisions.

The process used to develop the Roadmap is shown as a flow chart in Figure 1 below.

Figure 1: The Nonwovens Manufacturing Industry Roadmapping process

Through interviews with senior industry members Key Strategic Imperatives for the industry, based on commercial considerations, were identified. Key Technology Areas were then developed which encompassed the high priority innovation activities necessary for the industry to meet the strategic imperatives. Priority technology development projects were then detailed to populate the Key Technology Areas. The resulting Roadmap outlines a comprehensive technology innovation plan for the industry. It provides the industry and Government with an opportunity to put in place industry wide activities to build a competitive and sustainable nonwovens manufacturing industry.

This Technology Roadmap report provides an outline of the technology needs of the industry, a summary of what the industry may look like in 2020 and finally a summary of the way forward for the industry. For those readers not familiar with the nonwovens manufacturing process an overview is provided in Appendix A.
2. Strategic Imperatives for the Australian Nonwovens Industry

The Australian nonwovens industry is made up of a number of SMEs mainly privately owned. They manufacture products for insulation, filtration, geotextiles, hygiene, bedding, furnishing etc. Although there is a diversity of products there are many common issues across the industry. These are summarised below.

**Production costs**

One of the key issues is competition from lower cost imports. Some of these imports are of good quality but others often do not meet the necessary technical specifications but are still purchased on the basis of price alone. All the companies interviewed believe that they can successfully compete with imports based on quality, local after sales support and expertise, logistics and responsiveness as well as superior performing products. Nevertheless there is a relentless pressure on production costs.

Although Australia is a high labour cost country labour costs generally only represent around 10 to 15% of nonwovens production costs whereas input fibre materials are around 50%. The nonwovens industry is also very capital intensive and to be successful companies must maximise production through their machinery whilst minimising labour, material costs (including minimising wastage) and energy and other utility costs. In addition, for many Australian companies their business is made up of short product runs which leads to low machinery utilisation putting them at a disadvantage compared to overseas companies. Whether companies have short or longer product runs there is an ongoing need to increase production rates through their machinery to achieve a good return on capital investment as well increase productivity per person employed. It was made clear that a crucial element of a successful Australian nonwovens manufacturing business was to have an appropriate sized manufacturing operation for the size of the market being serviced. Although this may seem obvious it is not easily achieved in the Australian nonwovens industry because of its capital intensive but short run multiple product nature. Other issues such as number of product lines and stock holdings, transport costs and utility costs were identified as being crucial to a successful business.

The first key strategic imperative indentified for the nonwovens industry is to continually **lower production costs**.

**Value-add**

Nonwoven products are often highly specified yet relatively low value-add products and therefore margins are often very tight. It is a globalised industry and competition is fierce. Everyone interviewed agreed that improving product performance including incorporating new features was crucial to staying in business and they continually
look to find innovative ways of adding value. The second strategic imperative for the future success of the industry is to increase the value-add of the products produced by the industry.

**Sustainable manufacturing**

A global trend affecting all manufacturing industries is the trend towards sustainable manufacturing processes. The importance of these trends to the companies involved in the nonwovens industry was somewhat variable. For some product lines it is already important to have “green” credentials however in others it is of no importance. Nevertheless there is a clear move in the industry to use recycled polymer and fibres, move to zero waste manufacturing and reduce energy and water inputs. Whether this is driven by changing attitudes from customers or simply the need to reduce costs there will be a continuing trend towards sustainable manufacturing therefore the third key imperative is to make the industry more eco-efficient.

In summary, from close consultation with the industry, it was concluded that the key strategic imperatives which will drive technology needs will be:

- Reducing production costs
- Increasing value-add, and
- Making the industry more eco-efficient

These Strategic Imperatives are the basis of the Technology Roadmap. The Roadmap identifies technology developments which will achieve substantial impacts on these 3 key imperatives.
3. Key Technology Areas

Four key technology areas have been identified through industry consultation that encompass the developments which are necessary to achieve meaningful progress in the strategic imperatives. These are:

- Process development
- Materials development
- Knowledge management, digital and lean manufacturing
- Material, energy and water utilisation

Table 1 shows the major relationships between the Key Technology Areas and the Strategic Imperatives.

**Table 1: Relationship between Key Technology Areas and Strategic Imperatives**

<table>
<thead>
<tr>
<th>Key Technology Areas</th>
<th>Strategic Imperatives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reduce Production Costs</td>
</tr>
<tr>
<td>Process development</td>
<td>X</td>
</tr>
<tr>
<td>Materials development</td>
<td></td>
</tr>
<tr>
<td>Knowledge management, digital and lean manufacturing</td>
<td>X</td>
</tr>
<tr>
<td>Materials, energy and water utilisation</td>
<td>X</td>
</tr>
</tbody>
</table>

The industry has been driven by *Process development* and there are now many options for producing nonwoven products. Australian companies mainly use carding to produce fibre webs and bond the web using thermo bonding, needle punching or hydro entanglement. Spunbonding and meltblowing are used extensively overseas but less so in Australia. It is likely that nonwoven processes will continue to evolve and that the Australian industry will have to carefully consider what investments should be made in equipment to maintain or improve their global position. Increased productivity, processing of finer fibres, novel surface treatments and the production of novel three dimensional structures will lead to reductions in processing costs and the opportunity for more value added products.
Material costs can represent as much as 70% of the cost of nonwoven roll goods. Obviously *Material developments* will affect production costs and the performance of the nonwoven product. The materials used will also control the biodegradability and recyclability of the product. There is a reasonably level playing field in terms of fibre costs as most nonwoven manufacturers can source the same fibres from the same fibre producers around the world. Developments will therefore focus more on added value achieved through smart structures and chemical treatments which impart novel properties to the product or significantly reduce the weight of material necessary to meet performance requirements. Material development will lead to lighter weight, smarter products that better meet end-user needs and may open up opportunities for the supplier to offer a service as well as a product. Over time there will be increasing pressure to use sustainable materials, design for recyclability and take a whole of life approach to products. This will drive the development of fibres from sources other than hydrocarbons. However in the long term, it will not be sustainable to produce fibres from agricultural products at the expense of food crops.

Of all of the textile manufacturing processes, nonwoven production is the most suited to taking a process engineering approach and utilising automation, robotics and process monitoring and control. There is an increasing opportunity to apply a form of *digital manufacturing* to nonwoven production where the final properties of the fabric are entered into a computer and the flow of fibre from blending towers through web production, web bonding and final conversion is computer controlled. Depending on the number of sensors which can be deployed in the manufacturing process this form of manufacturing can lead to higher quality products and reduced waste. The challenge is in developing sensors which provide the critical on-line measurements of intermediate and final product quality to ensure the process can be optimised and controlled by the digital systems. It is important that the nonwovens industry learns from other industries such as the petro-chemical industry where process control techniques are widely deployed and other manufacturing sectors where lean manufacturing techniques are widely utilised. *Knowledge management* in terms of benchmarking within and outside of the industry is therefore a key activity to ensure progress is made in manufacturing methods which can be applied to nonwoven production.

In an increasingly resource and carbon constrained world there will be more pressure to reduce energy and water inputs to manufacturing processes into the future. Although at the moment in Australia there are no strong regulatory signals to push companies to produce green products some pressures are emerging from supply chain partners. It is therefore a long term priority to reduce inputs, strive for zero waste and closed loop manufacturing therefore *material utilisation and energy and water* inputs are important focus areas.

These key technology areas were developed from discussions with industry experts rather than researchers therefore it was decided to carry out a simple analysis of the academic research literature to see if the subjects being researched are aligned with these industry needs. This analysis was undertaken by carrying out a Google Scholar search for papers with nonwovens in the title. The search was limited to papers published from 2000 onwards. The papers found were categorised in Table 2 as follows:
Table 2 Analysis of academic papers published in past 10 years by subject

<table>
<thead>
<tr>
<th>Subject</th>
<th>Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanofibres/microfibres</td>
<td>31</td>
</tr>
<tr>
<td>Functional nonwoven materials including chemical and plasma treatments</td>
<td>70</td>
</tr>
<tr>
<td>Biodegradable fibres/fabrics</td>
<td>18</td>
</tr>
<tr>
<td>Relationship between manufacturing processes and nonwoven structures and properties, including new instruments for characterising nonwovens</td>
<td>96</td>
</tr>
</tbody>
</table>

It can be seen that there is a strong concentration of effort in material science including nanofibres and methods to impart additional functionality to the finished nonwoven. Papers dealing with biodegradability of nonwovens were relatively few and there were no papers dealing with the use of recycled fibres. However, papers dealing with the relationship between processing parameters and the nonwoven structures produced and their properties were well represented. These papers included modelling of nonwoven processes as well as methods to measure nonwoven properties.

Other than the production of nanofibres, no papers reported new nonwovens machinery or processes. This research is more likely to be carried out by machinery manufacturers, who have the large resources required, rather than academic institutions. These developments are also more likely to be contained within the patent literature than the scientific literature. However the lack of academic research in this area probably indicates that there is unlikely to be radical machinery developments for the nonwovens industry.

To derive further information on research trends, activities within Nonwovens Research Centres were investigated. Although nonwoven research is carried out in many Universities and research institutes there are 4 specialised centres for nonwovens research. These are housed in the University of Leeds, North Carolina State University, the University of Tennessee and CSIRO Materials Science and Engineering. Their research activities are described in Appendix B. Similar to the findings of the analysis of publications, there is a strong focus in the research centres on material research, in particular research aimed at adding functionality to nonwovens for advanced applications, as well as fundamental studies of process – property relationships. The University of Leeds has an effort in sustainable nonwovens manufacturing.

Clearly global research is concentrated on materials development to enable more functional and therefore more value add products and knowledge management activities such as process modelling, structure-property relationships and new measurement systems. This indicates that these are fertile areas for technology developments. Process developments are likely to be related to nanofibre production or methods of treating fibres to impart new functionalities.

Based on industry input and research trends the priority technology developments for the industry and how they map on to the Key Technology Areas and Strategic Imperatives are detailed in the next section.
4. Technology Development Priorities for the Nonwovens Industry

Based on interviews with nonwoven manufacturers and an analysis of research trends, a number of Priority Technology Development needs have been identified. How these map on to the Key Technology Areas identified in the previous section is shown below.

Table 2: Relationship between Priority Technology Needs and Key Technology Areas

<table>
<thead>
<tr>
<th>Priority Technology Development Needs</th>
<th>Key Technology Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Process Development</td>
</tr>
<tr>
<td>Lighter weight nonwoven materials</td>
<td>X</td>
</tr>
<tr>
<td>High specific strength geotextiles</td>
<td>X</td>
</tr>
<tr>
<td>Engineering the properties of nonwovens</td>
<td>X</td>
</tr>
<tr>
<td>High production rate micro/nanofibres</td>
<td>X</td>
</tr>
<tr>
<td>End use innovation</td>
<td></td>
</tr>
<tr>
<td>Active nonwoven materials</td>
<td>X</td>
</tr>
<tr>
<td>New products from recycled fibres</td>
<td></td>
</tr>
<tr>
<td>Reduce waste, energy and water</td>
<td></td>
</tr>
<tr>
<td>On-line sensing, process control and automation</td>
<td>X</td>
</tr>
<tr>
<td>Benchmarking with other process engineering industries</td>
<td></td>
</tr>
</tbody>
</table>
A detailed description of each Priority Technology Development Need and how they impact on the Strategic Imperatives is given in the following pages.
## Lightweight nonwoven materials

Light-weighting nonwoven products while maintaining or improving performance particularly for insulation and filtration products is crucial to the future viability of many Australian nonwoven manufacturing enterprises. Input material costs represent a high proportion of the final product cost and in many applications such as automotive insulation there is a continued demand for a reduction in weight of component parts.

<table>
<thead>
<tr>
<th>Technology Risk</th>
<th>Moderate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential Payoff</td>
<td>High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Technology Direction</th>
<th>Impact on Strategic Imperatives</th>
</tr>
</thead>
</table>
| Decrease weight of nonwoven products whilst maintaining or improving performance | Use of finer fibres to increase surface area for a given mass of fibres | Reduced Costs  
High                                           |
| Applications in insulation, filtration, hygiene | Innovative structures to improve performance without increasing mass | Value Add  
Medium                                          |
|                                                  |                                                            | Eco-Efficiency  
Medium                                          |
**High specific strength nonwovens**

The Holy Grail in geotextiles is to increase strength/unit weight of fabric. This is particularly relevant in Australia where mining applications present severe challenges for geotextiles because of the loads that mine infrastructures have to endure. Other applications for nonwovens such as filters for the mining industry and some building products would also benefit from improved strength. The improved strength must be achieved without affecting other performance related properties of the fabric. Because of the high proportion of final product cost attributed to the input fibre the increase in strength must be achieved with no increase in material input. Therefore an important challenge is to find ways of achieving this whilst also achieving equal strength in each direction of the fabric.

**Technology Risk**    Moderate  
**Potential Payoff**    High

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Technology Direction</th>
<th>Impact on Strategic Imperatives</th>
</tr>
</thead>
</table>
| Increase strength of nonwoven products without increasing weight | New web bonding techniques  
Innovative structures which provide higher strength to weight ratios  
Incorporation of new high strength fibres | Reduced Costs  
Value Add  
Eco-Efficiency |
| Applications in geotextiles, filtration, building products etc | | Low  
High  
Low |
**Engineering the properties of nonwovens**

The previous two priority technology needs target specific fabric characteristics which have been identified by the industry. More generally there is a need to be able to engineer the properties of nonwoven products to better meet customer needs. Nonwoven properties, in practice, are determined by empirical means at the factory level. The engineering of properties based on more rigorous processes could lead to significant savings and improvements in nonwovens properties such as isotropic strength, porosity, bulk etc. Anisotropy of properties often means extra weight has to be used to achieve a target strength in the weaker direction whereas isotropic strength would mean less material could be used. Bulk or low density of nonwovens means higher than necessary transport costs. The ability to pack densely but have good recovery later would reduce transport costs as well as improve productivity both at manufacture and converting due to increased roll change intervals.

**Technology Risk**  Medium

**Potential Payoff**  Medium

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Technology Direction</th>
<th>Impact on Strategic Imperatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>To develop techniques and knowledge to be better able to engineer nonwovens properties, in particular, to improve isotropy, and ability to engineer bulk, porosity etc</td>
<td>Investigate machinery settings and configurations which control key nonwovens properties</td>
<td>Reduced Costs High</td>
</tr>
<tr>
<td></td>
<td>Develop relationships between machinery parameters and nonwovens properties</td>
<td>Value Add Medium</td>
</tr>
<tr>
<td></td>
<td>Develop new options for controlling web and final product properties through machinery and process control innovation</td>
<td>Eco-Efficiency Medium</td>
</tr>
</tbody>
</table>
**High production rate micro and nanofibre processing**

The larger surface area and finer pores that result from using finer fibres opens up new product opportunities where performance is determined by these properties of the nonwoven product. However, production and processing rates decrease as the fibres become finer. If this nexus can be broken, it will open up the possibility of new high performance products which can be produced at commercial production rates.

<table>
<thead>
<tr>
<th>Technology Risk</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential Payoff</td>
<td>High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Technology Direction</th>
<th>Impact on Strategic Imperatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>High production micro/nanofibre production and processing</td>
<td>Melting sub-micron fibres</td>
<td>Reduced Costs</td>
</tr>
<tr>
<td></td>
<td>High production rate electrospinning of nanofibres</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>New carding technology with higher production rates for processing micro-fibres</td>
<td>Value Add</td>
</tr>
<tr>
<td>Applications in insulation, filtration, hygiene, healthcare</td>
<td>Splittable fibres processed by hydroentanglement or chemical processing to produce micro-fibre nonwoven fabrics</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Forcespinning of nanofibres</td>
<td>Eco-Efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
</tr>
</tbody>
</table>
**End use innovation**

Australian nonwovens manufacturing suffers from short product runs which leads to low machine utilisation and therefore high production costs. There is a constant need to find new markets for existing products to increase the length of product runs. Many metal and plastic materials are being replaced by fibrous materials and there needs to be a concerted effort in Australia to find new applications for the products which are manufactured by this sector of the industry.

**Technology Risk**  Low

**Potential Payoff**  High

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Technology Direction</th>
<th>Impact on Strategic Imperatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>To find new end uses for existing nonwoven products</td>
<td>Survey emerging end use applications in the global nonwovens market.</td>
<td>Reduced Costs High</td>
</tr>
<tr>
<td>Applications across the industry</td>
<td>Survey current R&amp;D relevant to the application of fibrous materials</td>
<td>Value Add Low</td>
</tr>
<tr>
<td></td>
<td>Through industry associations build cooperative approach to developing new end use markets for nonwoven materials</td>
<td>Eco-Efficiency Low</td>
</tr>
</tbody>
</table>
**Active nonwoven materials**

Nonwovens are often highly engineered but commodity products with little differentiation between products supplied by different manufacturers. The Australian industry needs to add value by developing products which perform an additional “active” function. Examples include filter materials that can selectively remove target contaminants, products which can sense their own condition such as damage or strain in filter belts or geotextiles, healthcare products which can sense and react e.g. a wound dressing which can sense the onset of an infection and release appropriate drugs, nonwoven packaging which can sense and indicate food freshness etc.

**Technology Risk**  High  
**Potential Payoff**  High

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Technology Direction</th>
<th>Impact on Strategic Imperatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>To develop nonwoven products which have smart or active functions which add value to the end user and can attract a premium in the marketplace</td>
<td>Embedding or attaching active molecules to fibres through chemical treatments</td>
<td>Reduced Costs Low</td>
</tr>
<tr>
<td></td>
<td>Printing active materials onto fabric</td>
<td>Value Add High</td>
</tr>
<tr>
<td></td>
<td>Embedding MEMS devices in nonwoven fabric</td>
<td>Eco-Efficiency Low</td>
</tr>
<tr>
<td></td>
<td>Using conducting fibres in fabric</td>
<td></td>
</tr>
<tr>
<td>Applications in filtration, healthcare, geotextiles, packaging papermaking</td>
<td>3D structures for enhanced functionality</td>
<td></td>
</tr>
</tbody>
</table>
**New products from recycled fibres**

There is increasing demand to reduce the amount of textile waste which goes to landfill and in the longer term hydrocarbon based fibres may become less available and more expensive. There are, however, large quantities of recycled fibres potentially available to be processed into nonwoven materials (e.g. it was estimated by the EPA that 11.9 million tons of textile waste was generated in the United States alone in 2007). But there are considerable challenges to be overcome before the use of recycled fibres can be an economic alternative to the use of virgin fibres. A particular challenge for Australia is its small population separated by large distances which makes collection of economic quantities problematic. Recycled textiles are often a blend of different fibres which are difficult to separate and this places limits on end products that can be easily manufactured using recycled fibres. Also the processing of recycled textiles to liberate individual fibres can lead to reduced fibre length. As a result recycled fibres tend to be used in low value applications such as mattress ticking, packing materials and carpet underlays. If a profitable industry is to be established based around the use of recycled fibres higher value products must be developed which utilise this raw material.

**Technology Risk**  High  
**Potential Payoff**  Medium
**Reduced waste, energy and water**

There is a rapidly growing awareness that the next wave of industrial innovation will be based around sustainability.

> “Sustainability is now the key driver of innovation, and the sustainability performance of a company is a measure of its management quality.” Bjorn Stigson

*President World Business Council for Sustainable Development*

Sustainability issues coupled with the need to reduce production costs gives rise to the challenge of reducing waste discharged to the environment as well as reducing energy, water and chemical usage in nonwovens manufacturing. It is also likely that Australia will see rising costs of electricity due to the implementation of some form of carbon emissions reduction scheme making it even more urgent to reduce energy inputs.

**Technology Risk**  
Low

**Potential Payoff**  
Medium

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Technology Direction</th>
<th>Impact on Strategic Imperatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>To reduce waste, energy and water inputs</td>
<td>Benchmark companies in industry to identify best practice</td>
<td>Reduced Costs High</td>
</tr>
<tr>
<td>Applications in all nonwoven manufacturing</td>
<td>Investigate use of solar energy, smart electricity meters, waste heat recovery, water recycling and use of green chemicals</td>
<td>Value Add Low</td>
</tr>
<tr>
<td></td>
<td>Investigate energy use in nonwoven processes and devise means to minimise it</td>
<td>Eco-Efficiency High</td>
</tr>
</tbody>
</table>
**Knowledge management, process control and automation**

The nonwovens sector of the textile industry is the most suited to the implementation of the process monitoring and control philosophies commonly used in other process and manufacturing industries. There is a clear opportunity to develop knowledge based process control techniques and automated systems to reduce costs and improve quality in nonwoven processes. The challenge is to identify and develop appropriate monitoring and control systems that add value, are reliable and can operate continuously in a nonwovens mill environment. An additional challenge is to develop automation and flexible systems which maximise machinery utilisation in a short run manufacturing environment.

**Technology Risk**  Low

**Potential Payoff**  Medium

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Technology Direction</th>
<th>Impact on Strategic Imperatives</th>
</tr>
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<tr>
<td>Develop systems to provide process monitoring and control and increase the levels of automation in nonwoven processes</td>
<td>Benchmark within and outside of industry to identify opportunities for improved process control</td>
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<tr>
<td>Applications in all nonwoven processes</td>
<td>Develop knowledge based models of nonwovens processes to provide a basis for control techniques</td>
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<td></td>
<td>Develop cost effective on-line sensing techniques which will allow zero defect manufacturing</td>
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<tr>
<td></td>
<td>Identify opportunities for robotic handling of materials</td>
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<tr>
<td></td>
<td><strong>Reduced Costs</strong>  High</td>
<td></td>
</tr>
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<td></td>
<td><strong>Value Add</strong>  Low</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Eco-Efficiency</strong>  Medium</td>
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</table>
5. The Future Nonwovens Industry

A Roadmap for the implementation of the Technology Development priorities is shown in Figure 2.

If this roadmap is implemented what will the Australian nonwovens manufacturing industry look like in 20 years time? The reality is, as in most manufacturing sectors, there is unlikely to be a revolutionary change to the industry but rather a continuous evolution to meet market needs with competitively priced, high performing products. By following this Roadmap, by 2020, the industry will have:

- Reduced its production costs by implementing innovative ways of reducing the weight of fabric used in products and by the intensive use of lean manufacturing principles
- Increased its focus on high value added products including active and smart products
- Moved substantially towards or achieved zero defect production
- Increased the efficiency of consumption of resources, including using recycled fibres, and will have achieved zero waste manufacturing
- Become a leader in managing short run production
- Become a major exporter of nonwoven products to the world

It has been emphasised by manufacturers that the industry cannot take a technology push approach to its development. To be successful companies must take a disciplined market driven approach with the adoption of lean manufacturing principles. Therefore the technology developments described in this Roadmap must always be seen in the context of allowing manufacturers to better meet the needs of the market. If this can be achieved the Australian nonwoven manufacturing industry can prosper and be seen as a successful, high tech advanced materials manufacturing sector.

There is no guarantee that the industry will be successful and some rationalisation may occur in the future, but most owners of nonwoven businesses interviewed in the course of the development of this Roadmap are optimistic about the future.
Figure 2: Roadmap for Implementation of Development Priorities

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Continued incremental decrease in weight of products whilst maintaining or improving properties (ongoing)</td>
<td>Increased use of process monitoring, control and robotics to improve quality, increase machine utilisation and reduce costs (ongoing)</td>
<td>High value products from recycled fibres and formation of cooperative structures within Australian industry to facilitate supply and usage of recycled fibres</td>
<td>Evolution of all these technologies will continue to ensure Australian manufacturers are at forefront of technologies to produce lightweight, smart and eco-efficient products</td>
</tr>
<tr>
<td>Micro/nanofibres manufactured and introduced into nonwoven products in Australia</td>
<td>Active products such as selective filters, geotextiles with monitoring capability, sensing healthcare products etc introduced to market</td>
<td>Smart products manufactured in Australia for a range of markets</td>
<td>Nano and microfibres used along with novel structures to produce ultra lightweight materials for specific applications</td>
</tr>
<tr>
<td>Reduced energy inputs</td>
<td></td>
<td>Closed loop manufacturing, use of sustainable materials and significantly reduced environmental footprint</td>
<td></td>
</tr>
</tbody>
</table>

In summary by 2020 the industry will have:

- Reduced its production costs by implementing innovative ways of reducing weight of fabric used in products, through use of process control and robotic technologies and by the intensive use of lean manufacturing principles
- Increased its focus on high value added products
- Moved substantially towards or achieved zero defect production
- Increased the efficiency of consumption of resources, including using recycled fibres and will have achieved zero waste manufacturing
- Become a leader in managing short run production
- Become a major exporter of nonwoven products to the world
6. Roadmap Implementation

There have been many reports written about the Australian TCF Industries and action agendas proposed. The most challenging issue is implementing the findings or recommendations of the report to achieve a positive impact. The recent Commonwealth Government Review found that the key success factor for the TCF industries is the development of innovative capability at the level of the enterprise and workplace. The emphasis on innovation at the enterprise level was echoed in a recent European paper which dealt with the issues facing their manufacturing sector “Factories of the Future PPP Strategic Multi-annual Roadmap” which stated “in order to face the challenge of global competition, the European manufacturing industry will increasingly be forced to concentrate on specific issues providing a large competitive advantage through long term innovation at the factory level.”

The implementation of this Roadmap will only be effective if individual companies embrace the findings and build capability at their factory level to provide the necessary innovation to meet the challenges outlined in the Roadmap. It is important to note that the Roadmap does not provide solutions rather it provides a map of the challenges and technology needs which are necessary to be addressed to ensure that the industry is successful. It is therefore a guide to where innovation capability needs to be deployed but there is much work to be done to develop project activities for each priority need, resource projects and achieve real outcomes that benefit the industry.

Public sector researchers can play an important role in providing innovative capability and specialised expertise but the industry cannot expect these researchers to provide the solutions to industry problems in isolation from the industry. There needs to be a much stronger partnership between private enterprise and public sector researchers that results in a building of innovative capability at the factory level rather than within public institutions. Schemes such as Enterprise Connect’s Researcher-in-Business are ideal for achieving this.

Many of the challenges identified are common across the industry and there is scope for collaborative approaches to technology development. Also the sharing of best practice in non-competitive areas would be highly beneficial. However history shows that cooperation in many areas of technology development are difficult to achieve and attempts to build vehicles for cooperative research often result in highly bureaucratic structures.

The question remains how will this Roadmap be implemented? In short the industry has to take the lead. The industry must come together in order to:

- Ensure key stakeholders understand the priorities of the industry and thus help inform public policy
- Leverage industry research funds with relevant Government funds
- Share best practice in non-competitive areas
- Provide a forum for the discussion of the future technology goals of the industry and update the Roadmap as circumstances change
- And most importantly initiate activities to address the development needs of the industry
Existing structures such as the TCF Innovation Council, the TTNA and the Enterprise Connect TCF Network are all potential vehicles for helping to coordinate activities but individual companies must embrace the need for innovation at the factory level and put the necessary resources into advancing the initiatives from the Roadmap.
Bibliography


Factories of the Future PPP, Strategic Multiannual Roadmap, Prepared by Ad-hoc Industry Advisory Group 2010
Appendix A: Nonwoven Manufacturing

Nonwoven businesses, in general, rely on high volume production which is highly engineered and, because of competitive pressures, there is a constant need to innovate to ensure high quality, in-specification products are produced at the minimum cost. The industry is driven by technology developments in machinery, process control and materials and, to have a sustainable future, nonwovens enterprises need to be at the forefront of these developments. The following sections describe in more detail the nonwovens manufacturing process.

What is a nonwoven fabric?

Nonwoven fabrics are broadly defined as web structures bonded together by entangling fibres mechanically, thermally fusing the fibres or chemically bonding the fibres. Nonwovens are defined more exactly by various bodies one of the most often quoted is the International Nonwovens & Disposables Association (INDA) definition:

Nonwovens are a sheet, web, or bat of natural and/or man-made fibres or filaments, excluding paper, that have not been converted into yarns, and that are bonded to each other by any of several means.

The various methods for bonding are:

a) Adding an adhesive
b) Thermally fusing the fibres to each other or to the other meltable fibres or powders.
c) Fusing fibres by first dissolving, and then re-solidifying their surfaces.
d) Creating physical tangles or tuft among the fibres.
e) Stitching the fibres or filaments in place

Nonwovens are not made by weaving or knitting and do not require converting the fibres to yarn. Nonwoven fabrics are engineered fabrics that may be single-use disposable or a very durable fabric. They are used in numerous applications, including; baby diapers, adult incontinence products, wet wipes, surgical drapes and covers, liquid cartridge and bag filters, face masks, air-conditioning filters, soil stabilizers and roadway underlayment, erosion control, drainage systems, insulation (fibreglass batting), pillows, cushions, and upholstery padding, carpet backing, automotive headliners and upholstery, house wraps, and disposable clothing (foot coverings, coveralls).

Nonwoven manufacturing processes

Nonwoven manufacturing can be described in simple terms as a series of manufacturing steps consisting of forming a fibrous web, entangling or bonding the fibres in the web to impart mechanical integrity to the structure and finishing/converting the fabric to impart some special properties to the fabric that the customer specifies. The manufacturing steps are described below:
Web formation

The characteristics of the fibrous web are a key determinant of the physical properties of the final product. The choice of methods for forming webs is determined by fibre length. Initially, the methods for the formation of webs from staple-length fibres were based on the textile carding process, whereas web formation from short fibres was based on a wet laid process similar to papermaking. These technologies are still in use, but methods based on forming a web directly from filaments immediately they exit an extruder (Spunlaid) have also been developed.

Figure A1: Schematic diagram of a typical nonwoven card with condenser rollers, (eg Thibeau, Spinnbau, FOR)

Figure A2: Air laid web formation.

Fibrous webs have little mechanical strength and a further manufacturing process is necessary to form a fabric with useful properties. There are a number of processes which are used to accomplish this as described in the next section.
Web bonding

Needlepunching is a process of bonding nonwoven web structures by mechanically interlocking the fibers through the web. Barbed needles, mounted on a board, punch fibers into the web and then are withdrawn leaving the fibers entangled. The needles are spaced in a non-aligned arrangement and are designed to release the fiber as the needle board is withdrawn.

![Diagram of Needlepunching](image)

Stitch bonding is a method of consolidating fiber webs with knitting elements with or without yarn to interlock the fibers. There are a number of different yarns that can be used. Kevlar® is used for strength in the fabric for protective vests. Lycra® is used for stretch in the fabric. Home furnishings are a big market for these fabrics. Other uses are vacuum bags, geotextiles, filtration and interlinings. In many applications stitch-bonded fabrics are taking the place of woven goods because they are faster to produce and, hence, the cost of production is considerably less.

Thermal bonding is the process of using heat to bond or stabilize a web structure that consists of a thermoplastic fiber. All part of the fibers act as thermal binders, thus eliminating the use of latex or resin binders. Thermal bonding is the leading method used by the cover stock industry for baby diapers. Polypropylene has been the most suitable fiber with a low melting point of approximately 165°C. It is also soft to touch. The fiber web is passed between heated calender rollers, where the web is bonded. In most cases point bonding by the use of embossed rolls is the most desired method, adding softness and flexibility to the fabric. Use of smooth rolls bonds the entire surface of the fabric increasing the strength, but reduces drape and softness.

Chemical bonding is the process of bonding a web by means of a chemical and is one of the most common methods of bonding. The chemical binder is applied to the web and is cured. The most commonly used binder is latex, because it is economical,
easy to apply and very effective. Several methods are used to apply the binder and include saturation bonding, spray bonding, print bonding and foam bonding.

**Hydroentanglement** is a process of using fluid forces to lock the fibers together. This is achieved by fine water jets directed through the web, which is supported by a conveyor belt. Entanglement occurs when the water strikes the web and the fibers are deflected. The vigorous agitation within the web causes the fibers to become entangled.

**Finishing and converting**

Finishing and converting are the last operations performed on the fabric before it is delivered to the customer. Finishing includes operations such as coating and laminating, calendering and embossing to impart particular surface properties, corona and plasma treatments to change the wetting properties of the fabric, wet chemical treatments to impart anti-static properties, anti-microbial properties, flame retardant properties etc. After finishing the fabric, it is usually cut to the width the customer specifies and rewound ready for shipment. This is known as converting.
Figure A5: Cutting and slitting system. Automated shape cutting and stacking systems
Combinations of pneumatics, and conveyor belts. Cutters can be mechanical, laser, water jets,
thermal and ultrasonic
Appendix B: Nonwovens Research Centres

University of Leeds Nonwovens Research Centre

This research centre’s interests are

Hygiene Materials

Research spans both single use and durable hygiene materials. The process-structure-property modeling paradigm underpins much of the research in this area. Modeling of the structure-dependent directional permeability in nonwoven materials in the x-y-z planes, in-plane liquid transport and droplet penetration through-plane is a particular focus. These models have enabled linkage of liquid handling properties with measurable aspects of the fabric microstructure and this is enabling process as well as product developments in the hygiene industry. Collaboration with the University’s Centre for Computational Fluid Dynamics is underway to further develop understanding of the fabric structure-fluid flow relationships. The engineering of improved levels of thermo-physical and tactile comfort in wearable hygiene materials is a further area of fundamental research. Studies of the mechanisms of particle pick-up, retention and release in wet and dry conditions are in progress and experimental research is studying the influence of fibre composition and fabric structure on wipe performance. Additional research is concerned with the physical chemistry of adsorption of antimicrobial agents onto fibres and their performance and the structure-property relations of Lyocell absorbent hygiene fabrics.

Active Delivery & Storage Fabrics

The research aims to improve the targeted delivery of chemical and biochemical agents for healthcare, drug release in medicine, liquid filtration and personal care. The controlled release of chemical and biochemical agents from nonwovens to target contact surfaces can be achieved by exploiting established diffusion, polymer swelling and fracture or degradation approaches amongst others. We are also studying local microstructural engineering of fabrics to introduce local variations in specific permeability in both monolithic and three-dimensional materials. A family of hydroentangled internally micro-channeled nonwoven architectures (Hydrospace) that are pre-loaded with actives are being studied to control the delivery rate and facilitate guided delivery. Storage of actives and the direct injection and encapsulation of nanoporous silica gels, SAP, waxes, metals and ceramics to functionalise such fabrics is also being studied.

Protective Fabrics

This research is principally concerned with:

- Light-weight fabrics and flexible protective garments in which nonwoven materials form part of the garment assembly: impact resistant, stab and cut resistant materials, exo- and endothermic vapour permeable fabrics, chemical protection membranes and nanoporous thermal insulation materials.

- Insecticidal materials that do not rely on biochemical mechanisms to induce a lethal response. This research aims to reduce the reliance on neurotoxic insecticidal chemicals in mosquito nets that are currently used to combat malaria and disease transmission by biting insects.
- Durable materials suitable for clothing and other high attrition areas continues to pose challenges for nonwoven materials. Research in this area addresses fundamental aspects concerned with the mechanisms of pilling and abrasion in nonwovens, colouration and functional finishing of nonwovens including modelling of the dye transport mechanisms, structural patterning and visual surface effects, engineering of fabric and garment elasticity, garment assembly and construction including consideration of block design.

**Tissue Engineering Scaffolds**

The construction of advanced nonwoven scaffolds for tissue engineering forms part of a collaboration between NRG and The Institute of Molecular and Cellular Biology. This work is principally focused on soft tissue engineering, particularly ligaments. It is well known that biocompatible porous nonwoven scaffolds can be populated by cells and that pore size and pore size distribution influence the supply of nutrients through infiltration. Studies have demonstrated that fibre orientation has little influence on cell seeding and proliferation except in the initial stages of culturing, however, the bridging of cells between adjacent fibres depends on inter-fibre spacing and the corresponding fibre cross-over angles. Our studies have progressed from static culturing to dynamic uniaxial tensile regimes. In collaboration with The Institute of Molecular and Cellular Biology we are developing a dynamic system for culturing nonwovens and textiles. We are engineering extensible and elastic nonwoven scaffolds to accommodate strains up to approx. 10%; some of these approaches do not require elastomeric polymers and are applicable to biological polymers. Additionally, we are developing a rudimentary vascular system within such scaffolds by microstructural engineering of the fabric during its formation.

**Wound Care Materials**

Interests are in the formation and structure of wound and healthcare materials composed of absorbent and hydrogel forming fibres. Understanding and modelling of the liquid transport and distribution within woundcare materials is an important area both in respect of functional performance and infection control.

**Gas & Liquid Filtration Materials**

Experimental and theoretical studies of gas filtration media and mechanisms in nonwovens continue to be an important area of research. The influence of specific permeability, pore size distribution, average pore size and surface finishing has been explored. Other research interests are in the filtration of oil aerosols and the factors affecting recontamination of the airflow and high permeability triboelectrically charged dry-laid filter media in air filtration.

**Composites**

The formation, structure and properties of composites reinforced with nonwoven materials is an important development area and is particularly focused toward light RTM (Resin Transfer Moulding) applications. High and low modulus reinforcements and flow media are being studied, reinforced with glass and with recovered high modulus fibres including carbon, recovered glass and aramid. The structure-property relations of surface energy modified bast fibre composites and those reinforced with more unconventional biological materials is an additional research interest. Other composite interests are in the area of nonwoven breather membranes.
Sustainable Industrial Materials

This research is directed at improving the understanding and knowledge needed to address challenges particularly in the automotive and transport, composites, building and construction industries. Significant progress has been made that has already led to industrially-relevant outcomes.

Research interests are focused in three main areas:

- Improved dry processing techniques for mixed fibre waste and short particles to enable the formation of industrially-applicable nonwoven materials.
- The processing, structure and property relationships of sustainable crop-fibre based nonwoven materials (including wool and hair, bast fibres, regenerated natural polymers, wood pulp, stem and leaf material and carbonised particles.
- Approaches for the recycling, reuse and conversion of recovered fibres for industrial processes and products to enable better use of environmental and economic resources.

**North Carolina State University Nonwovens CRC**

**Core Research**

Core research programs are developed jointly by the Center faculty/staff and the NCRC member companies. Core research programs focus on areas such as

- 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

Core research programs are supported by funds from the State of North Carolina and fees from NCRC member companies. The results of the research are proprietary to the NCRC and to all member companies of the Center. This information is placed in the public domain, through presentations and publications, poster presentations, software, and patent disclosures, only after the approval of the Industrial Advisory Board of NCRC. The policies governing the ownership of intellectual property are discussed under the policy section.

NCRC supports a total of 20 active research programs. Details of these programs are confidential until published.

The Centre has pilot facilities for manufacturing various types of nonwovens.

- The Staple nonwovens lab offers carding, crosslapping, needling, calendering, and thru-air bonding. Wet-lay and airlay web forming is also offered. These capabilities are modular and allow the formation of very unique nonwovens.
- SpunMelt Pilot Lab represents a unique world class research and product development laboratory. The line currently includes bicomponent fiber formation in both spunbond and meltblown, in-line hydroentangling for bonding and splitting bicomponent fibers, and thermal bonding equipment. The lab equipment can be operated at full commercial through put speeds (approx. 300m/min), while only requiring material for a 1/2 meter wide line.
This will allow our clients to use relatively low volumes of raw materials to produce working prototypes.

**The University of Tennessee Nonwovens Research Laboratory**

The Nonwovens Research Lab (UTNRL) is located on campus at The University of Tennessee, Knoxville, USA. It features several advanced melt blown pilot lines and many other processing and test facilities designed to make a fully equipped nonwovens research lab.

At UTNRL, university professors, students, and engineers come together to create a facility to support nonwovens studies, research, and applications. Our research meltblowing lines are available to private industry as well as government through research grants. Operators are available on-site to man the machinery and help troubleshoot any problems with the processing of your materials. Engineers are available to help you determine the viability of your product, how to improve it, and how to acquire the properties that you desire. They can also help determine a course of action when an unexpected result occurs during the processing of your material. We have expertise in Materials Science and Engineering, Polymer Engineering, Chemical engineering, Physics, Imaging, Parts Manufacture, and Textile Science.

Associated with UTNRL is its commercial arm the Textiles and Nonwovens development Center (TANDEC) which is a leading applications development facility for melt processing nonwovens. TANDEC encourages relationships between academics and industry to provide leadership in research, education, and industry services, fostering new developments in melt processed nonwovens. TANDEC operates a 500 mm Reifenhäuser melt blowing pilot line with bicomponent fiber technology.

**CSIRO Materials Science and Engineering**

Nonwoven production and research at CSIRO is supported by capabilities in:

- forming a fibre web by carding and air laying
- bonding by chemical or heat treatment, needlepunch, or hydroentanglement
- production of fibres, including bicomponent fibres that can be split into microfibres
- spun-bond processing, with extrusion of continuous fibre filaments for immediate assembly into a web, followed by hydroentanglement bonding.

Equipment is designed for small volume sample production and higher volume pilot scale production. Natural and synthetic fibres from as fine as one denier can be processed. These include specialist fibres, bicomponent, soluble, Kevlar, Nomex etc.

The products CSIRO are able to produce include:

- filters
- industrial felts
- quilting
- thermal insulation
- sound insulation
- automotive nonwoven components
- medical textiles
- specialised industrial composites
- apparel
- wipes.

The facilities are used for product development, processing and instrumentation research, prototyping, and low volume sample production.

Technical textile and nonwovens projects have included:
- wool blend quilts
- fibre-reinforced composites
- wetsuits
- automotive trims (including hot pressed non-wovens)
- air filters
- geotextiles production
- protective apparel.
Appendix C: Roadmap Contributors

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